Interconnecting Cisco Network Devices, Part 2 (ICND2)

Foundation Learning Guide

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John Tiso

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Foundation Learning Guide, Fourth Edition

John Tiso

Cisco Press

800 East 96th Street

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John Tiso, CCIE #5162, holds a variety of industry certifications in addition to his Cisco CCIE. These include the Cisco CCDP, Cisco CCNP-Voice, Cisco CCT, and several specializations from Cisco. He is a Microsoft MCSE and also holds certifications from CompTIA, Nortel Networks, Novell, Sun Microsystems, IBM, and HP.

John has a Graduate Citation in Strategic Management from Harvard University and a B.S. degree from Adelphi University. His writing has been published in a variety of industry journals and by Cisco Press. He has served as a technical editor for McGraw-Hill and Cisco Press. John is a past Esteemed Speaker for Cisco Networkers (Live!) and was a speaker at the National CIPTUG Conference. He has been an expert on Cisco's "Ask the Expert" NetPro forum and a question developer for the CCIE program.

John's current role is as a senior engineer at a Cisco Partner. He has a quarter of a century experience in the technology industry, after deciding to stop carrying refrigerators in the family business. Prior to his current position, he held multiple roles while working at Cisco, including TAC Engineer, Systems Engineer, and Product Manager. While at Cisco, one of John's last projects was as a member of the team that developed the recent updates to the CCNA program. Prior to joining Cisco, he was a lead architect and consultant for a Cisco Gold Partner.

John currently resides in Amherst, New Hampshire, with his wife Lauren and their three children, Kati, Nick, and Danny. John is a nine-time marathon finisher and also a Therapy Dog International certified handler of his therapy dog and running partner, Molly. He can be reached at johnt@jtiso.com.

About the Technical Reviewers

Marjan Bradeško has always practiced this principle: If you know something, if you experienced something, if you learned something—tell. That's exactly what he has done throughout his many years at NIL Ltd., and he continues to strive to do it today in his role of Content Development Manager.

Marjan was involved in learning services even prior to joining NIL in 1991. He came from the Faculty of Computer and Information Science at the University of Ljubljana, where he achieved his M.Sc. in computer science and was a teaching assistant. Soon after he joined NIL, the company became a Cisco Systems VAR, and Marjan's subsequent years are all "flavored" with Cisco. In all his various roles—from network engineer, consultant, or instructor to various management positions—Marjan's major goal has always been to educate, teach, and help people to achieve competencies in whatever they do. He has always been passionate about the importance of enthusiastic presentation of high-quality content to motivated people. He has long aided NIL employees in excelling at presentation skills and creating content to help NIL customers achieve competencies in IT and communications technologies. Marjan has also been heavily involved in promoting networking, Internet, cloud, and similar new technologies and publishing articles in numerous magazines.

Through his transitions from software engineer to his current position selling learning services as Content Development Manager, Marjan has gained broad knowledge and many competencies that he gladly shares with customers and coworkers. Marjan became a CCIE in 1995, stayed a CCIE for 16 years, and is now CCIE Emeritus. As a networking veteran, he has seen frequent technology reinventions, and he has had to learn and relearn repeatedly as innovative solutions have revolutionized the industry.

Marjan's passion for sharing his experiences is reflected in his private life as well. As an enthusiastic traveler and nature lover, especially of mountains, he has published many articles and books on nature and beautiful places of the world. In addition, he writes articles and books on presentation skills and sales, showing everyone that competencies are not given, but rather are a merging of talent, learning, and hard work.

Diane Teare, CCNP, CCDP, PMP, is a professional in the networking, training, project management, and e-learning fields. She has more than 25 years of experience in designing, implementing, and troubleshooting network hardware and software, and has been involved in teaching, course design, and project management. She has extensive knowledge of network design and routing technologies, and is an instructor with one of the largest authorized Cisco Learning Partners. She was the director of e-learning for the same company, where she was responsible for planning and supporting all the company's e-learning offerings in Canada, including Cisco courses. Diane has a bachelor's degree in applied science in electrical engineering and a master's degree in applied science in management science.

Dedication

To everyone who helped me find my way back.

Acknowledgments

I'd like to thank the crew at Cisco Press. This includes Brett Bartow, Chris Cleveland, Marianne Bartow (who was my savior, yet again), and Mandie Frank. Your support and sticking with me through the difficulties and challenges I faced during this project meant a lot to me, and was much appreciated. Thank you.

I'd like to thank the technical editors, Marjan and Diane. I'm happy I had the opportunity to meet you in person before I left Cisco and ask you to work on this project. I found your experience with the ICND2 course, your industry experience, and your diligent attention to detail invaluable. I really made you earn your money on this one! Thanks so much!

Lauren, Danny, Nick, and Kati; Thank you for bearing with me under both our normal day-to-day life, as well as when I had to disappear to work on this project. I'd also like to thank Lauren for her photography on several of the photos as well.

I'd also like to thank you, the reader and certification candidate, for your selection of this book.

For everyone else who I did not directly mention, thanks for everything. I keep the words of "The Boss" in my head, "It ain't no sin to be glad you're alive."

Contents at a Glance

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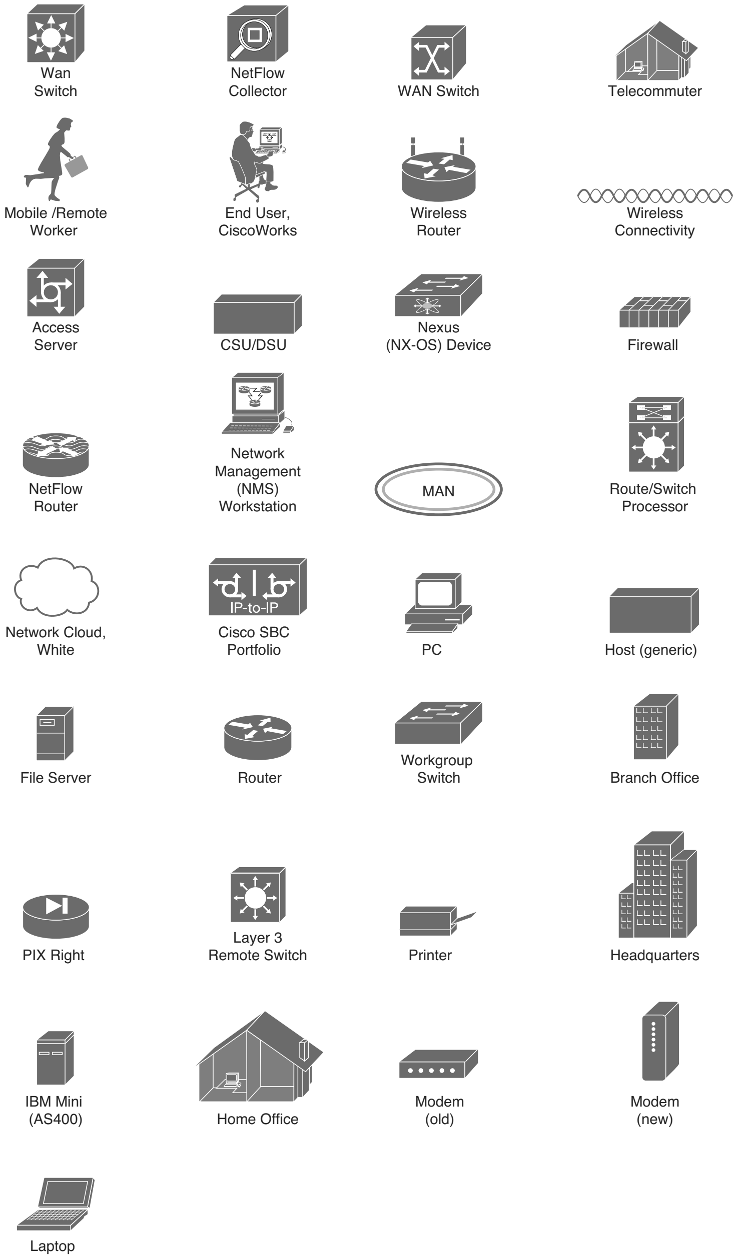
Wan Switch
NetFlow Collector
WAN Switch
Telecommuter
Mobile /Remote Worker
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Access Server
CSU/DSU
Nexus (NX-OS) Device
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Home Office
Modem (old)
Modem (new)
Laptop

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the Cisco IOS Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally, as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italics* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate optional elements.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Introduction

The purpose of this book is to enable readers to obtain a higher level of foundational knowledge beyond the ICND1 books and course. This book provides numerous illustrations, examples, photographs, self-check questions, and additional background information for reinforcement of the information presented. I have drawn on real-world experience and examples for some of the information.

Cisco develops the career certifications, such as CCNA, to align to job roles. Cisco Press introduced the Foundation Learning Guide Series as a learning tool and a parallel resource for the instructor-led Cisco courses. This book is intended both to teach the fundamentals that a CCNA needs in their job role and to provide the knowledge required to pass the ICND2 exam (or the ICND2 components in the CCNA Composite exam).

In my last role at Cisco, I was involved in the development of the updates to the CCNA program. Based on this experience, I have included some fundamental information in this book that is not directly part of the current ICND2 or CCNA composite exams or the ICND2 instructor-led training (however, it may very well be included in subsequent updates to the CCNA). I included this information (that you will not find in any other CCNA book) to help create and support the foundation necessary for both the job role and to obtain the certification. Areas that I have included that are not necessarily part of the CCNA certification are: MPLS, virtualization, and advanced troubleshooting techniques such as information on IOS debugging.

Debugging is a useful skill for diagnosing network problems. It is also key to understanding how protocols and features work, by using debugging in a lab environment (examples of both uses are given in Chapter 7, "Advanced Troubleshooting"). Improper use of debugging can also cripple a network (also discussed in Chapter 7). Therefore, this type of supplemental knowledge helps support both the job role of a CCNA and the use of alternate techniques and technologies as a study tool.

If you are a certification candidate, I strongly suggest you check the exam blueprints on the Cisco Learning Network (https://learningnetwork.cisco.com/) before embarking on your studying adventure.

Thanks for selecting this book as part of your library, and all the best of luck in your quest for knowledge and certification.

Who Should Read This Book?

There are four primary audiences for this text:

- The network engineer who needs to review key technologies that are important in today's networks
- The reader who is interested in learning about computer networking but might lack any previous experience in the subject
- The reader in the job role targeted for a CCNA who needs to obtain and update fundamental knowledge
- The reader who is interested in obtaining the Cisco CCNA certification

How This Book Is Organized

Certainly, this book may be read cover to cover. But it is designed to be flexible and to allow you to easily move between chapters and sections of chapters to cover only the material you need to learn or would like to revisit. If you do intend to read all of the chapters, the order in which they are presented is an excellent sequence.

Chapter 1: Implementing Scalable Medium Sized Networks. This chapter explores the basic foundational topics of internetworking. VLANs, EtherChannel, Spanning-Tree Protocol, and router redundancy (HSRP, VRRP, GLBP).

Chapter 2: Troubleshooting Basic Connectivity. Tools, techniques, and understanding basic error messaging and using host based and Cisco IOS Software are reviewed. IPv4, IPv6, and Virtualization are explored.

Chapter 3: Implementing an EIGRP Solution. EIGRP theory, operation, and troubleshooting for both IPv4 and IPv6 are discussed.

Chapter 4: Implementing a Scalable Multiarea Network with OSPF. The OSPF routing protocol is introduced. OSPF terminology, operation, configuration, and troubleshooting are explored.

Chapter 5: Understanding WAN technologies. WAN technologies are explored. This includes terminology, theory, configuration, and basic troubleshooting. VPNs are included as part of the chapter. This includes their comparison and integration with traditional WAN technology.

Chapter 6: Network Device Management. This chapter explores the various protocols such as SNMP, SYSLOG, and Cisco Flexible NetFlow. The architecture of the Cisco Integrated Service Routers is discussed. The management of configurations, Cisco IOS Software images, and licensing is explored.

Chapter 7: Advanced Troubleshooting. This chapter explores fundamental theory around advanced troubleshooting. It involves advanced diagnostics, Cisco IOS Software bugs, and Cisco IOS Debugging. The topics in this chapter are all directly outside the scope of the CCNA exam. However, understanding these topics will help the reader in both the job role as a CCNA and in exam preparation.

Appendix A: This appendix contains answers to the end of chapter questions.

Appendix B: This appendix contains information on very basic (customer side) configuration and troubleshooting of the MPLS WAN protocol. Again, the topics in this appendix are all directly outside the scope of the CCNA exam. However, understanding these topics will help the reader in both the job role as a CCNA and in exam preparation.

Glossary: Internetworking terms and acronyms are designed to assist the reader in the understanding of the text.

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Chapter 3

Implementing an EIGRP Solution

This chapter contains the following sections:

- Dynamic Routing Review
- EIGRP Features and Function
- Troubleshooting EIGRP
- Implementing EIGRP for IPv6
- Chapter Summary
- Review Questions

EIGRP, Enhanced Interior Gateway Protocol, is an advanced distance vector routing protocol that was developed by Cisco over 20 years ago. It is suited for many different topologies and media. EIGRP scales well and provides extremely quick convergence times with minimal overhead. EIGRP performs in both well-designed networks and poorly designed networks. It is a popular choice for a routing protocol on Cisco devices. EIGRP did have a predecessor, Interior Gateway Protocol (IGRP), which is now obsolete and is not included in Cisco IOS 15.

EIGRP was historically a Cisco proprietary and closed protocol. However, as of this writing, Cisco is in the process of releasing the basic functions to the IETF as an RFC (Request For Comments, a standards document; see http://tools.ietf.org/html/draft-savage-eigrp-00).

This chapter begins with a review of dynamic routing. It then examines the operation, configuration, and troubleshooting of EIGRP for IPv4 and IPv6.

Chapter Objectives:

- Review key concepts for Dynamic Routing Protocols
- Understand how a Cisco Router populates its routing table
- Understand the features, operation, theory, and functions of EIGRP
- Configure and troubleshoot EIGRP for IPv6 and IPv4

Dynamic Routing Review

A dynamic routing protocol is a set of processes, algorithms, and messages that is used to exchange routing and reachability information within the internetwork. Without a dynamic routing protocol, all networks, except those connected directly with the router, must be statically defined. Dynamic routing protocols can react to changes in conditions in the network, such as failed links.

Routing

All routing protocols have the same purpose: to learn about remote networks and to quickly adapt whenever there is a change in the topology. The method that a routing protocol uses to accomplish this purpose depends upon the algorithm that it uses and the operational characteristics of the protocol. The performance of a dynamic routing protocol varies depending on the type of routing protocol.

Although routing protocols provide routers with up-to-date routing tables, there are costs that put additional demands on the memory and processing power of the router. First, the exchange of route information adds overhead that consumes network bandwidth. This overhead can be a problem, particularly for low-bandwidth links between routers. Second, after the router receives the route information, the routing protocol needs to process the information received. Therefore, routers that employ these protocols must have sufficient resources to implement the algorithms of the protocol and to perform timely packet routing and forwarding.

Routing Domains

An autonomous system (AS), otherwise known as a routing domain, is a collection of routers under a common administration. A typical example is an internal network of a company and its interconnection to the network of an ISP. The ISP and a company's internal network are under different control. Therefore, they need a way to interconnect. Static routes are often used in this type of a scenario. However, what if there are multiple links between the company and the ISP? What if the company uses more than one ISP? Static routing protocols would not be suitable. To connect the entities, it is necessary to establish communication with the bodies under different administration. Another example would be a merger, acquisition, or development of a subsidiary that maintains its own IT resources. The networks may need to be connected, but they also may need to be maintained as separate entities. There must be a way to communicate between the two. The third example, which is intimated by the first, is the public Internet. Many different entities are interconnected here as well. Figure 3-1 is a representation of three autonomous systems, one for a private company and two ISPs.

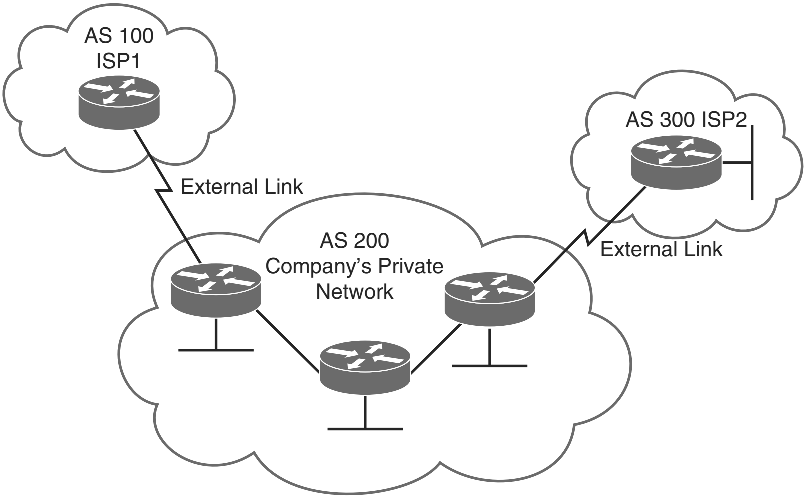


Figure 3-1 *Connection of Three Distinct Autonomous Systems (AS)*

To accommodate these types of scenarios, two categories of routing protocols exist:

- **Interior Gateway Protocols (IGP):** These routing protocols are used to exchange routing information within an autonomous system. EIGRP, IS-IS (Intermediate System-to-Intermediate System) Protocol, RIP (Routing Information Protocol), and OSPF (Open Shortest Path First) Protocol are examples of IGPs.
- **Exterior Gateway Protocols (EGP):** These routing protocols are used to route between autonomous systems. BGP (Border Gateway Protocol) is the EGP of choice in networks today. *The* Exterior Gateway Protocol, designed in 1982, was the first EGP. It has since been deprecated in favor of BGP and is considered obsolete. BGP is the routing protocol used on the public Internet.

Classification of Routing Protocols

EGPs and IGPs are further classified depending on how they are designed and operate. There are two categories of routing protocols:

- **Distance vector protocols:** The distance vector routing approach determines the direction (vector) and distance (hops) to any point in the internetwork. Some distance vector protocols periodically send complete routing tables to all of the connected neighbors. In large networks, these routing updates can become enormous, causing significant traffic on the links. This can also cause slow convergence, as the whole routing table could be inconsistent due to network changes, such as a link down, between updates. RIP is an example of a protocol that sends out periodic updates.

Distance vector protocols use routers as signposts along the path to the final destination. The only information that a router knows about a remote network is the distance or metric to reach that network and which path or interface to use to get there. Distance vector routing protocols do not have an actual map of the network topology. EIGRP is another example of the distance vector routing protocol. However, unlike RIP, EIGRP does not send out full copies of the routing table once the initial setup occurs between two neighboring routers. EIGRP only sends updates when there is a change.

- **Link-state protocols:** The link-state approach, which uses the shortest path first (SPF) algorithm, creates an abstract of the exact topology of the entire internetwork, or at least of the partition in which the router is situated. Using a link-state routing protocol is like having a complete map of the network topology. Signposts along the way from the source to the destination are not necessary because all link-state routers are using an identical "map" of the network. A link-state router uses the link-state information to create a topology map and select the best path to all destination networks in the topology. Link-state protocols only send updates when there is a change in the network. BGP, OSPF, and IS-IS are examples of link-state routing protocols.

Note EIGRP was originally classified as a "hybrid" routing protocol, the combination of link state and distance vector. However, it is truly a rich-featured distance vector protocol. A major differentiator to support this is that EIGRP does not have a full picture of the topology in each node.

Classful Routing Versus Classless Routing

IP addresses are categorized in classes: A, B, and C. Classful routing protocols only recognize networks as directly connected by class. So, if a network is subnetted, there cannot be a classful boundary in between. In Figure 3-2, Network A cannot reach Network B using a classful routing protocol because they are separated by a different class network. The term for this scenario is *discontiguous subnets*.

Classful routing is a consequence when subnet masks are not disclosed in the routing advertisements that most distance vector routing protocols generate. When a classful routing protocol is used, all subnetworks of the same major network (Class A, B, or C) must use the same subnet mask, which is not necessarily a default major-class subnet mask. Routers that are running a classful routing protocol perform automatic route summarization across network boundaries. Classful routing has become somewhat obsolete because the classful model is rarely used on the Internet. Because IP address depletion problems occur on the Internet, most Internet blocks are subdivided using classless routing and variable-length subnet masks. You will most likely see classful address allocation inside private organizations that use private IP addresses as defined in RFC 1918 in conjunction with Network Address Translation (NAT) at AS borders.

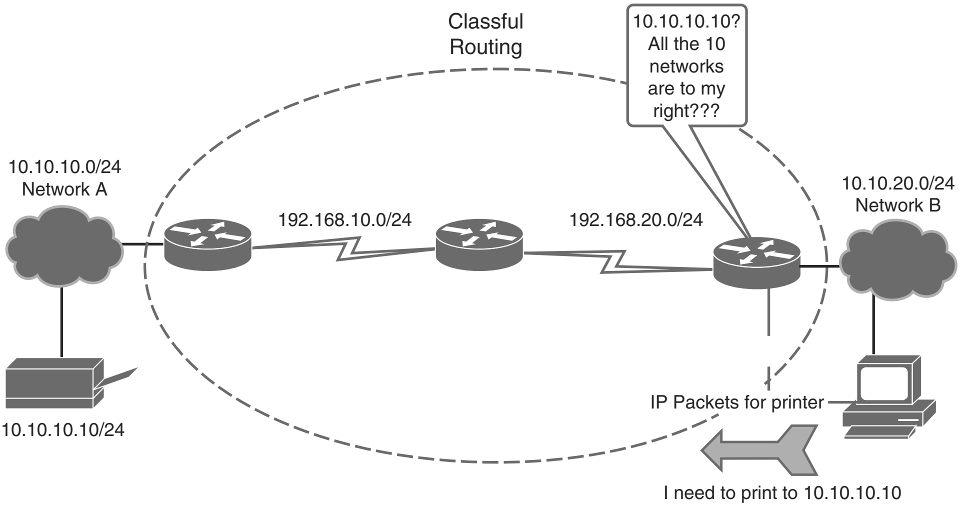


Figure 3-2 *Sample Classful Routing Domain*

Classless routing protocols can be considered second-generation protocols because they are designed to address some of the limitations of the earlier classful routing protocols. A serious limitation in a classful network environment is that the subnet mask is not exchanged during the routing update process, thus requiring the same subnet mask to be used on all subnetworks within the same major network. Another limitation of the classful approach is the need to automatically summarize to the classful network number at all major network boundaries. In the classless environment, the summarization process is controlled manually and can usually be invoked at any bit position within the address. Because subnet routes are propagated throughout the routing domain, manual summarization may be required to keep the size of the routing tables manageable. Classless routing protocols include BGP, RIPv2, EIGRP, OSPF, and IS-IS. Classful routing protocols include Cisco IGRP and RIPv1.

Note RFC 1918 defines the following networks for private use, meaning they are not routed on the public Internet: 10.0.0.0/8, 172.16.0.0/16–172.31.0.0/26, and 192.168.0.0/24–192.168.255.0/24. For more information on RFC 1918, see http://tools.ietf.org/html/rfc1918.

Administrative Distance

Multiple routing protocols and static routes may be used at the same time. If there are several sources for routing information, including specific routing protocols, static routes, and even directly connected networks, an administrative distance value is used to rate the trustworthiness of each routing information source. Cisco IOS Software uses the administrative distance feature to select the best path when it learns about the exact same destination network from two or more routing sources.

An administrative distance is an integer from 0 to 255. A routing protocol with a lower administrative distance is more trustworthy than one with a higher administrative distance. Table 3-1 displays the default administrative distances.

Table 3-1 *Default Administrative Distances*

Route Source	Default Administrative Distance
Directly connected interface	0
Static route	1
eBGP (external BGP; between two different AS)	20
EIGRP	90
OSPF	110
RIP (both v1 and v2)	120
EIGRP External	170
iBGP (internal BGP, inside AS)	200
Unknown/untrusted source	255

Note There are other administrative distances, the discussion of which is beyond the scope of this text. See http://www.cisco.com/en/US/tech/tk365/technologies_tech_note09186a0080094195.shtml for more information.

As shown in the example in Figure 3-3, the router must deliver a packet from Network A to Network B. The router must choose between two routes. One is routed by EIGRP, and the other is routed by OSPF. Although the OSPF route appears to be the logical choice, given that it includes fewer hops to the destination network, the EIGRP route is identified as more trustworthy and is added to the routing table of the router.

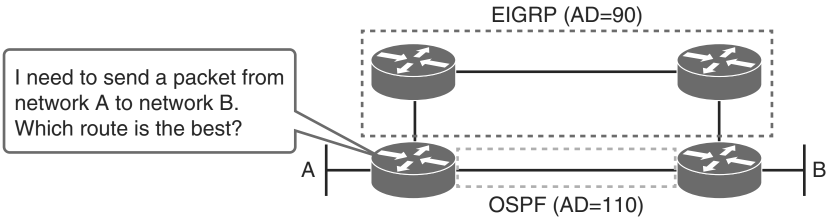


Figure 3-3 *Administrative Distance*

A good way to detect which routing protocols are configured on the router is to execute **show ip protocols.** Example 3-1 gives output from a sample router running OSPF, EIGRP, and BGP. The command provides details regarding each routing protocol, including the administrative distance (Distance), values the routing protocol is using, and other features such as route filtering.

Example 3-1 show ip protocols *Command Output*

```
Branch# show ip protocols
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 metric weight K1=1, K2=0, K3=1, K4=0, K5=0
  EIGRP maximum hopcount 100
  EIGRP maximum metric variance 1
  Redistributing: eigrp 1
  EIGRP NSF-aware route hold timer is 240s
  Automatic network summarization is in effect
  Automatic address summarization:
    192.200.200.0/24 for Loopback0, Loopback100
    192.168.1.0/24 for Loopback0, Vlan1
    172.16.0.0/16 for Loopback100, Vlan1
      Summarizing with metric 128256
  Maximum path: 4
  Routing for Networks:
    0.0.0.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    (this router)         90      00:00:18
  Distance: internal 90 external 170

Routing Protocol is "eigrp 100"
  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 metric weight K1=1, K2=0, K3=1, K4=0, K5=0
  EIGRP maximum hopcount 100
  EIGRP maximum metric variance 1
  Redistributing: eigrp 100
  EIGRP NSF-aware route hold timer is 240s
  Automatic network summarization is in effect
  Automatic address summarization:
```

```
    192.168.1.0/24 for Loopback0
    172.16.0.0/16 for Loopback100
      Summarizing with metric 128256
  Maximum path: 4
  Routing for Networks:
    172.16.1.0/24
    192.168.1.0
  Routing Information Sources:
    Gateway         Distance      Last Update
    (this router)         90      00:00:19
  Distance: internal 90 external 170

Routing Protocol is "ospf 100"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 172.16.1.100
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    255.255.255.255 0.0.0.0 area 0
 Reference bandwidth unit is 100 mbps
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)

Routing Protocol is "bgp 100"
  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
  Maximum path: 1
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: external 20 internal 200 local 200
```

EIGRP Features and Function

EIGRP is a Cisco proprietary routing protocol that combines the advantages of link-state and distance vector routing protocols. EIGRP may act like a link-state routing protocol as it uses a Hello protocol to discover neighbors and form neighbor relationships, and only partial updates are sent when a change occurs. However, EIGRP is still based on the key distance vector routing protocol principle in which information about the rest of the network is learned from directly connected neighbors. EIGRP is an advanced distance vector routing protocol that includes the following features:

- **Rapid convergence:** EIGRP uses the DUAL algorithm to achieve rapid convergence. As the computational engine that runs EIGRP, DUAL is the main computational engine of the routing protocol, guaranteeing loop-free paths and backup paths (called *feasible successors*) throughout the routing domain. A router that uses EIGRP stores all available backup routes for destinations so that it can quickly adapt to alternate routes. If the primary route in the routing table fails, the best backup route is immediately added to the routing table. If no appropriate route or backup route exists in the local routing table, EIGRP queries its neighbors to discover an alternate route.
- **Load balancing:** EIGRP supports both equal and unequal metric load balancing, which allows administrators to better distribute traffic flow in their networks.
- **Loop-free, classless routing:** Because EIGRP is a classless routing protocol, it advertises a routing mask for each destination network. The routing mask feature enables EIGRP to support discontiguous subnets and variable-length subnet masks (VLSM).
- **Reduced bandwidth usage:** EIGRP uses the terms *partial* and *bounded* when referring to its updates. EIGRP does not make periodic updates. *Partial* means that the update includes only information about the route changes. EIGRP sends these incremental updates when the state of a destination changes, instead of sending the entire contents of the routing table. *Bounded* refers to the propagation of partial updates that are sent specifically to those routers that are affected by the changes. By sending only the necessary routing information to those routers that need it, EIGRP minimizes the bandwidth required to send EIGRP updates. EIGRP uses multicast and unicast rather than broadcast. Multicast EIGRP packets employ the reserved multicast address of 224.0.0.10. As a result, end stations are unaffected by routing updates and requests for topology information.

EIGRP has four basic components:

- Neighbor discovery/recovery
- Reliable Transport Protocol
- DUAL finite state machine
- Protocol-dependent modules

Neighbor discovery/recovery is the process that routers use to dynamically learn about other routers on their directly attached networks. Routers must also discover when their neighbors become unreachable or inoperative. This process is achieved with low overhead by periodically sending small hello packets. As long as hello packets are received, a router can determine that a neighbor is alive and functioning. Once this is confirmed, the neighboring routers can exchange routing information.

The reliable transport protocol (not to be confused with Real Time Protocol-RTP, which is used to carry Voice over IP traffic) is responsible for guaranteed, ordered delivery of EIGRP packets to all neighbors. It supports the simultaneous usage of multicast or unicast packets. Only some EIGRP packets must be transmitted perfectly. For efficiency, reliability is provided only when necessary. For example, on a multiaccess network that has multicast capabilities, such as Ethernet, sending hellos reliably to all neighbors individually is not required. So, EIGRP sends a single multicast hello with an indication in the packet informing the receivers that the packet does not need to be acknowledged. Other types of packets, such as updates, require acknowledgment, and that is indicated in the packet. The reliable transport protocol has a provision to send multicast packets quickly when there are unacknowledged packets pending. This ensures that convergence time remains low in the presence of links with varying speed.

The DUAL finite state machine embodies the decision process for all route computations. It tracks all routes advertised by all neighbors. The distance information, known as a *metric*, is used by DUAL to select efficient loop-free paths. DUAL selects routes to be inserted into a routing table based on feasible successors. A successor is a neighboring router used for packet forwarding that has a least cost path to a destination that is guaranteed not to be part of a routing loop. When there are no feasible successors but there are neighbors advertising the destination, a recomputation must occur. This is the process where a new successor is determined. The amount of time it takes to recalculate the route affects the convergence time. Even though the recomputation is not processor-intensive, it is better to avoid it if possible. When a topology change occurs, DUAL tests for feasible successors. If there are feasible successors, it uses any it finds in order to avert any unnecessary recomputation. Feasible successors are defined in detail later in this book.

The protocol-dependent modules are responsible for network layer, protocol-specific requirements. For example, the IP-EIGRP module is accountable for sending and receiving EIGRP packets that are encapsulated in IP. IP-EIGRP is responsible for parsing EIGRP packets and informing DUAL of the new information received. IP-EIGRP asks DUAL to make routing decisions, the results of which are stored in the IP routing table. IP-EIGRP is accountable for redistributing routes learned by other IP routing protocols.

EIGRP Packet Types

EIGRP uses five packet types:

- Hello/ACKs
- Updates
- Queries
- Replies
- Requests

As stated earlier, hellos are multicast for neighbor discovery/recovery. They do not require acknowledgment. A hello with no data is also used as an acknowledgment (ACK). ACKs are always sent using a unicast address and contain a non-zero acknowledgment number.

Updates are used to give information on routes. When a new neighbor is discovered, update packets are sent so that the neighbor can build up its EIGRP topology table. In this case, update packets are unicast. In other cases, such as a link cost change, updates are multicast.

Queries and replies are used for finding and conveying routes. Queries are always multicast unless they are sent in response to a received query. ACKs to queries always unicast back to the successor that originated the query. Replies are always sent in response to queries to indicate to the originator that it does not need to go into Active state because it has feasible successors. Replies are unicast to the originator of the query. Both queries and replies are transmitted reliably.

Note EIGRP has two other type of packets, but they are insignificant: request packets and IPX SAP packets. Request packets are specialized packets that were never fully implemented in EIGRP. EIGRP for Internet Packet Exchange (IPX) has IPX SAP packets. These packets have an optional code in them, technically making them another packet type.

EIGRP Path Selection

Each EIGRP router maintains a neighbor table. This table includes a list of directly connected EIGRP routers that have an adjacency with this router. Neighbor relationships are used to track the status of these neighbors. EIGRP uses a low-overhead Hello protocol to establish and monitor the connection status with its neighbors.

Each EIGRP router maintains a topology table for each routed protocol configuration. The topology table includes route entries for every destination that the router learns from its directly connected EIGRP neighbors. EIGRP chooses the best routes to a destination from the topology table and places these routes in the routing table.

Figure 3-4 gives an example of the neighbor table, the topology table, and the subsequent derived routing table from the example.

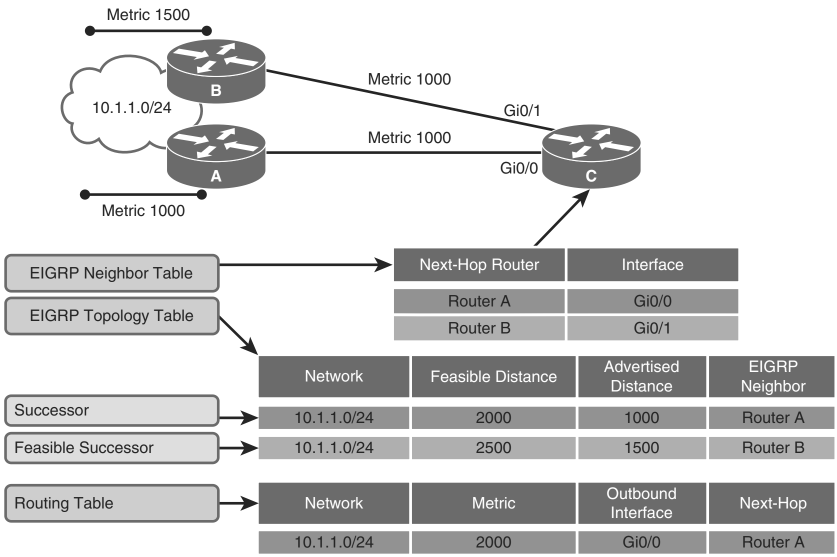


Figure 3-4 *EIGRP Path Selection*

To determine the best route (successor) and any backup routes (feasible successors) to a destination, EIGRP uses the following two parameters:

- **Advertised distance (AD):** The EIGRP metric for an EIGRP neighbor to reach a particular network.
- **Feasible distance (FD):** The AD for a particular network that is learned from an EIGRP neighbor plus the EIGRP metric to reach that neighbor. This sum provides an end-to-end metric from the router to that remote network. A router compares all FDs to reach a specific network and then selects the lowest FD and places it in the routing table.

The EIGRP topology table contains all of the routes that are known to each EIGRP neighbor. As shown in Figure 3-4, Routers A and B sent their routing tables to Router C, whose table is displayed. Both Routers A and B have routes to network 10.1.1.0/24 as well as to other networks that are not shown.

Router C has two entries to reach 10.1.1.0/24 in its topology table. The EIGRP metric for Router C to reach both Routers A and B is 1000. Add this metric (1000) to the respective AD for each route, and the results represent the FDs that Router C must travel to reach network 10.1.1.0/24.

Router C chooses the least FD (2000) and installs it in the IP routing table as the best route to reach 10.1.1.0/24. The route with the least FD that is installed in the routing table is called the *successor route*.

If one or more feasible successor routes exist, Router C chooses a backup route to the successor, called a *feasible successor route*. To become a feasible successor, a route must satisfy this feasibility condition: a next-hop router must have an AD that is less than the FD of the current successor route. (Hence, the route is tagged as a feasible successor, which is a loop-free path to the destination). This rule is used to ensure that the network is loop-free.

If the route via the successor becomes invalid, possibly because of a topology change, or if a neighbor changes the metric, DUAL checks for feasible successors to the destination route. If one is found, DUAL uses it, avoiding the need to recompute the route. A route changes from a passive state to an active state (actively sending queries to neighboring routers for alternative routes) if a feasible successor does not exist and recomputation is necessary to determine the new successor.

Note In Figure 3-4, values for the EIGRP metric and for FDs and ADs are simplified to make the scenario easier to understand. The metrics in a real-world example would normally be larger.

Understanding the EIGRP Metric

The EIGRP metric can be based on several criteria, but EIGRP uses only two of these by default:

- **Bandwidth:** The smallest bandwidth of all outgoing interfaces between the source and destination in kilobits per second.
- **Delay:** The cumulative (sum) of all interface delay along the route in tenths of microseconds.

The following criteria also can be used for the EIGRP metric, but using them is not recommended because they typically result in frequent recalculation of the topology table:

- **Reliability:** This value represents the worst reliability between the source and destination, which is based on keepalives.
- **Load:** This value represents the worst load on a link between the source and destination, which is computed based on the packet rate and the configured bandwidth of the interface.
- **K values:** K values are administratively set parameters that manipulate the value of the EIGRP Metrics. Changing them is not recommended. They are involved in the metric calculation and are set to 1 and 0 to default,. This way, the default K values do not affect the metric(K1, K3 are one – K1, K4, K5 are zero). The K values are
    - K1 = Bandwidth modifier
    - K2 = Load modifier
    - K3 = Delay modifier

- K4 = Reliability modifier
- K5 = Additional Reliability modifier

The composite metric formula is used by EIGRP to calculate metric value. The formula consists of values K1 through K5, which are known as EIGRP metric weights. By default, K1 and K3 are set to 1, and K2, K4, and K5 are set to 0. The result is that only the bandwidth and delay values are used in the computation of the default composite metric. The metric calculation method (K values) and the EIGRP AS number must match between EIGRP neighbors. Figure 3-5 shows a sample metric calculation with default K values and scaled metrics.

EIGRP uses scaled values to determine the total metric: 256 * ([K1 * bandwidth] + [K2 * bandwidth] / [256 – Load] + K3 * Delay) * (K5 / [Reliability + K4]), where if K5 = 0, the (K5 / [Reliability + K4]) part is not used (that is, equals to 1). Using the default K values, the metric calculation simplifies to 256 * (bandwidth + delay). Figure 3-5 gives the metrics in scaled values. Delay and bandwidth are scaled to mathematically fit the equation. 10^7 is used for bandwidth, and 10 is used for delay. This helps keep the metric as a manageable number.

Although a maximum transmission unit (MTU) is exchanged in EIGRP packets between neighbor routers, the MTU is not factored into the EIGRP metric calculation.

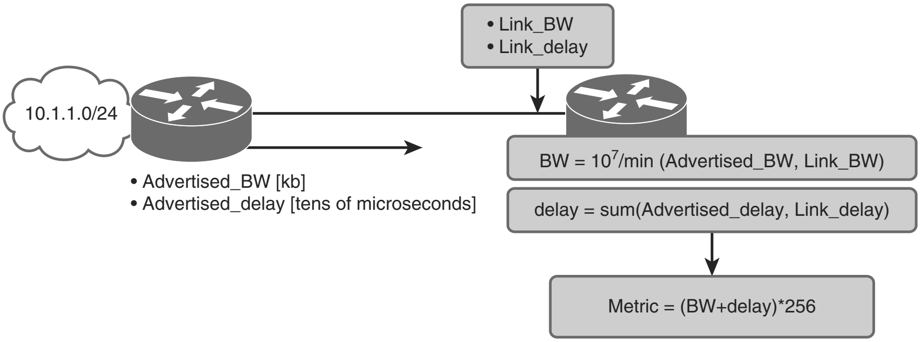


Figure 3-5 *EIGRP Metric*

By using the **show interface** command, you can examine the actual values that are used for bandwidth, delay, reliability, and load in the computation of the routing metric. The output in Example 3-2 shows the values that are used in the composite metric for the Serial0/0/0 interface.

Example 3-2 show interface *to Verify the EIGRP Metric*

```
HQ# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is down
  Hardware is GT96K Serial   Description: Link to Branch
   MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
<output truncated>
```

EIGRP Basic Configuration

The **router eigrp** global configuration command enables EIGRP. Use the **router eigrp** and **network** commands to create an EIGRP routing process. Note that EIGRP requires an AS number. The AS parameter is a number between 1 and 65,535 that is chosen by the network administrator and must match all routers in the EIGRP AS. The **network** command is used in the router configuration mode.

Figure 3-6 shows a sample two-node network that is the basis for the following examples explaining how to configure EIGRP.

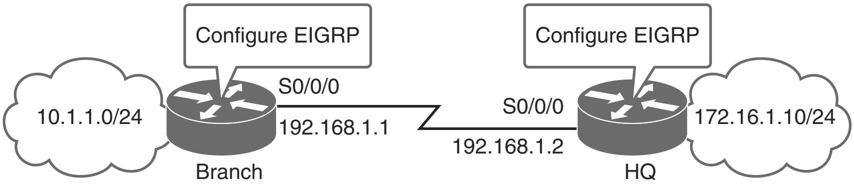


Figure 3-6 *Example Network for EIGRP Configuration*

Example 3-3 shows how to configure EIGRP on the Branch router.

Example 3-3 *Configuring EIGRP on the Branch Router*

```
Branch(config)# router eigrp 100
Branch(config-router)# network 10.1.1.0
Branch(config-router)# network 192.168.1.0
```

Example 3-4 shows how to configure EIGRP on the HQ router.

Example 3-4 *Configuring EIGRP on the HQ Router*

```
HQ(config)# router eigrp 100
HQ(config-router)# network 172.16.1.0 0.0.0.255
HQ(config-router)# network 192.168.1.0 0.0.0.255
```

Table 3-2 describes the EIGRP commands in detail.

Table 3-2 *EIGRP Commands*

Command	Description
router eigrp *as_number*	Enables the EIGRP routing process for the AS number that is specified.
network *network_id wildcard_mask*	Associates the network with the EIGRP routing process. Use of the wildcard mask to match multiple networks is optional.

In Examples 3-3 and 3-4 the **router eigrp** and **network** commands were used to create an EIGRP routing process. Note that EIGRP requires an AS number. In this case, the AS number is 100 on both routers, because the AS parameter must match in all EIGRP routers for the formation of neighbor adjacency and for routes to be exchanged.

The **network** command defines a major network number to which the router is directly connected. Any interface on this router that matches the network address in the **network** command is enabled to send and receive EIGRP updates. The EIGRP routing process searches for interfaces that have an IP address that belongs to the networks specified with the **network** command. The EIGRP process begins on these interfaces. As you can see in Example 3-5, the EIGRP process is running on the interface. However, a second EIGRP process has been configured, but it does not match any interfaces in the **network** command.

Example 3-5 *Reviewing the EIGRP Neighbors*

```
HQ# show ip eigrp neighbors
IP-EIGRP neighbors for process 100
H   Address                 Interface       Hold  Uptime    SRTT   RTO  Q  Seq
                                            (sec)           (ms)       Cnt Num
0   192.168.1.2             FastEthernet0/0    11 00:04:17   8     200  0   2
IP-EIGRP neighbors for process 100
```

Note For more details regarding the **router eigrp** command, check out the *Cisco IOS IP Routing: EIGRP Command Reference* at http://www.cisco.com/en/US/docs/ios/iproute_eigrp/command/reference/ire_book.html.

For more details regarding the **network** command, see the *Cisco IOS IP Routing: Protocol-Independent Command Reference* at http://www.cisco.com/en/US/docs/ios/iproute_pi/command/reference/iri_book.html.

Verification of EIGRP Configuration and Operation

Use the **show ip eigrp neighbors** command to display the neighbors that EIGRP discovered and determine when they become active and inactive. The command is also useful for debugging when neighbors are not communicating properly.

As you can see in Figure 3-7, the Branch router has a neighbor relationship with the HQ router, which is also shown in the following command output:

```
Branch# show ip eigrp neighbors
IP-EIGRP neighbors for AS(100)
H      Address       Interface        Hold   Uptime        SRTT    RTO    Q       Seq
                                      (sec)                (ms)          Cnt      Num
0      192.168.1.2   S0/0/0             12   00:03:10      1231    4500   0        3
```

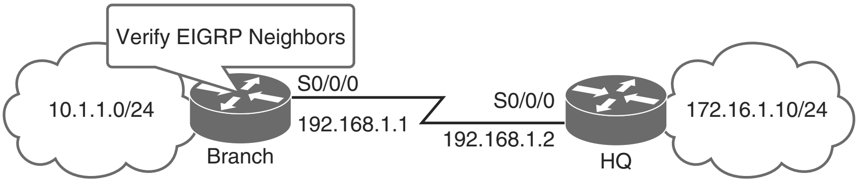


Figure 3-7 *Verification of EIGRP Configuration with* **show ip eigrp neighbors** *Command*

Table 3-3 identifies the key fields in the output of **show ip eigrp neighbors**.

Table 3-3 *Key Output Fields from* **show ip eigrp neighbors** *Command*

Field	Definition
AS	AS identifier for this EIGRP process.
Address	IP address of the neighbor.
Interface	The interface that EIGRP receives hello packets from the neighbor on.
Hold	Length of time (in seconds) that Cisco IOS Software waits to hear from the peer before declaring it down. If the peer is using the default hold time, this number is less than 15. If the peer configures a nondefault hold time, the nondefault hold time is displayed.
Uptime	Elapsed time (in hours:minutes:seconds) since the local router first heard from this neighbor.
Q Cnt	Number of EIGRP packets (update, query, and reply) that the software is waiting to send.
Seq Num	Sequence number of the last update, query, or reply packet that was received from this neighbor.

Use the **show ip eigrp interfaces** command to determine active EIGRP interfaces and learn information regarding those interfaces. If you specify an interface (for example, **show ip eigrp interfaces FastEthernet0/0**), only that interface is displayed. Otherwise, all interfaces on which EIGRP is running are shown. If you specify an AS (for example, **show ip eigrp interfaces 100),** the only thing displayed is the routing process for the specified AS. Otherwise, all EIGRP processes are shown.

Table 3-4 defines the fields in **show ip eigrp interfaces**.

Table 3-4 *Key Output Fields from* **show ip eigrp interfaces** *Command*

Field	Description
Interface	Interface that EIGRP is configured on.
Peers	List of directly connected EIGRP neighbors.
Xmit Queue Unreliable/Reliable	Number of packets remaining in the Unreliable and Reliable queues.
Mean SRTT	Mean smooth round-trip time (SRTT) interval (in milliseconds).
Pacing Time Un/Reliable	Pacing time (how long to wait) used to determine when EIGRP packets should be sent out the interface (Unreliable and Reliable packets).
Multicast Flow Timer	Maximum number of seconds that the router will wait for an ACK packet after sending a multicast EIGRP packet, before switching from multicast to unicast.
Pending Routes	Number of routes in the packets sitting in the transmit queue waiting to be sent.

The **show ip route** command, as seen in the next section, in Example 3-6, displays the current entries in the routing table. EIGRP has a default administrative distance of 90 for internal routes and 170 for routes that are redistributed (redistributed routes are routes brought into a routing protocol from an external source; a routing protocol or static routes). When compared to other IGPs, EIGRP is the most preferred by Cisco IOS Software because it has the lowest administrative distance.

EIGRP Passive Interfaces

Most routing protocols have a passive interface. A passive interface suppresses some routing updates but also allows other updates to be exchanged normally. EIGRP is slightly different from other routing protocols. Routing updates are not received and processed. No neighbor relationships are established via a passive interface.

Passive interfaces are set in EIGRP configuration mode, as shown next, and are not configured on the interface:

```
router eigrp 1
passive-interface FastEthenet0/0
```

This sets passive interface status on FastEthernet0/0. The following sets passive interface status as the default behavior, and explicitly specifies which interfaces should not be "passive":

```
router eigrp 1
passive-interface default
no passive-interface FastEthenet0/0
```

This sets all interfaces to passive, except FastEthernet0/0.

Figure 3-8 displays a sample network for verification using the **show ip route** command.

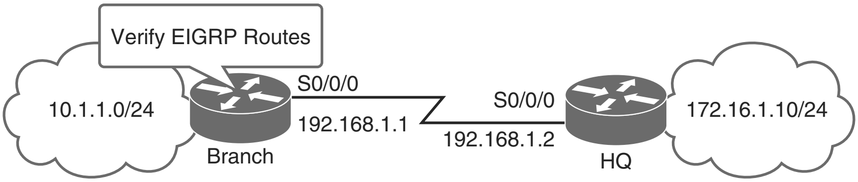


Figure 3-8 *Verification of EIGRP Configuration with* **show ip route** *Command*

The routing table is shown in Example 3-6.

Example 3-6 *Reviewing the Routing Table Using Passive Interfaces*

```
Branch# show ip route
Codes: 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

Gateway of last resort is not set

     10.0.0.0/24 is subnetted, 1 subnets
C       10.1.1.0/24 is directly connected, GigabitEthernet0/0
L       10.1.1.1/32 is directly connected, GigabitEthernet0/0
     172.16.0.0/24 is subnetted, 1 subnets
D       172.16.1.0 [90/156160] via 192.168.1.2, 02:02:02, Serial 0/0/0
     192.168.1.0/24 is subnetted, 1 subnets
C       192.168.1.0/24 is directly connected, Serial0/0/0
L       192.168.1.1/32 is directly connected, Serial0/0/0
```

For the example network depicted in Example 3-7, the **show ip eigrp topology** command displays the EIGRP topology table, the active or passive state of routes, the number of successors, and the FD to the destination. Use the **show ip eigrp topology all-links** command to display all paths, even those that are not feasible.

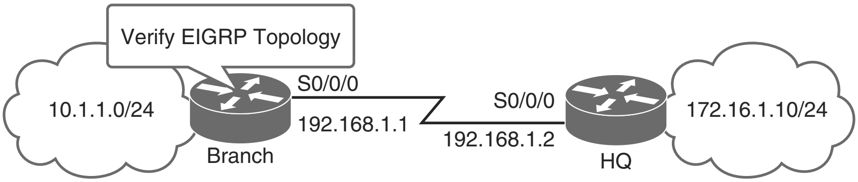


Figure 3-9 *Verification of EIGRP Configuration with* **show ip eigrp topology** *Command*

Example 3-7 *Using the* **show ip eigrp topology** *Command*

```
Branch# show ip eigrp topology
IP-EIGRP Topology Table for AS(100)/ID(192.168.1.1)

Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
       r - reply Status, s - sia Status

P 192.168.1.0/24, 1 successors, FD is 28160
        via Connected, Serial0/0/0
P 172.16.1.0/24, 1 successors, FD is 156160
        via 192.168.1.2 (156160/128256), Serial0/0/0
P 10.1.1.0/24, 1 successors, FD is 28160
        via Connected, GigabitEthernet0/0
```

Table 3-5 defines the fields in the **show ip eigrp topology** command.

Table 3-5 *Key Output Fields from* **show ip eigrp topology** *Command*

Field	**Description**
Codes	State of this topology table entry. Passive and Active refer to the EIGRP state with respect to this destination; Update, Query, and Reply refer to the type of packet that is being sent. P – Passive: No EIGRP computations are being performed for this destination. A – Active: EIGRP computations are being performed for this destination. U – Update: An update packet was sent to this destination. Q – Query: A query packet was sent to this destination. R – Reply: A reply packet was sent to this destination. r – Reply status Flag that is set after the software has sent a query and is waiting for a reply.

Field	Description
172.16.1.0 /24	Destination IP network number and bits in the subnet mask (/24=255.255.255.0)
successors	Number of successors. This number corresponds to the number of next hops in the IP routing table. If "successors" is capitalized, then the route or next hop is in a transition state.
FD	Feasible distance. The FD is the best metric to reach the destination or the best metric that was known when the route went active. This value is used in the feasibility condition check. If the advertised distance (AD) of the router (the metric after the slash) is less than the FD, the feasibility condition is met and that path is a feasible successor. Once the software determines it has a feasible successor, it does not need to send a query for that destination.
replies	Number of replies that are still outstanding (have not been received) with respect to this destination. This information appears only when the destination is in Active state.
via	IP address of the peer that informed the software about this destination. The first *N* of these entries, where *N* is the number of successors, are the current successors. The remaining entries on the list are feasible successors.
(156160/128256)	The first number is the EIGRP metric that represents the cost to the destination. The second number is the EIGRP metric that this peer advertised.
Serial0/0/0	Interface from which this information was learned.

Load Balancing with EIGRP

Every routing protocol supports equal-cost path load balancing, which is the ability of a router to distribute traffic over all of its network ports that are the same metric from the destination address. Load balancing increases the use of network segments and increases effective network bandwidth. EIGRP also supports unequal-cost path load balancing. You use the **variance** *n* command to instruct the router to include routes with a metric of less than *n* times the minimum metric route for that destination. The variable *n* can take a value between 1 and 128. The default is 1, which specifies equal-cost load balancing. Traffic is also distributed among the links with unequal costs, proportionately, with respect to the metric.

Here's a quick comparison of the two types of load balancing offered by EIGRP:

- **Equal-cost load balancing**
  - By default, up to four routes with a metric equal to the minimum metric are installed in the routing table.
  - By default, the routing table can have up to 16 entries for the same destination.
- **Unequal-cost load balancing**
  - By default, it is not turned on.
  - Load balancing can be performed through paths that are 128 times less desirable than the route with the lowest FD.

For IP, Cisco IOS Software applies load balancing across up to four equal-cost paths by default. With the **maximum-paths** router configuration command, up to 32 equal-cost routes can be kept in the routing table, depending on the router type and Cisco IOS version. If you set the value to 1, you disable load balancing. When a packet is process-switched, load balancing over equal-cost paths occurs on a per-packet basis. When packets are fast-switched, load balancing over equal-cost paths occurs on a per-destination basis.

Per-packet load balancing is problematic for applications such as voice and video, which require packets to arrive in order. Per-destination switching is the default and must be changed to per-packet using the interface command **ip load-sharing per-packet**. Unless your network is free of applications that require packets in order, changing this parameter is not recommended.

Variance

This section provides an example of variance for the sample network depicted in Figure 3-10.

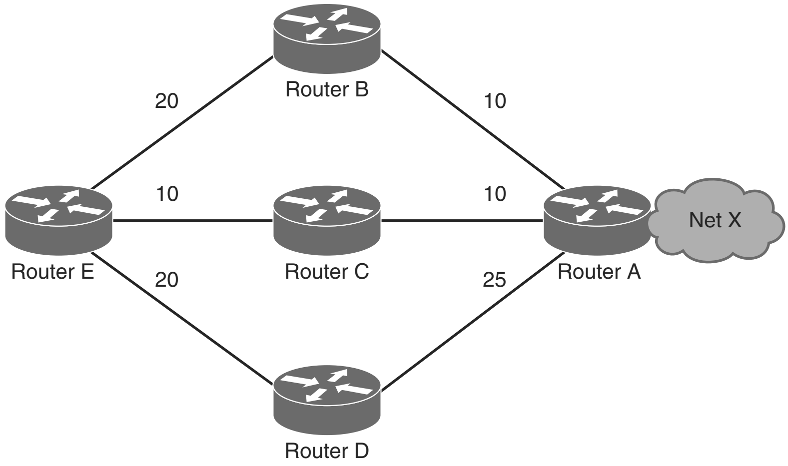


Figure 3-10 *Example Network to Display Metrics*

In Figure 3-10, there are three ways to get from Router E to Network X:

- E-B-A with a metric of 30
- E-C-A with a metric of 20
- E-D-A with a metric of 45

Router E chooses the path E-C-A with a metric of 20 because 20 is better than 30 and 45. To instruct EIGRP to select the path E-B-A as well, you would configure **variance** with a multiplier of 2:

```
router eigrp 1
network x.x.x.x variance 2
```

This configuration increases the minimum metric to 40 (2 * 20 = 40). EIGRP includes all routes that have a metric of less than or equal to 40 and satisfy the feasibility condition. The configuration in this section illustrates that EIGRP now uses two paths to reach Network X, E-C-A and E-B-A, because both paths have a metric of under 40. EIGRP does not use path E-D-A because that path has a metric of 45, which is not less than the value of the minimum metric of 40 because of the variance configuration. Also, the AD of neighbor D is 25, which is greater than the FD of 20 through C. This means that, even if variance is set to 3, the E-D-A path is not selected for load balancing because Router D is not a feasible successor.

Traffic Sharing

EIGRP provides not only unequal-cost path load balancing, but also intelligent load balancing, such as traffic sharing. To control how traffic is distributed among routes when multiple routes for the same destination network have different costs, use the **traffic-share balanced** command. With the keyword **balanced**, the router distributes traffic proportionately to the ratios of the metrics that are associated with different routes. This is the default setting:

```
router eigrp 1
network x.x.x.x  variance 2
traffic-share balanced
```

The traffic share count for the example in Figure 3-10 is

- **For path E-C-A:** 30 / 20 = 3 / 2 = 1
- **For path E-B-A:** 30 / 30 = 1

Because the ratio is not an integer, you round down to the nearest integer. In this example, EIGRP sends one packet to E-C-A and one packet to E-B-A.

If we change the metric between links E and B in the example, the result would be the change in metric between B and A changes to 15. In this case, the E-B-A metric is 40. However, this path will not be selected for load balancing because the cost of this path, 40, is not less than (20 * 2), where 20 is the FD and 2 is the variance. To also include this path in load sharing, the variance should be changed to 3. In this case, the traffic share count ratio is

- **For path E-C-A:** 40 / 20 = 2
- **For path E-B-A:** 40 / 40 = 1

In this situation, EIGRP sends two packets to E-C-A and one packet to E-B-A. Therefore, EIGRP provides both unequal-cost path load balancing and intelligent load balancing.

Similarly, when you use the **traffic-share** command with the keyword **min**, the traffic is sent only across the minimum-cost path, even when there are multiple paths in the routing table:

```
router eigrp 1
network x.x.x.x  variance 3
  traffic-share min across-interfaces
```

In this situation, EIGRP sends packets only through E-C-A, which is the best path to the destination network. This is identical to the forwarding behavior without use of the **variance** command. However, if you use the **traffic-share min** command and the **variance** command, even though traffic is sent over the minimum-cost path only, all feasible routes get installed into the routing table, which decreases convergence times.

EIGRP Authentication

Many routing protocols allow the addition of some sort of authentication to protect against accepting routing messages from other routers that are not configured with the same preshared key. If this authentication is not configured, a malicious or misconfigured device can be introduced into the network. This may inject different or conflicting route information into the network, causing loss of service.

To configure EIGRP authentication, the router must first be configured globally with a "key chain," using the **key chain** command in global configuration mode. Then, each interface that uses EIGRP must be configured individually in the device. In Example 3-9, MD5 type key encryption is used.

Example 3-8 *Configuring EIGRP Authentication*

```
Branch# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Branch(config)# key chain 1
Branch(config-keychain)# exit
Branch(config)# key chain key4eigrp
Branch(config-keychain)# key 1
Branch(config-keychain-key)# key-string secureeigrp
Branch(config-keychain-key)# exit
```

With the global key chain configured, other applications, besides EIGRP, such as the RIP version 2 routing protocol, can now use this key chain. Next, apply it to the EIGRP interface configuration. EIGRP authentication is on a per-link basis. Neighboring interfaces must be configured with the same key chain. Other interfaces can be configured with other key chains or can have no authentication, as long as all neighbors are configured similarly. Example 3-9 provides the configuration necessary for application of the key chain to a single interface. The routers that are directly connected neighbors from interface FastEthernet0/0 in Example 3-9 must use the same authentication mode and the same key chain.

Example 3-9 *Placing Authentication on an Interface*

```
Branch# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Branch(config)# interface FastEthernet0/0
Branch(config-if)# ip authentication mode eigrp 100 md5
Branch(config-if)# ip authentication key-chain eigrp 100 key4eigrp
Branch(config-if)# exit
```

Note For more information on EIGRP authentication, see the Cisco document "EIGRP Message Authentication Configuration Example" at http://www.cisco.com/en/US/tech/tk365/technologies_configuration_example09186a00807f5a63.shtml.

Troubleshooting EIGRP

The ability to troubleshoot problems related to the exchange of routing information and missing information from the routing table is one of the most essential skills for a network engineer who is involved in the implementation and maintenance of a routed enterprise network that uses a routing protocol.

This section provides a suggested troubleshooting flow and explains the Cisco IOS commands that you can use to gather information from the EIGRP data structures and routing processes to detect and correct routing issues.

Components of Troubleshooting EIGRP

In troubleshooting EIGRP, as with any networking issue, follow a structured methodology. Figure 3-11 shows a suggested flowchart.

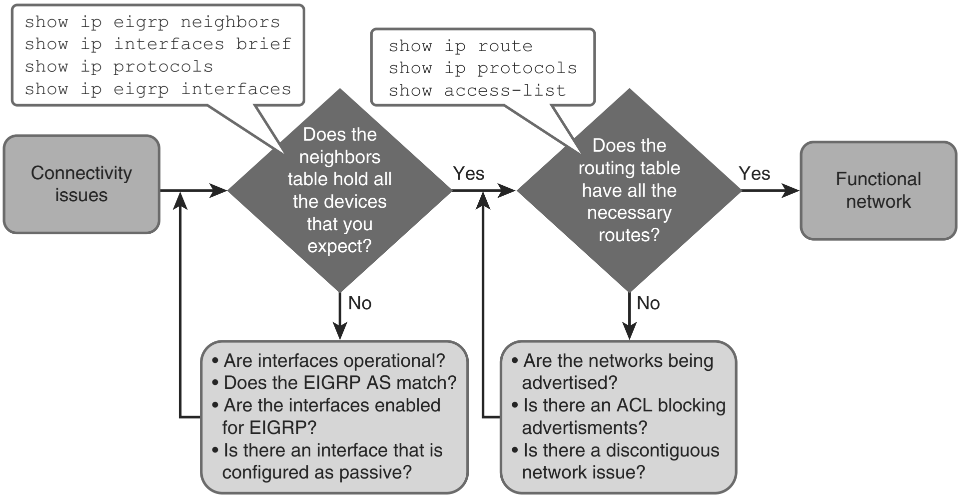


Figure 3-11 *EIGRP Troubleshooting Flowchart*

After configuring EIGRP, first test connectivity to the remote network, using ping. If the ping fails, check that the router has EIGRP neighbors and troubleshoot on a link-by-link basis. Neighbor adjacency might not be running for a number of reasons. Figure 3-12 provides a very basic design with two EIGRP neighbors connected by an Ethernet switch. The HQ router has three loopback interfaces, and both routers have two FastEthernet interfaces. One FastEthernet (0/0) interface from each router is connected to a switch. The switch has only one VLAN for all ports.

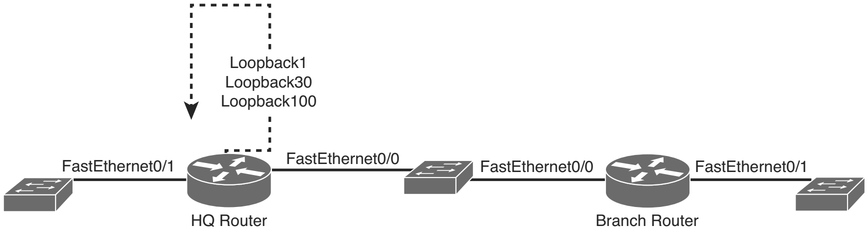


Figure 3-12 *Simple Network Example*

Now let's examine a few potential scenarios, via **show** commands:

- The interface between the devices is down:

HQ# **show ip interface brief**

Interface	IP-Address	OK?	Method	Status	Protocol
FastEthernet0/0	192.168.1.20	YES	NVRAM	down	down
FastEthernet0/1	10.5.0.1	YES	NVRAM	up	up
Loopback1	5.5.5.5	YES	NVRAM	up	up
Loopback30	2.2.2.2	YES	NVRAM	up	up
Loopback100	1.1.1.1	YES	NVRAM	up	up

In this case, FastEthernet0/0 is down. Possibilities include a disconnected cable, a down switch, or faulty hardware.

- The two routers have mismatching EIGRP AS numbers:

```
HQ# show ip protocol
Routing Protocol is "eigrp 1"
<output omitted>

Branch# show ip protocol
Routing Protocol is "eigrp 10"
<output omitted>
```

In this case, the Branch and HQ routers are misconfigured with different EIGRP AS numbers.

- Proper interfaces are not enabled for the EIGRP process:

```
HQ# show running-config
<output omitted>
router eigrp 1
network 192.168.1.0 255.255.255.0
<output omitted>

HQ# show ip interface brief
Interface          IP-Address         OK?    Method     Status        Protocol
FastEthernet0/0    192.168.1.20       YES    NVRAM      up            up
FastEthernet0/1    10.5.0.1           YES    NVRAM      up            up
Loopback1          5.5.5.5            YES    NVRAM      up            up
Loopback30         2.2.2.2            YES    NVRAM      up            up
Loopback100        1.1.1.1            YES    NVRAM      up            up
```

In this case, there is only a single interface configured for EIGRP.

- The interface between the devices is up but can't ping:

```
HQ# show ip interface brief
Interface        IP-Address           OK?    Method     Status        Protocol
FastEthernet0/0  192.168.1.20         YES    NVRAM      up            up
FastEthernet0/1  10.5.0.1             YES    NVRAM      up            up
Loopback1        5.5.5.5              YES    NVRAM      up            up
Loopback30       2.2.2.2              YES    NVRAM      up            up
Loopback100      1.1.1.1              YES    NVRAM      up            up
Branch# show ip interface brief
Interface        IP-Address           OK?    Method     Status        Protocol
FastEthernet0/0  192.168.1.25         YES    NVRAM      up            up
FastEthernet0/1  10.20.0.1            YES    NVRAM      up            up
```

In this case, a potential Layer 2 problem exists. This could be a misconfigured switch port and/or VLAN misconfiguration.

- An interface is configured as passive:

```
HQ# show running-config
<output omitted>
router eigrp 1
  passive-interface FastEthernet0/0
network 192.168.1.0 255.255.255.0
<output omitted>
```

  In this case, a *passive-interface* is configured. The **show ip protocols** command will also identify passive interfaces.

Aside from the issues reviewed here, there are a number of other, more advanced concerns that can prevent neighbor relationships from forming. Two examples are misconfigured EIGRP authentication or mismatched K values, depending on which EIGRP calculates its metric. The next section covers specifically neighbor adjacency.

Troubleshooting EIGRP Neighbor Issues

The previous section examined several possible reasons why EIGRP might not be working properly. This section takes a closer look at troubleshooting EIGRP neighbor relationships. As previously mentioned, a major prerequisite for the neighbor relationship to form between routers is Layer 3 connectivity. By investigating the output of **show ip interface brief**, you can verify that the status and protocol are both up for the interface between the routers. In Figure 3-13 and Example 3-10, the Serial0/0/0 interface that is connected to the Branch router is up. A successful ping then confirms IP connectivity between routers.

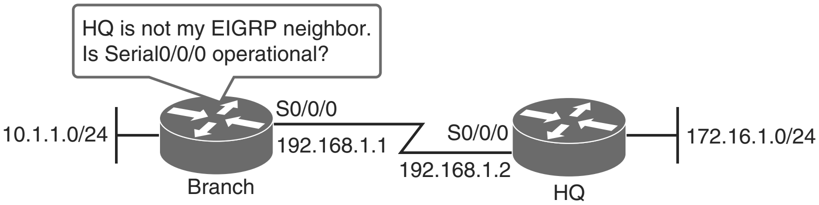


Figure 3-13 *Determining If the Interface Is Operational*

Example 3-10 *Verifying Protocol and Status of Link Between Neighbors*

```
Branch# show ip interface brief
Interface              IP-Address      OK?     Method      Status           Protocol
GigabitEthernet0/0     10.1.1.1        YES     NVRAM       up               up
Serial0/0/0            192.168.1.1     YES     NVRAM       up               up

Branch# 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 0 percent (0/5)
```

If the ping is not successful, as shown in Example 3-10, you should use the technologies discussed in Chapter 2, "Troubleshooting Basic Connectivity." First, check the cabling and verify that the interfaces on connected devices are on a common subnet.

If you notice a log message such as the following that states that EIGRP neighbors are "not on common subnet," this indicates that there is an improper IP address on one of the two EIGRP neighbor interfaces:

```
*Mar  28 04:04:53.778: IP-EIGRP(Default-IP-Routing-Table:100): Neighbor
192.168.100.1 not on common subnet for Serial0/0/0
```

If this message was received on the Branch router, you can see that the reported IP address of the neighbor does not match what you expected. However, you can still have an IP address mismatch and not see this message.

Next, check that the AS numbers are the same between neighbors. The command that starts the EIGRP process is followed by the AS number, **router eigrp** *as_number*. This AS number is significant to the entire network, as it must match between all the routers within the same routing domain. In other routing protocols, the numbering used to start the process may have only local significance (for instance, the OSPF routing protocol is started with a process-id and does not use an AS number).

In Figure 3-14 and Example 3-11, **show ip protocols** helps to determine if the AS numbers match.

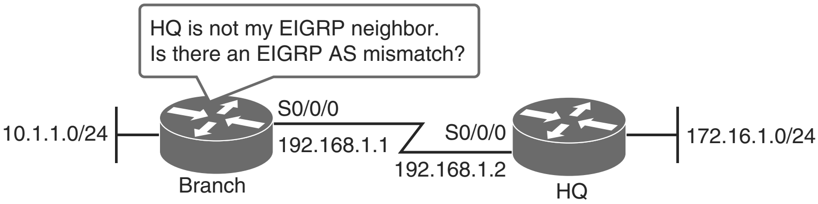


Figure 3-14 *Determining AS Numbers*

Example 3-11 *Using* **show ip protocols** *to Verify EIGRP AS Numbers*

```
Branch# show ip protocols
Routing Protocol is "EIGRP 1"
<output omitted>

HQ# show ip protocols
Routing Protocol is "EIGRP 2"
<output omitted>
```

> **Note** For more details about **show ip protocols** and related commands, see the *Cisco IOS IP Routing: Protocol-Independent Command Reference* at http://www.cisco.com/en/US/docs/ios/iproute_pi/command/reference/iri_book.html.

Also confirm that EIGRP is running on the correct interfaces. The **network** command configured under the EIGRP routing process indicates which router interfaces will participate in EIGRP.

The **show ip eigrp interfaces** *interface* command shows you which interfaces are enabled for EIGRP. If connected interfaces are not enabled for EIGRP, then neighbors will not form an adjacency. If an interface is not on the list, that means the router is not communicating EIGRP through that interface. Figure 3-15 shows that EIGRP is running on the Branch router. Run the same command on the HQ router and look for the same results. In this case, both routers are neighbors.

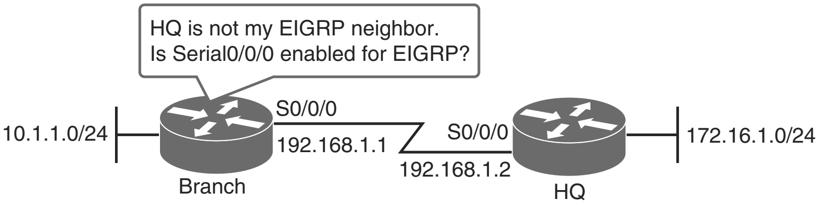


Figure 3-15 *EIGRP Interface Enabled*

You can also check the interface by referring to the "Routing for Networks" section of the **show ip protocols** command output. As shown in Example 3-12, this indicates which networks have been configured; any interfaces in those networks participate in EIGRP.

Example 3-12 *Check the "Routing for Networks" Output*

```
HQ# show ip protocols
<output omitted>
Routing Protocol is "eigrp 1"
 <output omitted>
Routing for Networks:
     172.16.0.0
     192.168.1.0
  Passive Interface(s):
      Serial0/0/0
 <output omitted>
```

With the **show ip protocols** command, you can also confirm if an interface is in passive mode only. The **passive-interface** command prevents both outgoing and incoming routing updates, because the effect of the command causes the router to stop sending and receiving hello packets over an interface. For this reason, routers do not become neighbors. An example where you would need to configure an interface as passive toward a specific LAN. You want to advertise LANs but don't want to have the security risk of transmitting hello packets into the LAN. A final suggestion for checking a failed neighbor relationship is to confirm a mismatch in the authentication parameters. The key authentication configuration must match on both neighbors. The key number and key string should be checked in the running configuration.

Troubleshooting EIGRP Routing Table Issues

This section covers issues that cause missing entries in the routing table when proper connectivity and neighbor relationships exist. The exclusion of routes that should be in the routing table can be caused by routes not being advertised, by route filtering, or by network summarization. Missing routing entries due to these issues can be related to a problem either with a directly connected EIGRP neighbor or with an EIGRP router that is in another section of the network.

Issues Caused by Unadvertised Routes

Routing table issues caused by unadvertised routes are indicated by a failed ping test. Figure 3-16 illustrates the Branch/HQ example that has been implemented. It is established by checking the neighbor adjacency.

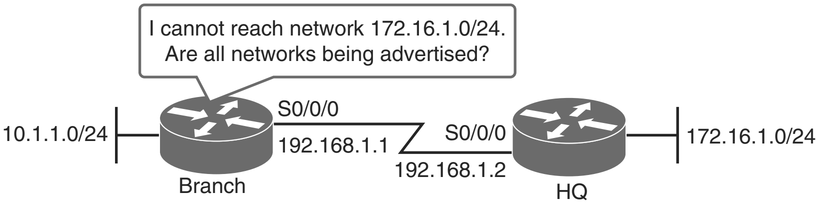


Figure 3-16 *Troubleshooting EIGRP Routing Table Issues with the* **show ip protocols** *Command*

In this case, checking the **show ip protocols** command output from the HQ router indicates the HQ router is not advertising 172.16.1.0/24. Adding the **network** statement to EIGRP, as demonstrated in Example 3-13, should resolve the issue.

Example 3-13 *Adding the Correct Network Command*

```
HQ(config)# router eigrp 1
HQ(config-router)# network 172.16.1.0
```

This should restore the routing table. If it does not, check route filtering. Route filtering can be performed by route maps or ACLs, as discussed in the next section.

Issues Caused by Route Filtering

Routing protocols can be configured to filter routes. This is a powerful tool, especially when connecting different routing domains (different AS). However, a misconfigured filter can be difficult to detect.

> **Note** Route maps and distribute lists are not part of the CCNA curriculum, but are visited as part of the CCNP curriculum. This book contains only brief coverage of distribute lists. For more information on route maps, see Chapter 8, "EIGRP Support for Route Map Filtering," of the *IP Routing EIGRP Configuration Guide, Cisco IOS Release 15S*: http://www.cisco.com/en/US/docs/ios-xml/ios/iproute_eigrp/configuration/15-s/ire-15-s-book.pdf.

When investigating filtering issues, first check the **show ip protocols** command, as demonstrated in Example 3-14.

Example 3-14 *Indentifying Incoming Filtering*

```
Branch# show ip protocols
Routing Protocol is "eigrp 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is 1
```

As you can see, there is an ACL. Next, check the ACL, as shown in Example 3-15.

Example 3-15 *Identifying Access List Used for Filtering*

```
Branch# show ip access-lists
Standard IP access list 1
    10 deny   172.16.0.0, wildcard bits 0.0.255.255 (2 matches)
    20 permit any (6 matches)
```

The ACL matches the missing network. In this case, remove the ACL from the EIGRP configuration, as demonstrated in Example 3-16.

Example 3-16 *Removing the Distribute List Used for Filtering*

```
Branch# config t
Enter configuration commands, one per line.  End with CNTL/Z.
Branch(config)# router EIGRP 1
Branch(config-router)# no distribute-list 1 in
```

The console output shows the change in the adjacency after changing the configuration, as demonstrated in Example 3-17.

Example 3-17 *Console Reporting Neighbor Change Due to Reconfiguration*

```
*Mar  1 00:17:37.775: %DUAL-5-NBRCHANGE: IP-EIGRP(0) 1: Neighbor 192.168.1.1
(FastEthernet0/0) is down: route configuration changed
*Mar  1 00:17:41.431: %DUAL-5-NBRCHANGE: IP-EIGRP(0) 1: Neighbor 192.168.1.1
(FastEthernet0/0) is up: new adjacency
```

Caution Do not remove an actual ACL without first removing the ACL reference from other configuration/interfaces. Otherwise, you may create instability in the configuration!

Take notice of the "in" on the **distribute-list**. ACLs can be placed in both inbound and outbound directions. Inbound and outbound lists are structured the same, but the transmission or reception of routes is controlled by direction.

Issues Caused by Automatic Network Summarization

EIGRP can be configured to automatically summarize routes at classful boundaries. If you have discontiguous networks, automatic summarization can cause inconsistencies in the routing tables.

In Figure 3-17, Router B is not receiving individual routes for the 172.16.1.0/24 and 172.16.2.0/24 subnets. Both Router A and Router C automatically summarized those subnets to the 172.16.0.0/16 classful boundary when sending EIGRP update packets to Router C.

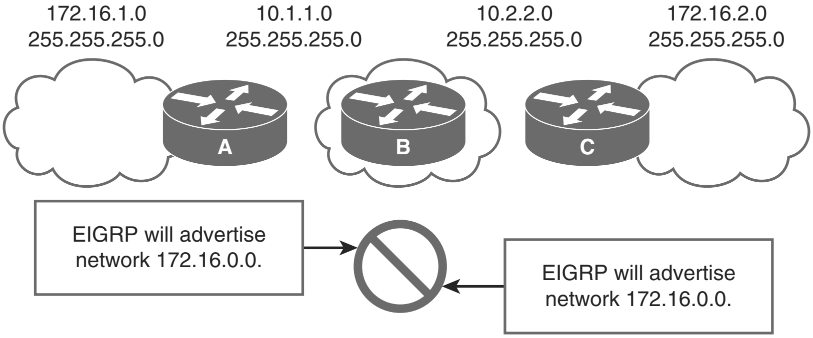


Figure 3-17 *Automatic Summarization Issues*

Router B has two routes to 172.16.0.0/16 in the routing table, which can result in inaccurate routing and packet loss, as shown in Example 3-18.

Example 3-18 *Inaccurate Routing Entries*

```
RouterB# show ip route
<output omitted>

 Gateway of last resort is not set
     10.0.0.0/24 is subnetted, 2 subnets
C     10.1.1.0 is directly connected, Serial0/2/0
C     10.2.2.0 is directly connected, Serial0/3/0
D   172.16.0.0/16 [90/2172416] via 10.1.1.1, 00:03:51, Serial0/2/0
                                   [90/2172416] via 10.2.2.3, 00:00:14, Serial0/3/0
```

Note The behavior of the **auto-summary** command is disabled by default on Cisco IOS version 15. Older versions of Cisco IOS Software may have automatic summarization enabled by default.

In Example 3-19, automatic summarization is disabled by entering the **no auto-summary** command in the router eigrp configuration mode:

Example 3-19 *Disable Automatic Summarization*

```
RouterB(config)# router eigrp 1
RouterB(config-if)# no auto-summary
```

Implementing EIGRP for IPv6

Although EIGRP is a Cisco proprietary protocol, it and its predecessor, IGRP (IGRP is an obsolete protocol and removed from production in Cisco IOS 12.3 and later), have been widely deployed in enterprise networks. EIGRP has also supported multiple protocols besides IP (AppleTalk and Novell IPX). For these reasons, it is logical that EIGRP would continue to be used in the IPv6 world. This section describes Cisco EIGRP support for IPv6. The theory and operation of EIGRP only differs slightly between IPv6 and IPv4. The main differences are where IPv6 and IPv4 deviate as a protocol, so parts of this section will serve as a review.

EIGRP IPv6 Theory of Operation

Although the configuration and management of EIGRP for IPv4 and EIGRP for IPv6 are similar, they are configured and managed separately.

As previously mentioned, EIGRP is inherently a multiprotocol routing protocol because it has supported non-IP protocols. Novell IPX and AppleTalk were protocols with early support from EIGRP. As with the non-IP protocols, IPv6 support is added as a separate module within the router. IPv6 EIGRP is configured and managed separately from IPv4 EIGRP, but the mechanisms and configuration techniques for IPv6 EIGRP will be very familiar to engineers who have worked with EIGRP for IPv4.

EIGRP maintains feature parity across protocols, where appropriate. Due to the differences in protocols, configuration and operation can slightly differ. Much of the theory in key areas such as DUAL and metrics are the same.

The following are a few (not all) examples of similarities shared by IPv4 EIGRP and IPv6 EIGRP:

- DUAL is used for route calculation and selection with the same metrics.
- It is scalable to large network implementations.
- Neighbor, routing, and topology tables are maintained.
- Both equal-cost load balancing and unequal-cost load balancing are offered.

A few (not all) examples of differences include these:

- The **network** command is not used in IPv6; EIGRP is configured via links.
- The **ipv6** keyword is used in many of the EIGRP commands.
- Needs to be explicitly enabled on each interface when configuring EIGRP.

The basic components of EIGRP for IPv6 remain the same as in the IPv4 version. So, this section contains a review of the operation of EIGRP and DUAL.

As in IPv4, EIGRP in IPv6 uses a hello packet to discover other EIGRP-capable routers on directly attached links and to form neighbor relationships. Updates may be acknowledged by using a reliable transport protocol, or they may be unacknowledged—depending on the specific function that is being communicated. The protocol provides the flexibility necessary to unicast or multicast updates, acknowledged or unacknowledged.

Hello packets and updates are set to the well-known, link-local multicast address FF02::A, which Cisco has obtained from the Internet Assigned Numbers Authority (IANA). This multicast distribution technique is more efficient than the broadcast mechanism that is used by earlier, more primitive routing protocols such as RIPv1. EIGRP for IPv4 also uses multicast for update distribution.

Note For more information on IANA numerical assignments, see http://www.iana.org/numbers.

EIGRP sends incremental updates when the state of a destination changes, instead of sending the entire contents of the routing table. This feature minimizes the bandwidth that is required for EIGRP packets.

DUAL, which is an EIGRP algorithm for determining the best path through the network, uses several metrics to select efficient, loop-free paths. Figure 3-18 shows a topology with sample metrics. When multiple routes to a neighbor exist, DUAL determines which route has the lowest metric (the FD) and enters this route into the routing table. Other possible routes to this neighbor with larger metrics are received, and DUAL determines the AD to this network. The AD is defined as the total metric that is advertised by an upstream neighbor for a path to a destination. DUAL compares the AD with the FD, and if the AD is less than the FD, DUAL considers the route to be a feasible successor and enters the route into the topology table. The feasible successor route that is reported with the lowest metric becomes the successor route to the current route if the current route fails. To avoid routing loops, DUAL ensures that the AD is always less than the FD for a neighbor router to reach the destination network; otherwise, the route to the neighbor may loop back through the local router.

When there are no feasible successors to a route that has failed, but there are neighbors advertising the route, a recomputation must occur. This is the process where DUAL determines a new successor. The amount of time that is required to recompute the route affects the convergence time. Recomputation is processor-intensive, so avoiding unneeded recomputation is advantageous. When a topology change occurs, DUAL tests for feasible successors. If there are feasible successors, DUAL uses them to avoid unnecessary recomputation of the topology.

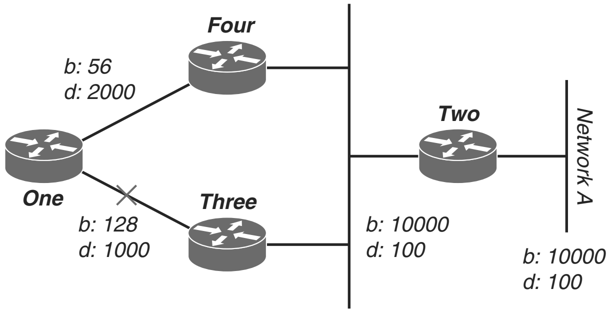


Figure 3-18 *EIGRP Path Selection*

Of these metrics, by default, only minimum bandwidth and delay are used to compute the best path. Unlike most metrics, minimum bandwidth is set to the minimum bandwidth of the entire path, and it does not reflect how many hops or low-bandwidth links are in the path. Delay is a cumulative value that increases by the delay value of each segment in the path. In Figure 3-18, Router One is computing the best path to Network A.

It starts with the two advertisements for this network: one through Router Four, with a minimum bandwidth of 56 and a total delay of 2200; and the other through Router Three, with a minimum bandwidth of 128 and a delay of 1200. Router One chooses the path with the lowest metric.

Let's compute the metrics. EIGRP calculates the total metric by scaling the bandwidth and delay metrics.

- EIGRP uses the following formula to scale the bandwidth:

  bandwidth = (10000000 / bandwidth(i)) * 256

  where bandwidth(i) is the least bandwidth (represented in kilobits) of all outgoing interfaces on the route to the destination network.

- EIGRP uses the following formula to scale the delay:

  delay = delay(i) * 256

  where delay(i) is the sum of the delays configured on the interfaces, on the route to the destination network, in tens of microseconds. The delay as shown in the **show ipv6 eigrp topology** command or the **show interface** command is in microseconds, so you must divide by 10 before you use it in this formula. Throughout the section, a delay is used as it is configured and shown on the interface.

- EIGRP uses these scaled values to determine the total metric to the network:

  metric = [K1 * bandwidth + (K2 * bandwidth) / (256 – load) + K3 * delay] * [K5 / (reliability + K4)]

Caution You should not change these K values without first giving the decision careful consideration. Any revisions should be avoided and completed only after careful planning. Mismatched K values prevent a neighbor relationship from being built, which causes the network to fail to converge.

Note If K5 = 0, the formula reduces to metric = [K1 * bandwidth + (K2 * bandwidth) / (256 – load) + K3 * delay].

The default values for K are

- K1 = 1
- K2 = 0
- K3 = 1
- K4 = 0
- K5 = 0

For default behavior, you can simplify the formula as follows:

metric = bandwidth + delay

Cisco routers round down to the nearest integer to properly calculate the metrics. In this example, the total cost through Router Four is

minimum bandwidth = 56 kb total delay = 100 + 100 + 2000 = 2200 [(10000000 / 56) + 2200] x 256 = (178571 + 2200) x 256 = 180771 x 256 = 46277376

And the total cost through Router Three is

> minimum bandwidth = 128kb total delay = 100 + 100 + 1000 = 1200 [(10000000 / 128) + 1200] x 256 = (78125 + 1200) x 256 = 79325 x 256 = 20307200

So to reach Network A, Router One chooses the route through Router Three.

Note that the bandwidth and delay values used are those configured on the interface through which the router reaches its next hop to the destination network. For example, Router Two advertised Network A with the delay configured on its Ethernet interface; Router Four added the delay configured on its Ethernet interface; and Router One added the delay configured on its serial interface.

When a router discovers a new neighbor, it records the neighbor address and interface as an entry in the neighbor table. One neighbor table exists for each protocol-dependent module (as stated earlier, EIGRP runs a protocol-independent module for each protocol running, so IPv4 and IPv6 are calculated independently). When a neighbor sends a hello packet, it advertises a hold time, which is the amount of time that a router treats a neighbor as reachable and operational. If a hello packet is not received within the hold time, the hold time expires and DUAL is informed of the topology change.

The topology table contains all destinations that are advertised by neighboring routers. Each entry in the topology table includes the destination address and a list of neighbors that have advertised the destination. For each neighbor, the entry records the advertised metric, which the neighbor stores in its routing table. An important rule that distance vector protocols must follow is that if the neighbor advertises this destination, the neighbor must use the route to forward packets. Although having a route and using it to forward packets may seem implicit, link-state protocols may advertise a route that is not necessarily a direct path. Explicitly, this can be done with the Border Gateway Protocol (BGP), but that topic is beyond the scope of this text.

> **Note** As in IPv4, the MTU in IPv6 is carried in the EIGRP hello packets but is not used in the metric calculation.

EIGRP IPv6 Feasible Successor

As previously defined, the feasible distance is the best metric along a path to a destination network, including the metric to the neighbor advertising that path. Reported distance is the total metric along a path to a destination network as advertised by an upstream neighbor. A feasible successor is a path whose AD is less than the FD (current best path). Figure 3-19 illustrates this process.

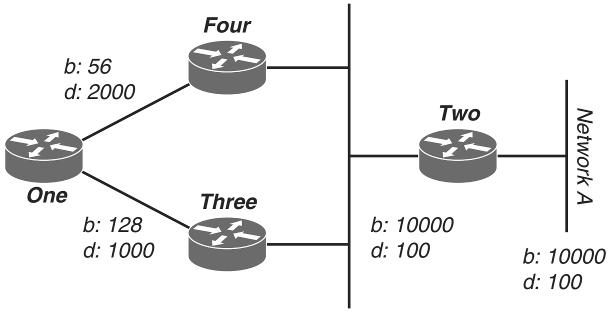


Figure 3-19 *Example Topology for Calculating Metric*

Router One recognizes two routes to Network A, one through Router Three and another through Router Four:

- The route through Router Four has a cost of 46277376 and an AD of 307200.
- The route through Router Three has a cost of 20307200 and an AD of 307200.

Note that in each case, EIGRP calculates the AD from the router advertising the route to the network. In other words, the AD from Router Four is the metric to get to Network A from Router Four, and the AD from Router Three is the metric to get to Network A from Router Three. EIGRP chooses the route through Router Three as the best path, and uses the metric through Router Three as the FD. Because the AD to this network through Router Four is less than the FD, Router One considers the path through Router Four a feasible successor.

When the link between Routers One and Three goes down, Router One examines each path it knows to Network A and finds that it has a feasible successor through Router Four. Router One uses this route, using the metric through Router Four as the new FD. The network converges instantly, and updates to downstream neighbors are the only traffic from the routing protocol.

EIGRP IPv6 Load Balancing

Similarly to IPv4, IPv6 supports equal-cost load balancing and unequal-cost load balancing.

Cisco IOS Software has the ability to load balance across up to four equal-cost paths by default. With the **maximum-paths** router configuration command, up to 32 equal-cost routes can be kept in the routing table, depending on the router type and Cisco IOS version. If you set the value to 1, you disable equal-cost load balancing.

EIGRP supports unequal-cost path load balancing. Use the **variance** *n* command to instruct the router to include routes with a metric of less than *n* times the minimum metric route for that destination. The variable *n* can take a value between 1 and 128. The default is 1, which means equal-cost load balancing. Traffic is also distributed among the links with unequal costs, proportionately, with respect to the metric. If a path is not a feasible successor, it is not used in load balancing.

EIGRP for IPv6 Command Syntax

This section covers some of the basics for EIGRP configuration under IPv6. Example 3-20 illustrates the process of basic IPv6 routing. It shows how to configure an IPv6 address and the EIGRP routing protocol on an interface, and verify that the EIGRP process has begun.

Example 3-20 *Configuring and Verifying EIGRP for IPv6*

```
IPv6-router# config terminal
Enter configuration commands, one per line.  End with CNTL/Z.
IPv6-router(config)# interface FastEthernet0/0
IPv6-router(config-if)# ipv6 address 2001:DB8:A00:1::1/32
IPv6-router(config-if)# no shutdown
IPv6-router(config-if)# exit
IPv6-router(config)# ipv6 unicast-routing
IPv6-router(config)# ipv6 router eigrp 1
IPv6-router(config-rtr)# no shutdown
IPv6-router(config-rtr)# interface FastEthernet0/0
IPv6-router(config-if)# ipv6 eigrp 1
IPv6-router(config-if)# exit
IPv6-router(config)# exit
*Apr  8 06:56:18.011: %SYS-5-CONFIG_I: Configured from console by console
IPv6-router# show ipv6 protocol
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "eigrp 1"
  EIGRP metric weight K1=1, K2=0, K3=1, K4=0, K5=0
  EIGRP maximum hopcount 100
  EIGRP maximum metric variance 1
  Interfaces: FastEthernet0/0
  Redistribution:
    None
  Maximum path: 16
  Distance: internal 90 external 170

IPv6-router#
```

Table 3-6 describes the basic commands used in Example 3-20.

Table 3-6 *Commands Used in Example 3-20*

Command(s)	Description
interface FastEthernet0/0	Enter interface mode
ipv6 address 2001:DB8:A00:1::1/32	Assign an IPv6 address on the interface
ipv6 unicast-routing	Enable IPv6 routing
ipv6 router eigrp 1	Configure EIGRP with AS number 1
no shutdown	Enable the EIGRP process
show ipv6 protocol	Verify the EIGRP process has started (more on EIGRP verification/**show** commands in the next section)

Note For more information on configuring IPv6, refer to the *IOS IPv6 Configuration Guide, Cisco IOS Release 15.1.S*: http://www.cisco.com/en/US/docs/ios-xml/ios/ipv6/configuration/15-1s/ipv6-15-1s-book.html.

Verification of EIGRP IPv6 Operation

Example 3-21 shows the EIGRP topology for IPv6. A good point to note is that the command execution and information displayed are similar to the IPv4 version of the command (see Figure 3-7), and are just differentiated by the IPv4 and IPv6 protocol differences.

Example 3-21 *EIGRP Topology for IPv6*

```
IPv6-router# show ipv6 eigrp topology

IPv6-EIGRP Topology Table for AS(1)/ID(2001:0DB8:10::/64)

Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
r - reply Status, s - sia Status

P 2001:0DB8:3::/64, 1 successors, FD is 281600
via Connected, Ethernet1/0
```

The EIGRP neighbors are shown in Example 3-22.

Example 3-22 *Verifying EIGRP Neighbors*

```
IPv6-router# show ipv6 eigrp neighbors
IPv6-EIGRP neighbors for process 1
H   Address                Interface   Hold   Uptime   SRTT    RTO    Q     Seq
                                       (sec)           (ms)           Cnt   Num
0   Link-local address:        Se0/0      13  15:17:58   44     264    0      12
    FE80::2
```

Example 3-23 displays the associated routing table.

Example 3-23 *Verifying the Routing Table*

```
IPv6-router# show ipv6 route eigrp
IPv6 Routing Table - 12 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B – BGP
              U - Per-user Static route, M - MIPv6
              I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
              O - OSPF intra, OI - OSPF inter, OE1 - OSPF ext 1, OE2 - OSPF ext 2
              ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
              D - EIGRP, EX - EIGRP external
D   1000:AB8::/64 [90/2297856]
         via FE80::2, Serial0/0
D   2000:AB8::/64 [90/2297856]
         via FE80::2, Serial0/0
D   3000:AB8::/64 [90/2297856]
         via FE80::2, Serial0/0
```

The **show** commands in Example 3-20 through Example 3-23 have the same role as in EIGRP for IPv4. The differences are related to the protocol output:

- To display entries in the EIGRP for IPv6 topology table, use the **show ipv6 eigrp topology** command in privileged EXEC mode.
- To display the neighbors discovered by EIGRP for IPv6, use the **show ipv6 eigrp neighbors** command.
- The **show ipv6 route eigrp** command reveals the content of the IPv6 routing table that includes the routes specific to EIGRP.

EIGRP for IPv6 Configuration Example

Figure 3-20 along with the configurations in Examples 3-24 and 3-25 provide a simple two-node network with a Branch router and an HQ router.

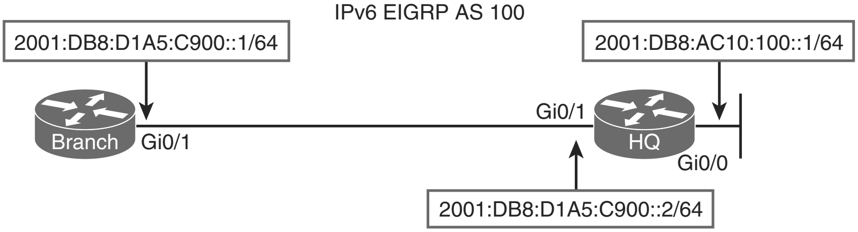


Figure 3-20 *Two-Router IPv6 Network*

On the Branch router, EIGRP for IPv6 is enabled with AS 100. EIGRP is then enabled on the interface GigabitEthernet0/1.

Example 3-24 *Branch Router Configuration*

```
Branch(config)# ipv6 router eigrp 100
Branch(config-router)# no shutdown
Branch(config-router)# exit
Branch(config)# interface GigabitEthernet0/1
Branch(config-if)# ipv6 eigrp 100
```

As displayed in Example 3-25, on the HQ router, first EIGRP for IPv6 is enabled with AS 100. Then interfaces GigabitEthernet0/0 and GigabitEthernet0/1 are enabled for IPv6 EIGRP.

Example 3-25 *HQ Router Configuration*

```
HQ(config)# ipv6 router eigrp 100
HQ(config-router)# no shutdown
HQ(config)# exit
HQ(config)# interface GigabitEthernet0/0
HQ(config-if)# ipv6 eigrp 100
HQ(config-if)# exit
HQ(config)# interface GigabitEthernet0/1
HQ(config-if)# ipv6 eigrp 100
```

In the **show ipv6 eigrp interfaces** command output that follows in Example 3-26 for the Branch router, one neighbor is on the GigabitEthernet0/1 interface, which is the only interface that is included in the EIGRP process.

Example 3-26 *Verifying EIGRP Interface*

```
Branch# show ipv6 eigrp interfaces
IPv6-EIGRP interfaces for AS(100)

                          Xmit Queue    Mean    Pacing Time    Multicast    Pending
Interface       Peers    Un/Reliable   SRTT    Un/Reliable    Flow Timer    Routes
Gi0/1             1          0/0          0        0/10            0           0

Un/reliable mcasts: 0/0 Un/reliable ucasts: 0/0
Mcast exceptions: 0 CR packets: 0 ACKs suppressed: 0
Retransmissions sent: 0 Out-of-sequence rcvd: 0
Authentication mode is not set
```

Example 3-27 shows the output of the **show ipv6 eigrp neighbors** command from the Branch router. The fields in the command output are described in Table 3-7.

Example 3-27 *Reviewing EIGRP Neighbors*

```
IPv6-router# show ipv6 eigrp neighbors
IPv6-EIGRP neighbors for process 1
H   Address                 Interface    Hold    Uptime    SRTT    RTO    Q   Seq
                                         (sec)             (ms)          Cnt  Num
0   Link-local address:         Gi0/1      12   00:20:48     9    100    0    2
    FE80::FE99:47FF:FEE5:2671
```

Table 3-7 *Significant Fields in the* **show ipv6 eigrp neighbors** *Command from the Branch Router*

Field	Description
Link-local address	The IPv6 interface address used for communication local to a single subnet only. Link-local packets are not routed. EIGRP IPv6 uses this to establish neighbor relationships.
Interface	The EIGRP interface.
Hold	The amount of time an EIGRP neighbor awaits a hello packet from a neighbor before determining that the neighbor relationship should be timed out and broken. The default is three times the hold timer.
Uptime	How long the neighbor relationship has been established.

The **show ipv6 eigrp topology** command displays the topology table of EIGRP for IPv6 routes, as demonstrated in Example 3-28. All the routes are present in the topology table, but only the best ones are in the routing table.

Example 3-28 *IPv6 Topology*

```
Branch# show ipv6 eigrp topology
EIGRP-IPv6 Topology Table for AS(100)/ID(209.165.201.1)
Codes: P - Passive, A - Active, U - Update, Q - Query, R - Reply,
              r - reply Status, s - sia Status
P 2001:DB8:D1A5:C900::/64, 1 successors, FD is 28160
        via Connected, GigabitEthernet0/1
P 2001:DB8:AC10:100::/64, 1 successors, FD is 156160
        via FE80::FE99:47FF:FEE5:2671 (156160/128256), GigabitEthernet0/1
```

Example 3-29 displays output from the **show ipv6 route eigrp** command. Here, you are presented with a route that is learned by the EIGRP routing protocol.

Example 3-29 *Verifying the EIGRP Routes in the Routing Table*

```
Branch# show ipv6 route eigrp
IPv6 Routing Table - default - 4 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
              B - BGP, R - RIP, I1 - ISIS L1, I2 - ISIS L2
              IA - ISIS interarea, IS - ISIS summary, D - EIGRP, EX - EIGRP external
             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
D   2001:DB8:AC10:100::/64 [90/156160]
          via FE80::FE99:47FF:FEE5:2671, GigabitEthernet0/1
```

Troubleshooting EIGRP for IPv6

When considering EIGRP for IPv6, there are many similarities to EIGRP for IPv4. The commands are comparable, the algorithm is the same, and the metrics work alike. However, being aware of some of the major differences and key points makes troubleshooting easier. The following points provide a brief summary:

- EIGRP for IPv6 is directly designed on the interfaces over which it runs. This feature allows EIGRP for IPv6 to be configured without the use of a global IPv6 address. There is no network statement in EIGRP for IPv6.
- In per-interface design at system startup, if EIGRP has been configured on an interface, then the EIGRP protocol may start running before any EIGRP router mode commands have been executed.
- An EIGRP for IPv6 protocol instance requires a router ID before it can start running.

- EIGRP for IPv6 has a shutdown feature. The routing process should be in **no shutdown** mode in order to start running.
- When using a passive-interface configuration, EIGRP for IPv6 does not need to be configured on the interface that is made passive.
- EIGRP for IPv6 provides route filtering using the **distribute-list** command.

Note As with IPv4 EIGRP, distribute lists are explored in more detail in the Implementing Cisco IP Routing (ROUTE) course and the related texts for preparation for the Implementing Cisco IP Routing (ROUTE) exam.

Chapter Summary

Dynamic routing protocols are defined by type, distance vector or link state. Distance vector protocols use a metric to determine the path through the network on a hop-by-hop basis. Link-state protocols keep a topology of all routers and links in the network. Examples of distance vector protocols are EIGRP and RIP. Examples of link-state protocols are OSPF and BGP.

Dynamic routing protocols are classified as Exterior Gateway Protocol (EGP) or Interior Gateway Protocol (IGP). An EGP is used between different autonomous systems, such as autonomous systems connected to the public Internet. IGPs are used inside a network. The only current EGP for IPv4 and IPV6 is BGP. Examples of IGPs are OSPF, EIGRP, and RIP.

EIGRP is an IGP that is considered an advanced distance vector protocol because it has many added features, such as partial updates. EIGRP uses the DUAL algorithm for its topology and metric calculations. It is suitable for many network designs. It supports multiple protocols through separate processes, called protocol-dependent modules.

EIGRP for IPv4 and EIGRP for IPv6 have very similar operating models, such as configuration and troubleshooting. The main deviations are where IPv4 and IPv6 differ as protocols. The primary differences are that IPv6 uses link-local addressing for EIGRP (IPv6) neighbor establishment; EIGRP for IPv6 is configured on an interface-by-interface basis; and the creation of passive interfaces in IPV6 is done not by configuring an interface but by adding configuration for the passive interface.

Review Questions

Use the questions here to review what you learned in this chapter. The correct answers are located in Appendix A, "Answers to Chapter Review Questions."

1. In which two ways does the configuration of EIGRP on IPv6 differ from the configuration of EIGRP on IPv4? (Choose two.) (Source: "EIGRP for IPv6 Command Syntax")
   a. The **network** command is changed into the **ipv6 network** command for EIGRP for IPv6.
   b. EIGRP for IPv6 can only be explicitly enabled with the **no shutdown** command. There is no **network** command.
   c. EIGRP for IPv6 is configured per interface on Cisco routers.
   d. If you run EIGRP for IPv6, you have to run EIGRP for IPv4; but if you run EIGRP for IPv4, you do not need to run EIGRP for IPv6.
2. Which command can you use to show if EIGRP for IPv6 is running? (Source: "EIGRP for IPv6 Command Syntax")
   a. **show ipv6 interface**
   b. **show ipv6 protocol**
   c. **show ipv6 eigrp dual**
   d. **show eigrp ipv6 dual**
3. Which is not a valid IPv6 EIGRP command? (Source: EIGRP Basic Configuration)
   a. **show ipv6 eigrp topology**
   b. **show ipv6 route eigrp**
   c. **show ipv6 eigrp status**
   d. **show ipv6 eigrp interfaces**
4. Which of the following applies to EIGRP AS numbers? (Source: "Troubleshooting EIGRP Neighbor Issues")
   a. Need to match between EIGRP neighbors only
   b. Need to match OSPF area numbers if routes are being redistributed
   c. Need to match between all EIGRP routers in the topology
   d. Don't need to match at all
   e. Must match BGP AS numbers
5. Which command is most useful for determining if an EIGRP neighbor relationship is not established due to a connectivity issue? (Source: "Troubleshooting EIGRP Neighbor Issues")
   a. **show ip protocols**
   b. **show ip eigrp neighbors**
   c. **show eigrp topology**
   d. **show ip protocols**
   e. **show ip interfaces brief**

6. Which of the following applies to an EIGRP passive interface? (Source: "Troubleshooting EIGRP Neighbor Issues")

- **a.** Only makes a neighbor relationship if a neighbor that is on a directly connected subnet initiates the connection
- **b.** Can be seen by the **show ip eigrp passive-interfaces** command
- **c.** Can be seen by the **show ip protocols** command
- **d.** Can have a different AS number assigned to it

7. Route filtering can be done on which of the following? (Source: "Issues Caused by Route Filtering")

- **a.** Inbound routes only
- **b.** Outbound routes only
- **c.** Either inbound or outbound routes

8. Where is automatic summarization performed? (Source: Classful Routing Versus Classless Routing)

- **a.** At any contiguous network block
- **b.** At classful network boundaries
- **c.** Can be performed on the same classful boundary on more than one network segment at the same time
- **d.** At the intersection of the classful and classless routing protocol.

9. Which command correctly specifies that network 10.0.0.0 is directly connected to a router that is running EIGRP and should be advertised? (Source: "Implementing EIGRP for IPv6")

- **a.** Router(config)# **network 10.0.0.0**
- **b.** Router(config)# **router eigrp 10.0.0.0**
- **c.** Router(config-router)# **network 10.0.0.0**
- **d.** Router(config-router)# **router eigrp 10.0.0.0**

10. Connect each EIGRP feature on the left with its description on the right. (Source: "Implementing EIGRP for IPv6")

1. Reduced bandwidth usage	a. EIGRP algorithm by which EIGRP achieves rapid convergence
2. Classless routing	b. A direct consequence of using partial updates
3. Load balancing	c. EIGRP knows two types: equal and unequal
4. DUAL	d. Routing mask is advertised for each destination network

11. Which two criteria does EIGRP use by default to calculate its metric? (Choose two.) (Source: "Implementing EIGRP for IPv6")

a. Bandwidth
b. Reliability
c. Load
d. MTU
e. Delay

12. Connect each term on the left to its description on the right. (Source: "Implementing EIGRP for IPv6")

1. Feasible distance	a. The best EIGRP metric for an EIGRP neighbor to reach a particular network
2. Advertised distance	b. The end-to-end metric that is transmitted from the router for a remote network
3. Administrative distance	c. The end-to-end EIGRP metric from a router to reach a particular network
4. Composite metric	d. Used to rate the trustworthiness of each routing information source

13. Which letter is used to signify that a route in the **show ip routes** command originates from EIGRP? (Source: "Verification of EIGRP Configuration and Operation")

a. A
b. D
c. E
d. L

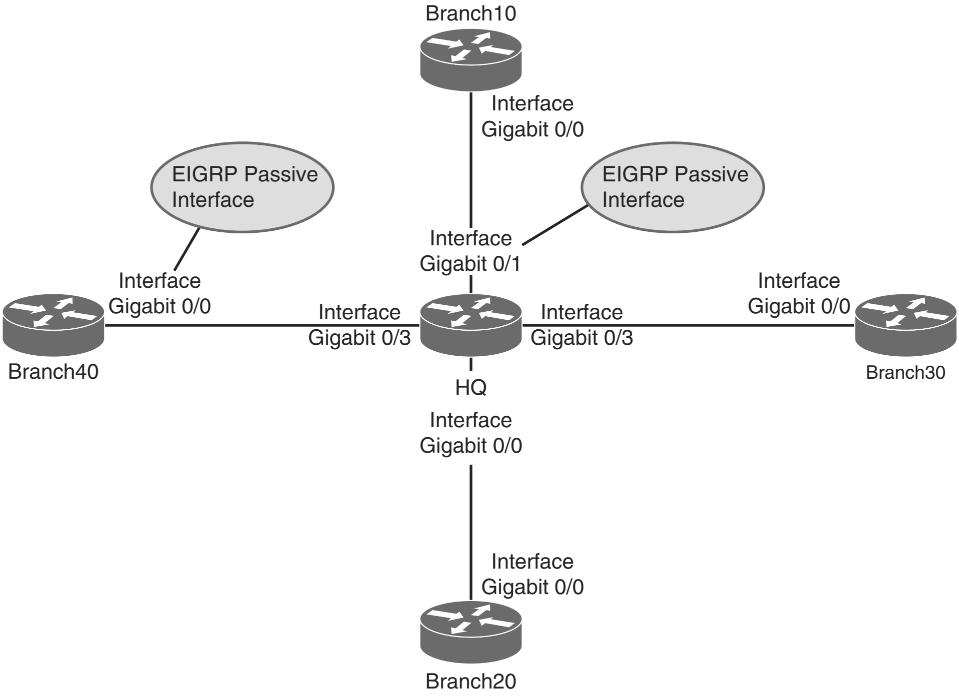
14. Which is not a valid command? (Source: "Verification of EIGRP Configuration and Operation")

a. **show ip eigrp dual process** *as_number*
b. **show ip eigrp interfaces**
c. **show ip route**
d. **show ip eigrp neighbors**

15. All routing protocols support uneven-cost load balancing. True or False? (Source: "Load Balancing with EIGRP")

16. Which interface(s) on the Branch router does not have an EIGRP neighbor? (Source: "Verification of EIGRP Configuration and Operation")

- **a.** Gigabit0/0
- **b.** Gigabit0/1
- **c.** Gigabit0/2
- **d.** Gigabit0/3
- **e.** All interfaces have an EIGRP neighbor
- **f.** No interfaces have an EIGRP neighbor



17. Which two choices are *not* a characteristic of EIGRP? (Source: "Dynamic Routing Overview")

- **a.** Determines distance to any destination in the network
- **b.** Uses an algorithm called DUAL
- **c.** Uses an algorithm called SPF
- **d.** Has a map of every destination in the network

18. Which command would you use to investigate which interfaces are enabled for the EIGRP routing process? (Source: "Troubleshooting EIGRP Neighbor Issues")

- **a.** **show ip eigrp interfaces**
- **b.** **show ip eigrp neighbors**
- **c.** **show ip interfaces brief**
- **d.** **show eigrp enabled interfaces**

19. Which of the following statements are false? (Source: "Troubleshooting EIGRP for IPv6")

a. In per-interface configuration at system startup, if IPv6 EIGRP has been configured on an interface, then the IPv6 EIGRP protocol may start running before any EIGRP router mode commands have been executed.

b. An EIGRP for IPv6 protocol instance does not need a router ID before it can start running. The router ID can be added later.

c. When using a passive-interface configuration, EIGRP for IPv6 does not need to be configured on the interface that is made passive.

d. EIGRP for IPv6 is not directly configured on the interfaces over which it runs. In the network statement in EIGRP for IPv6, the interface must be explicitly defined.

e. EIGRP for IPv6 has a shutdown feature. The routing process must be in **no shutdown** mode in order to start running.

f. EIGRP for IPv6 provides route filtering using the **distribute-list prefix-list** command. Use of the **route-map** command is not supported for route filtering with a distribute list.

g. EIGRP uses the advanced DUAL algorithm that maintains a database of every node on the network.

20. Which is not a basic component of EIGRP? (Source: "EIGRP Features and Function")

a. Topology database

b. DUAL algorithm

c. Protocol-dependent modules

d. Hello packets

21. Which is not a valid dynamic routing protocol classification? (Source: "Dynamic Routing Protocols")

a. Hybrid

b. Distance vector

c. Link state

22. Connect each term on the left with its definition on the right. (Source: "Dynamic Routing Review")

1. Distance vector protocol	a. Keeps track of all links and routers in the network
2. EGP	b. Internal routing for a single routing domain
3. Link-state protocol	c. Tracks the network path on a hop-by-hop basis
4. IGP	d. Connects routing domains

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