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Portable Command Guide

All the CCNA 200-301 commands in one compact, portable resource

Fifth Edition

Scott Empson

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CCNA 200-301 Portable Command Guide

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Dedications

As always, this book is dedicated to Trina, Zach, and Shae. Now that you are older and are in university, do you even know what I do when I write these books, or are you just happy that I can afford to take you to Disney again? Or pay for your tuition. Pick one... xxxooo :)

Acknowledgments

Just as it takes many villagers to raise a child, it takes many people to create a book. Without the following, I wouldn't be able to call myself an author; my title would probably be village idiot. Therefore, I must thank:

The team at Cisco Press. Once again, you amaze me with your professionalism and the ability to make me look good. James, Ellie, Bill, Tonya, and Vaishnavi: Thank you for your continued support and belief in my little engineering journal.

To my technical reviewer, Rick: We finally get to work together! Rick was one of the first people I met when getting involved with Cisco and the Cisco Academy all those years ago (2001?). I first met you in Las Vegas at a Networkers conference. You were brilliant then, and you are brilliant now. Thanks for correcting my mistakes and making me look smarter than I really am.

A special thanks to Mary Beth Ray: You were my first editor with Cisco Press and you were with me for every step over the last 15 years. Thank you for taking a risk on me and my idea. I hope that your post-publishing career is just as exciting and rewarding as your time was with us. I bow to the divine in you. Namaste.

If you like this book, it is all because of them. Any errors in this book are all on me.

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the 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).
- *Italic* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate an optional element.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Introduction

Welcome to *CCNA 200-301 Portable Command Guide*! As most of you know, Cisco has announced a complete revamp and update to its certifications. What you have here is the latest Portable Command Guide as part of these new outcomes and exams. For someone who originally thought that this book would be less than 100 pages in length and limited to the Cisco Networking Academy program for its complete audience, I am continually amazed that my little engineering journal has caught on with such a wide range of people throughout the IT community.

I have long been a fan of what I call the "engineering journal," a small notebook that can be carried around and that contains little nuggets of information—commands that you forget, the IP addressing scheme of some remote part of the network, little reminders about how to do something you only have to do once or twice a year (but is vital to the integrity and maintenance of your network). This journal has been a constant companion by my side for the past 20 years; I only teach some of these concepts every second or third year, so I constantly need to refresh commands and concepts and learn new commands and ideas as Cisco releases them. My journals are the best way for me to review because they are written in my own words (words that I can understand). At least, I had better understand them because if I can't, I have only myself to blame.

My first published engineering journal was the *CCNA Quick Command Guide*; it was organized to match the (then) order of the Cisco Networking Academy program. That book then morphed into the *Portable Command Guide*, the fifth edition of which you are reading right now. This book is my "industry" edition of the engineering journal. It contains a different logical flow to the topics, one more suited to someone working in the field. Like topics are grouped together: routing protocols, switches, troubleshooting. More complex examples are given. IPv6 has now been integrated directly into the content chapters themselves. IPv6 is not something new that can be introduced in a separate chapter; it is part of network designs all around the globe, and we need to be as comfortable with it as we are with IPv4. The popular "Create Your Own Journal" appendix is still here (blank pages for you to add in your own commands that you need in your specific job). We all recognize the fact that no network administrator's job can be so easily pigeonholed as to just working with CCNA topics; you all have your own specific jobs and duties assigned to you. That is why you will find those blank pages at the end of the book. Make this book your own; personalize it with what you need to make it more effective. This way your journal will not look like mine.

Private Addressing Used in This Book

This book uses RFC 1918 addressing throughout. Because I do not have permission to use public addresses in my examples, I have done everything with private addressing. Private addressing is perfect for use in a lab environment or in a testing situation because it works exactly like public addressing, with the exception that it cannot be routed across a public network.

Who Should Read This Book

This book is for those people preparing for the CCNA certification exam, whether through self-study, on-the-job training and practice, or study within the Cisco Networking Academy program. There are also some handy hints and tips along the way to make life a bit easier for you in this endeavor. This book is small enough that you will find it easy to carry around with you. Big, heavy textbooks might look impressive on your bookshelf in your office, but can you really carry them around with you when you are working in some server room or equipment closet somewhere?

Optional Sections

A few sections in this book have been marked as optional. These sections cover topics that are not on the CCNA certification exam, but they are valuable topics that should be known by someone at a CCNA level. Some of the optional topics might also be concepts that are covered in the Cisco Networking Academy program courses.

Organization of This Book

This book follows a logical approach to configuring a small to mid-size network. It is an approach that I give to my students when they invariably ask for some sort of outline to plan and then configure a network. Specifically, this approach is as follows:

Part I: Network Fundamentals

- **Chapter 1, "IPv4 Addressing—How It Works":** An overview of the rules of IPv4 addressing—how it works, what is it used for, and how to correctly write out an IPv4 address
- **Chapter 2, "How to Subnet IPv4 Addresses":** An overview of how to subnet, examples of subnetting (both a Class B and a Class C address), and using the binary AND operation
- **Chapter 3, "Variable Length Subnet Masking (VLSM)":** An overview of VLSM, and an example of using VLSM to make your IP plan more efficient
- **Chapter 4, "Route Summarization":** Using route summarization to make your routing updates more efficient, an example of how to summarize a network, and necessary requirements for summarizing your network
- **Chapter 5, "IPv6 Addressing—How It Works":** An overview of the rules for working with IPv6 addressing, including how it works, what is it used for, how to correctly write out an IPv6 address, and the different types of IPv6 addresses
- **Chapter 6, "Cables and Connections":** An overview of how to connect to Cisco devices, which cables to use for which interfaces, and the differences between the TIA/EIA 568A and 568B wiring standards for UTP
- **Chapter 7, "The Command-Line Interface":** How to navigate through Cisco IOS Software: editing commands, using keyboard shortcuts for commands, and using help commands

Part II: LAN Switching Technologies

- **Chapter 8, "Configuring a Switch":** Commands to configure Catalyst switches: names, passwords, IP addresses, default gateways, port speed and duplex, and static MAC addresses
- **Chapter 9, "VLANs":** Configuring static VLANs, troubleshooting VLANs, saving and deleting VLAN information, and configuring voice VLANs with and without trust
- **Chapter 10, "VLAN Trunking Protocol and Inter-VLAN Communication":** Configuring a VLAN trunk link, configuring VTP, verifying VTP, and configuring inter-VLAN communication using router-on-a-stick, subinterfaces, and SVIs
- **Chapter 11, "Spanning Tree Protocol":** Verifying STP, setting switch priorities, working with optional features, and enabling Rapid Spanning Tree
- **Chapter 12, "EtherChannel":** Creating and verifying Layer 2 and Layer 3 EtherChannel groups between switches
- **Chapter 13, "Cisco Discovery Protocol (CDP) and Link Layer Discovery Protocol (LLDP)":** Customizing and verifying both CDP and LLDP

Part III: Routing Technologies

- **Chapter 14, "Configuring a Cisco Router":** Commands needed to configure a single router: names, passwords, configuring interfaces, MOTD and login banners, IP host tables, saving and erasing your configurations
- **Chapter 15, "Static Routing":** Configuring IPv4 and IPv6 static routes in your internetwork
- **Chapter 16, "Open Shortest Path First (OSPF)":** Configuring and verifying OSPFv2 in single-area designs

Part IV: IP Services

- **Chapter 17, "DHCP":** Configuring and verifying DHCP on a Cisco IOS router, and using Cisco IP Phones with a DHCP server
- **Chapter 18, "Network Address Translation (NAT)":** Configuring and verifying NAT and PAT
- **Chapter 19, "Configuring Network Time Protocol (NTP)":** Configuring and verifying NTP, setting the local clock, and using time stamps

Part V: Security Fundamentals

- **Chapter 20, "Layer Two Security Features":** Setting passwords, configuring switch port security, using static and sticky MAC addresses, configuring and verifying DHCP snooping, and configuring and verifying Dynamic ARP Inspection (DAI)

- **Chapter 21, "Managing Traffic Using Access Control Lists (ACLs)":** Configuring standard ACLs, using wildcard masks, creating extended ACLs, creating named ACLs, using sequence numbers in named ACLs, verifying and removing ACLs, and configuring and verifying IPv6 ACLs
- **Chapter 22, "Device Monitoring and Hardening":** Device monitoring, backups, logging and the use of syslog, syslog message formats, configuring and encrypting passwords, configuring and verifying SSH, restricting virtual terminal access, and disabling unused services

Part VI: Wireless Technologies

- **Chapter 23, "Configuring and Securing a WLAN AP":** The initial setup for a Wireless LAN Controller, monitoring a WLC, configuring VLANs, DHCP, WLAN, RADIUS servers, other management options, and security on a WLC

Part VII: Appendices

- **Appendix A, "How to Count in Decimal, Binary, and Hexadecimal":** A refresher on how to count in decimal, and using those rules to count in binary and hexadecimal
- **Appendix B, "How to Convert Between Number Systems":** Rules to follow when converting between the three numbering systems used most often in IT: decimal, binary, and hexadecimal
- **Appendix C, "Binary/Hex/Decimal Conversion Chart":** A chart showing numbers 0 through 255 in the three numbering systems of binary, hexadecimal, and decimal
- **Appendix D, "Create Your Own Journal Here":** Some blank pages for you to add in your own specific commands that might not be in this book

Did I Miss Anything?

I am always interested to hear how my students, and now readers of my books, do on both certification exams and future studies. If you would like to contact me and let me know how this book helped you in your certification goals, please do so. Did I miss anything? Let me know. Contact me at PCG@empson.ca or through the Cisco Press website, http://www.ciscopress.com.

Figure Credits

Figure 6-3, screenshot of PC Settings © Microsoft, 2019.

Figure 23-7, 23 Logging into the WLC Screenshot of Logging into © Microsoft, 2019.

Figure 23-15, screenshot of Interface Address © Microsoft, 2019.

Figure 23-16, screenshot of Interface Address © Microsoft, 2019.

Figure 23-17, screenshot of Success ping message © Microsoft, 2019.

Figure 23-24, screenshot of Saving configuration © Microsoft, 2019.

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CHAPTER 4

Route Summarization

This chapter provides information concerning the following topics:

- Example for understanding route summarization
- Route summarization and route flapping
- Requirements for route summarization

Route summarization, or supernetting, is needed to reduce the number of routes that a router advertises to its neighbor. Remember that for every route you advertise, the size of your update grows. It has been said that if there were no route summarization, the Internet backbone would have collapsed from the sheer size of its own routing tables back in 1997!

Routing updates, whether done with a distance-vector protocol or a link-state protocol, grow with the number of routes you need to advertise. In simple terms, a router that needs to advertise ten routes needs ten specific lines in its update packet. The more routes you have to advertise, the bigger the packet. The bigger the packet, the more bandwidth the update takes, reducing the bandwidth available to transfer data. But with route summarization, you can advertise many routes with only one line in an update packet. This reduces the size of the update, allowing you more bandwidth for data transfer.

Also, when a new data flow enters a router, the router must do a lookup in its routing table to determine which interface the traffic must be sent out. The larger the routing tables, the longer this takes, leading to more used router CPU cycles to perform the lookup. Therefore, a second reason for route summarization is that you want to minimize the amount of time and router CPU cycles that are used to route traffic.

NOTE: This example is a very simplified explanation of how routers send updates to each other. For a more in-depth description, I highly recommend you go out and read Jeff Doyle and Jennifer Carroll's book *Routing TCP/IP, Volume I*, Second Edition (Cisco Press, 2005). This book has been around for many years and is considered by most to be the authority on how the different routing protocols work. If you are considering continuing on in your certification path to try and achieve the CCIE, you need to buy Doyle's book—and memorize it; it's that good.

Example for Understanding Route Summarization

Refer to Figure 4-1 to assist you as you go through the following explanation of an example of route summarization.

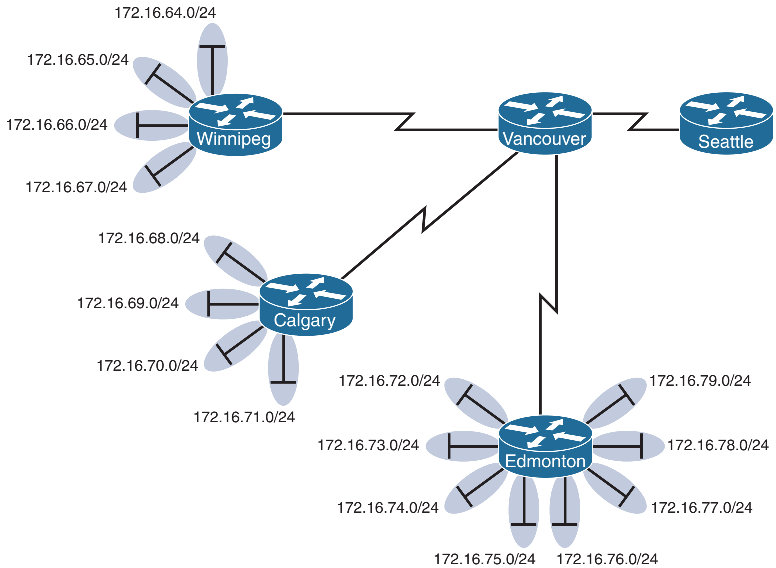


Figure 4-1 Four-City Network Without Route Summarization

As you can see from Figure 4-1, Winnipeg, Calgary, and Edmonton each have to advertise internal networks to the main router located in Vancouver. Without route summarization, Vancouver would have to advertise 16 networks to Seattle. You want to use route summarization to reduce the burden on this upstream router.

Step 1: Summarize Winnipeg's Routes

To do this, you need to look at the routes in binary to see if there are any specific bit patterns that you can use to your advantage. What you are looking for are common bits on the network side of the addresses. Because all of these networks are /24 networks, you want to see which of the first 24 bits are common to all four networks.

172.16.64.0 = **10101100.00010000.010000**00.00000000

172.16.65.0 = **10101100.00010000.010000**01.00000000

172.16.66.0 = **10101100.00010000.010000**10.00000000

172.16.67.0 = **10101100.00010000.010000**11.00000000

Common bits: **10101100.00010000.010000**xx

You see that the first 22 bits of the four networks are common. Therefore, you can summarize the four routes by using a subnet mask that reflects that the first 22 bits are common. This is a /22 mask, or 255.255.252.0. You are left with the summarized address of

172.16.64.0/22

This address, when sent to the upstream Vancouver router, will tell Vancouver: “If you have any packets that are addressed to networks that have the first 22 bits in the pattern of 10101100.00010000.010000xx.xxxxxxxx, then send them to me here in Winnipeg.”

By sending one route to Vancouver with this supernetted subnet mask, you have advertised four routes in one line instead of using four lines. Much more efficient!

Step 2: Summarize Calgary’s Routes

For Calgary, you do the same thing that you did for Winnipeg—look for common bit patterns in the routes:

172.16.68.0 = **10101100.00010000.010001**00.00000000

172.16.69.0 = **10101100.00010000.010001**01.00000000

172.16.70.0 = **10101100.00010000.010001**10.00000000

172.16.71.0 = **10101100.00010000.010001**11.00000000

Common bits: **10101100.00010000.010001**xx

Once again, the first 22 bits are common. The summarized route is therefore

172.16.68.0/22

Step 3: Summarize Edmonton’s Routes

For Edmonton, you do the same thing that you did for Winnipeg and Calgary—look for common bit patterns in the routes:

172.16.72.0 = **10101100.00010000.01001**000.00000000

172.16.73.0 = **10101100.00010000.01001**001.00000000

172.16.74.0 = **10101100.00010000 01001**010.00000000

172.16.75.0 = **10101100.00010000 01001**011.00000000

172.16.76.0 = **10101100.00010000.01001**100.00000000

172.16.77.0 = **10101100.00010000.01001**101.00000000

172.16.78.0 = **10101100.00010000.01001**110.00000000

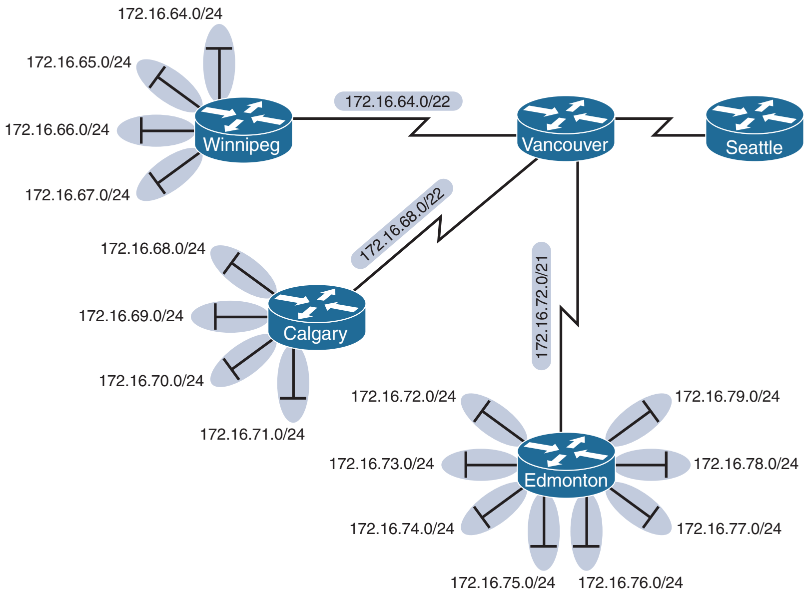
172.16.79.0 = **10101100.00010000.01001**111.00000000

Common bits: **10101100.00010000.01001**xxx

For Edmonton, the first 21 bits are common. The summarized route is therefore

172.16.72.0/21

Figure 4-2 shows what the network looks like, with Winnipeg, Calgary, and Edmonton sending their summarized routes to Vancouver.



/21	/22	/23	/24
172.16.64.0	172.16.64.0	172.16.64.0	172.16.64.0
			172.16.65.0
		172.16.66.0	172.16.66.0
			172.16.67.0
	172.16.68.0	172.16.68.0	172.16.68.0
			172.16.69.0
		172.16.70.0	172.16.70.0
			172.16.71.0
172.16.72.0	172.16.72.0	172.16.72.0	172.16.72.0
			172.16.73.0
		172.16.74.0	172.16.74.0
			172.16.75.0
	172.16.76.0	172.16.76.0	172.16.76.0
			172.16.77.0
		172.16.78.0	172.16.78.0
			172.16.79.0

Figure 4-2 Four-City Network with Edge Cities Summarizing Routes

Step 4: Summarize Vancouver's Routes

Yes, you can summarize Vancouver's routes to Seattle. You continue in the same format as before. Take the routes that Winnipeg, Calgary, and Edmonton sent to Vancouver, and look for common bit patterns:

172.16.64.0 = **10101100.00010000.0100**0000.00000000

172.16.68.0 = **10101100.00010000.0100**0100.00000000

172.16.72.0 = **10101100.00010000.0100**1000.00000000

Common bits: **10101100.00010000.0100**xxxx

Because there are 20 bits that are common, you can create one summary route for Vancouver to send to Seattle:

172.16.64.0/20

Vancouver has now told Seattle that in one line of a routing update, 16 different networks are being advertised. This is much more efficient than sending 16 lines in a routing update to be processed.

Figure 4-3 shows what the routing updates would look like with route summarization taking place.

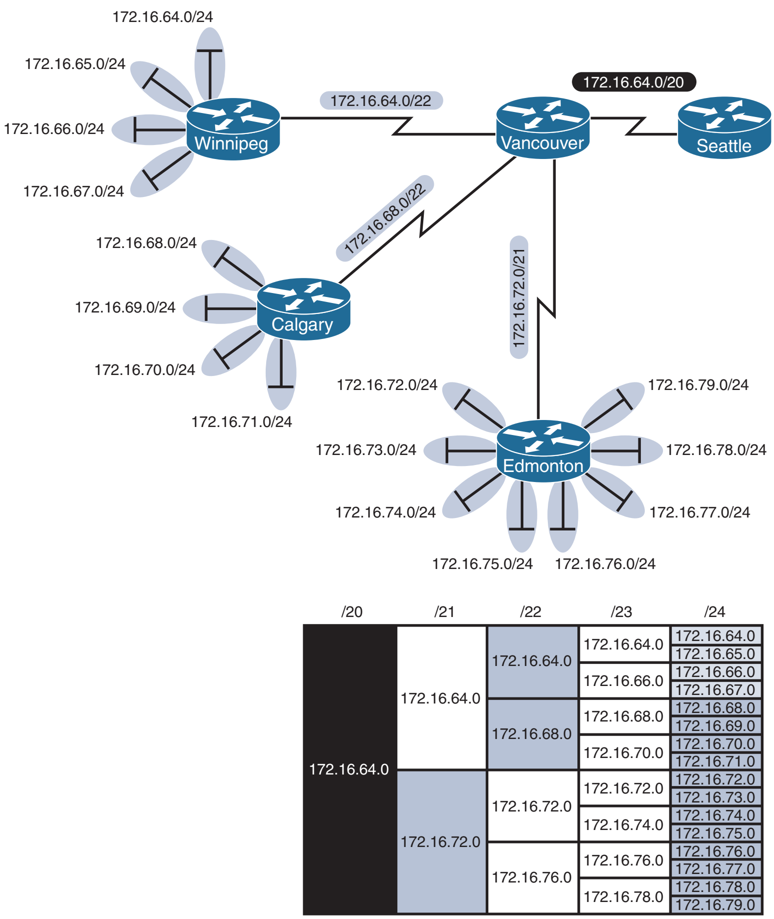


Figure 4-3 Four-City Network with Complete Route Summarization

Route Summarization and Route Flapping

Another positive aspect of route summarization has to do with route flapping. *Route flapping* is when a network, for whatever reason (such as interface hardware failure or misconfiguration), goes up and down on a router, causing that router to constantly advertise changes about that network. Route summarization can help insulate upstream neighbors from these problems.

Consider router Edmonton from Figure 4-1. Suppose that network 172.16.74.0/24 goes down. Without route summarization, Edmonton would advertise Vancouver to remove that network. Vancouver would forward that same message upstream to Calgary, Winnipeg, Seattle, and so on. Now assume the network comes back online a few seconds later. Edmonton would have to send another update informing Vancouver of the change. Each time a change needs to be advertised, the router must use CPU resources. If that route were to flap, the routers would constantly have to update their own tables, as well as advertise changes to their neighbors. In a CPU-intensive protocol such as OSPF, the constant hit on the CPU might make a noticeable change to the speed at which network traffic reaches its destination.

Route summarization enables you to avoid this problem. Even though Edmonton would still have to deal with the route constantly going up and down, no one else would notice. Edmonton advertises a single summarized route, 172.16.72.0/21, to Vancouver. Even though one of the networks is going up and down, this does not invalidate the route to the other networks that were summarized. Edmonton will deal with its own route flap, but Vancouver will be unaware of the problem downstream in Edmonton. Summarization can effectively protect or insulate other routers from route flaps.

Requirements for Route Summarization

To create route summarization, there are some necessary requirements:

- Routers need to be running a classless routing protocol, as they carry subnet mask information with them in routing updates. (Examples are RIP v2, OSPF, EIGRP, IS-IS, and BGP.)
- Addresses need to be assigned in a hierarchical fashion for the summarized address to have the same high-order bits. It does no good if Winnipeg has network 172.16.64.0 and 172.16.67.0 while 172.16.65.0 resides in Calgary and 172.16.66.0 is assigned in Edmonton. No summarization could take place from the edge routers to Vancouver.

TIP: Because most networks use NAT and the RFC 10.0.0.0/8 network internally, it is important when creating your network design that you assign network subnets in a way that they can be easily summarized. A little more planning now can save you a lot of grief later.

CHAPTER 5

IPv6 Addressing—How It Works

This chapter provides information concerning the following topics:

- IPv6: A very brief introduction
- What does an IPv6 address look like?
- Reducing the notation of an IPv6 address
  - Rule 1: Omit leading 0s
  - Rule 2: Omit all-0s hextet
  - Combining rule 1 and rule 2
- Prefix length notation
- IPv6 address types
  - Unicast addresses
    - Global unicast
    - Link-local
    - Loopback
    - Unspecified
    - Unique local
    - IPv4 embedded
  - Multicast addresses
    - Well-known
    - Solicited-node
  - Anycast addresses

NOTE: This chapter is meant to be a very high-level overview of IPv6 addressing. For an excellent overview of IPv6, I strongly recommend you read Rick Graziani's book from Cisco Press: *IPv6 Fundamentals: A Straightforward Approach to Understanding IPv6*, Second Edition. It is a brilliant read, and Rick is an amazing author. I am also very fortunate to call him a friend.

IPv6: A Very Brief Introduction

When IPv4 became a standard in 1980, its 32-bit address field created a theoretical maximum of approximately 4.29 billion addresses (2^{32}). IPv4 was originally conceived as an experiment, and not for a practical implementation, so 4.29 billion was considered to be an inexhaustible amount. But with the growth of the Internet, and the need for individuals and companies to require multiple addresses—your home PC, your cell phone, your tablet, your PC at work/school, your Internet-aware appliances—you can see that something larger than 32-bit address fields would be required. In 1993, the Internet Engineering Task Force (IETF) formed a working group called the IP Next Generation working group. In 1994 the IETF recommended an address size of 128 bits. While many people think that IPv6 is just a way to create more addresses, there are actually many enhancements that make IPv6 a superior choice to IPv4. Again, I recommend Rick Graziani's *IPv6 Fundamentals* as a must-have on your bookshelf for working with IPv6.

What Does an IPv6 Address Look Like?

The way that a computer or other digital device sees an IPv6 address and the way humans see an IPv6 address are different. A digital device looks at an IPv6 address as a 128-bit number. But humans have devised a way to convert this 128-bit number into something easier to look at and work with. For humans, an IPv6 address is a 128-bit number that is written as a string of hexadecimal digits. Hexadecimal is a natural fit for IPv6 addresses because any 4 bits can be represented as a single hexadecimal digit. Two hexadecimal digits represent a single byte, or octet (8 bits). The preferred form of an IPv6 address is *x:x:x:x:x:x:x:x*, where each *x* is a 16-bit section that can be represented using up to four hexadecimal digits. Each section is separated by a colon (:), as opposed to IPv4 addressing, which uses a period (.) to separate each section. The result is eight 16-bit sections (sometimes called *hextets*) for a total of 128 bits in the address. Figure 5-1 shows this format.

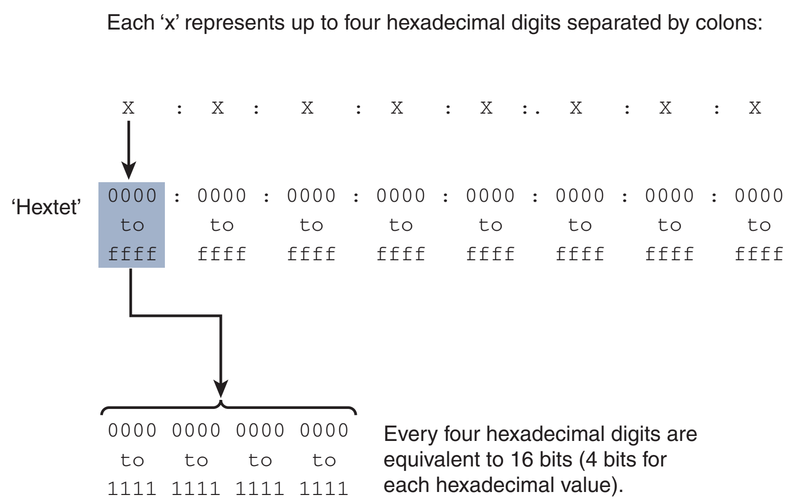


Figure 5-1 Format of an IPv6 Address

Showing all the hexadecimal digits in an IPv6 address is the longest representation of the preferred form. The next section shows you two rules for reducing the notation of an IPv6 address in the preferred format for easier use and readability.

TIP: If you need more practice working with hexadecimals and converting between hexadecimal, decimal, and binary, refer to both Appendix A, "How to Count in Decimal, Binary, and Hexadecimal," and Appendix B, "How to Convert Between Number Systems."

Reducing the Notation of an IPv6 Address

Looking at the longest representation of an IPv6 address can be overwhelming:

```
0000:0000:0000:0000:0000:0000:0000:0000
0000:0000:0000:0000:0000:0000:0000:0001
ff02:0000:0000:0000:0000:0000:0000:0001
fe80:0000:0000:0000:a299:9bff:fe18:50d1
2001:0db8:cafe:0001:0000:0000:0000:0200
```

There are two rules for reducing the notation.

Rule 1: Omit Leading 0s

Omit any leading 0s in any hextet (a 16-bit section). This rule applies only to leading 0s and not trailing 0s. Table 5-1 shows examples of omitting leading 0s in a hextet:

TABLE 5-1 Examples of Omitting Leading 0s in a Hextet (Leading 0s in bold; spaces retained)

Format	**IPv6 Address**
Preferred	**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 0 or 0:0:0:0:0:0:0:0
Preferred	**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**1
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 1 or 0:0:0:0:0:0:0:1
Preferred	ff02:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**1
Leading 0s omitted	ff02: 0: 0: 0: 0: 0: 0: 1 or ff02:0:0:0:0:0:0:1
Preferred	2001:**0**db8:1111:**000**a:**00**b0:**000**0:9000:**0**200
Leading 0s omitted	2001: db8: 1111: a: b0: 0:9000: 200 or 2001:db8:1111:a:b0:0:9000:200

Rule 2: Omit All-0s Hextet

Use a double colon (::) to represent any single, contiguous string of two or more hextets consisting of all 0s. Table 5-2 shows examples of using the double colon.

TABLE 5-2 Examples of Omitting a Single Contiguous String of All-0s Hextets (0s in Bold Replaced By a Double Colon)

Format	IPv6 Address
Preferred	**0000:0000:0000:0000:0000:0000:0000:0000**
(::) All-0s segments	::
Preferred	**0000:0000:0000:0000:0000:0000:0000**:0001
(::) All-0s segments	::0001
Preferred	ff02:**0000:0000:0000:0000:0000:0000**:0001
(::) All-0s segments	ff02::0001
Preferred	2001:0db8:aaaa:0001:**0000:0000:0000:**0100
(::) All-0s segments	2001:0db8:aaaa:0001::0100
Preferred	2001:0db8:**0000:0000**:abcd:0000:0000:1234
(::) All-0s segments	2001:0db8::abcd:0000:0000:1234

Only a single contiguous string of all 0s can be represented by a double colon; otherwise the address would be ambiguous. Consider the following example:

```
2001::abcd::1234
```

There are many different possible choices for the preferred address:

```
2001:0000:0000:0000:0000:abcd:0000:1234
2001:0000:0000:0000:abcd:0000:0000:1234
2001:0000:0000:abcd:0000:0000:0000:1234
2001:0000:abcd:0000:0000:0000:0000:1234
```

If two double colons are used, you cannot tell which of these addresses is correct.

If you have an address with more than one contiguous string of 0s, where should you place the double colon? RFC 5952 states that the double colon should represent

- The longest string of all-0s hextets.
- If the strings are of equal value, the first string should use the double colon notation.

Combining Rule 1 and Rule 2

You can combine the two rules to reduce an address even further. Table 5-3 shows examples of this.

TABLE 5-3 Examples of Applying Both Rule 1 and Rule 2 (Leading 0s in bold)

Format	IPv6 Address
Preferred	**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 0
(::) All-0s segments	::
Compressed	::
Preferred	**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**1
Leading 0s omitted	0: 0: 0: 0: 0: 0: 0: 1
(::) All-0s segments	::1
Compressed	::1
Preferred	ff02:**000**0:**000**0:**000**0:**000**0:**000**0:**000**0:**000**1
Leading 0s omitted	ff02: 0: 0: 0: 0: 0: 0: 1
(::) All-0s segments	ff02::1
Compressed	ff02::1
Preferred	fe80:**000**0:**000**0:**000**0:a299:9bff:fe18:50d1
Leading 0s omitted	fe80: 0: 0: 0:a299:9bff:fe18:50d1
(::) All-0s segments	fe80::a299:9bff:fe18:50d1
Compressed	fe80::a299:9bff:fe18:50d1
Preferred	2001:**0**db8:aaaa:0001:**000**0:**000**0:**000**0:**0**200
Leading 0s omitted	2001: db8:aaaa: 1: 0: 0: 0: 200
(::) All-0s segments	2001: db8:aaaa: 1:: 200
Compressed	2001:db8:aaaa:1::200

Prefix Length Notation

In IPv4, the prefix of the address (the network portion) can be represented either by a dotted-decimal netmask (the subnet mask) or through CIDR notation. When we see 192.168.100.0 255.255.255.0 or 192.168.100.0/24, we know that the network portion of the address is the first 24 bits of the address (192.168.100) and that the last 8 bits (.0) are host bits. IPv6 address prefixes are represented in much the same way as IPv4 address prefixes are written in CIDR notation. IPv6 prefixes are represented using the following format:

```
IPv6-Address/Prefix-Length
```

The *prefix-length* is a decimal value showing the number of leftmost contiguous bits of the address. It identifies the prefix (the network portion) of the address. In unicast addresses, it is used to separate the prefix portion from the Interface ID. The Interface ID is equivalent to the host portion of an IPv4 address.

Looking at the address

```
2001:db8:aaaa:1111::100/64
```

we know that the leftmost 64 bits are the prefix (network portion) and the remaining bits are the Interface ID (host portion). See Figure 5-2.

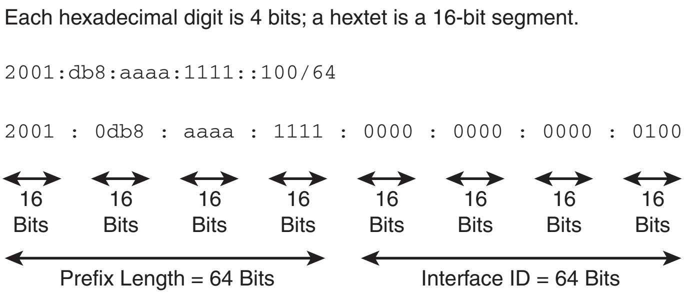


Figure 5-2 IPv6 Prefix and Prefix Length

A /64 prefix length results in an Interface ID of 64 bits. This is a common prefix length for most end-user networks. A /64 prefix length gives us 2^{64} or 18 quintillion devices on a single network (or subnet).

There are several more common prefix length examples, as shown in Figure 5-3. All of these examples fall either on a hextet boundary or on a nibble boundary (a multiple of 4 bits). Although prefix lengths do not need to fall on a nibble boundary, most usually do.

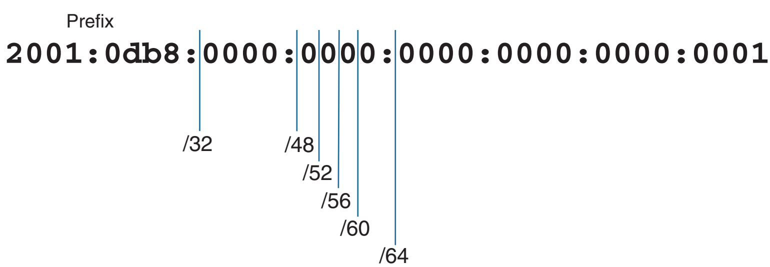


Figure 5-3 IPv6 Prefix Length Examples

IPv6 Address Types

In IPv6, there are three types of addresses: unicast, multicast, and anycast. This section gives a (very) high-level overview of these types.

> **NOTE:** IPv6 does not have a broadcast address. There are other options that exist in IPv6 that deal with this issue, but this is beyond the scope of this book.

Figure 5-4 diagrams the three types of addresses.

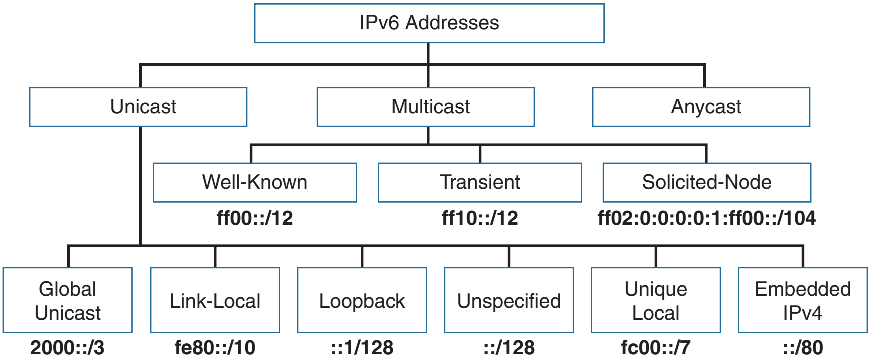


Figure 5-4 IPv6 Address Types

Unicast Addresses

A unicast address uniquely identifies an interface on an IPv6 device. A packet sent to a unicast address is received by the interface that is assigned to that address, Similar to IPv4, a source IPv6 address must be a unicast address.

As shown in Figure 5-4, there are six different types of unicast addresses:

1. **Global unicast:** A routable address in the IPv6 Internet, similar to a public IPv4 address.
2. **Link-local:** Used only to communicate with devices on the same local link.
3. **Loopback:** An address not assigned to any physical interface that can be used for a host to send an IPv6 packet to itself.
4. **Unspecified address:** Used only as a source address and indicates the absence of an IPv6 address.
5. **Unique local:** Similar to a private address in IPv4 (RFC 1918) and not intended to be routable in the IPv6 Internet. However, unlike RFC 1918 addresses, these addresses are not intended to be statefully translated to a global unicast address. Please see Rick Graziani's book *IPv6 Fundamentals* for a more detailed description of stateful translation.
6. **IPv4 embedded:** An IPv6 address that carries an IPv4 address in the low-order 32 bits of an IPv6 address.

Global Unicast Addresses

Global unicast addresses (GUAs) are globally routable and reachable in the IPv6 Internet. The generic structure of a GUA has three fields:

- **Global Routing Prefix:** The prefix or network portion of the address assigned by the provider, such as an ISP, to the customer site.

- **Subnet ID:** A separate field for allocating subnets within the customer site. Unlike IPv4, it is not necessary to borrow bits from the Interface ID (host portion) to create subnets. The number of bits in the Subnet ID falls between where the Global Routing Prefix ends and the Interface ID begins.
- **Interface ID:** Identifies the interface on the subnet, equivalent to the host portion of an IPv4 address. In most cases, the Interface ID is 64 bits in length.

Figure 5-5 shows the structure of a global unicast address.

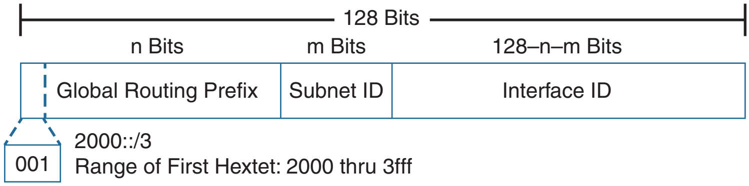


Figure 5-5 Structure of a Global Unicast Address

Link-Local Unicast Addresses

A link-local unicast address is a unicast address that is confined to a single link (a single subnet). Link-local addresses only need to be unique on the link (subnet) and do not need to be unique beyond the link. Therefore, routers do not forward packets with a link-local address.

Figure 5-6 shows the format of a link-local unicast address, which is in the range fe80::/10. Using this prefix and prefix length range results in the range of the first hextet being from fe80 to febf.

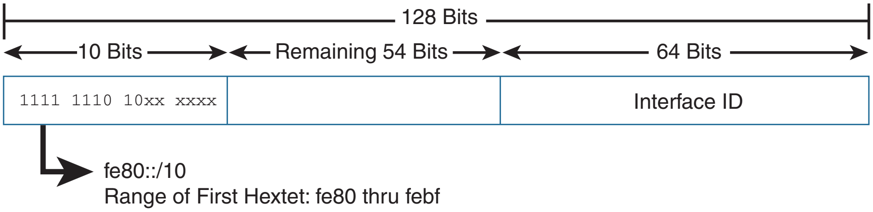


Figure 5-6 Structure of a Link-Local Unicast Address

NOTE: Using a prefix other than fe80 is permitted by RFC 4291, but the addresses should be tested prior to usage.

NOTE: To be an IPv6-enabled device, a device must have an IPv6 link-local address. You do not need to have an IPv6 global unicast address, but you must have a link-local address.

NOTE: Devices dynamically (automatically) create their own link-local IPv6 addresses upon startup. Link-local addresses can be manually configured.

NOTE: Link-local addresses only need to be unique on the link. It is very likely, and even desirable, to have the same link-local address on different interfaces that are on different links. For example, on a device named Router2, you may want all link-local interfaces to be manually configured to FE80::2, whereas all link-local interfaces on Router3 to be manually configured to FE80::3, and so on.

NOTE: There can be only one link-local address per interface. There can be multiple global unicast addresses per interface.

Loopback Addresses

An IPv6 loopback address is ::1, an all-0s address except for the last bit, which is set to 1. It is equivalent to the IPv4 address block 127.0.0.0/8, most commonly the 127.0.0.1 loopback address. The loopback address can be used by a node to send an IPv6 packet to itself, typically when testing the TCP/IP stack.

Table 5-4 shows the different formats for representing an IPv6 loopback address.

TABLE 5-4 IPv6 Loopback Address Representation

Representation	IPv6 Loopback Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0001
Leading 0s omitted	0:0:0:0:0:0:0:1
Compressed	::1

NOTE: A loopback address cannot be assigned to a physical interface.

Unspecified Addresses

An unspecified unicast address is an all-0s address (see Table 5-5), used as a source address to indicate the absence of an address.

Table 5-5 shows the different formats for representing an IPv6 unspecified address.

TABLE 5-5 IPv6 Unspecified Address Representation

Representation	IPv6 Unspecified Address
Preferred	0000:0000:0000:0000:0000:0000:0000:0000
Leading 0s omitted	0:0:0:0:0:0:0:0
Compressed	::

NOTE: An unspecified address cannot be assigned to a physical interface.

Unique Local Addresses

Figure 5-7 shows the structure of the unique local address (ULA), which is the counterpart of IPv4 private addresses. ULAs are used similarly to global unicast addresses, but are for private use and cannot be routed in the global Internet. ULAs are defined in RFC 4193.

Figure 5-7 shows the different formats for representing an IPv6 unspecified address.

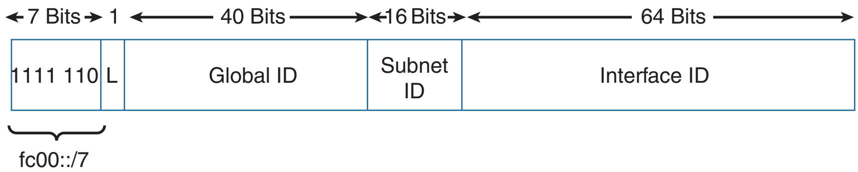


Figure 5-7 Structure of a Unique Local Unicast Address

IPv4 Embedded Addresses

Figure 5-8 shows the structure of IPv4 embedded addresses. They are used to aid in the transition from IPv4 to IPv6. IPv4 embedded addresses carry an IPv4 address in the low-order 32 bits of an IPv6 address.

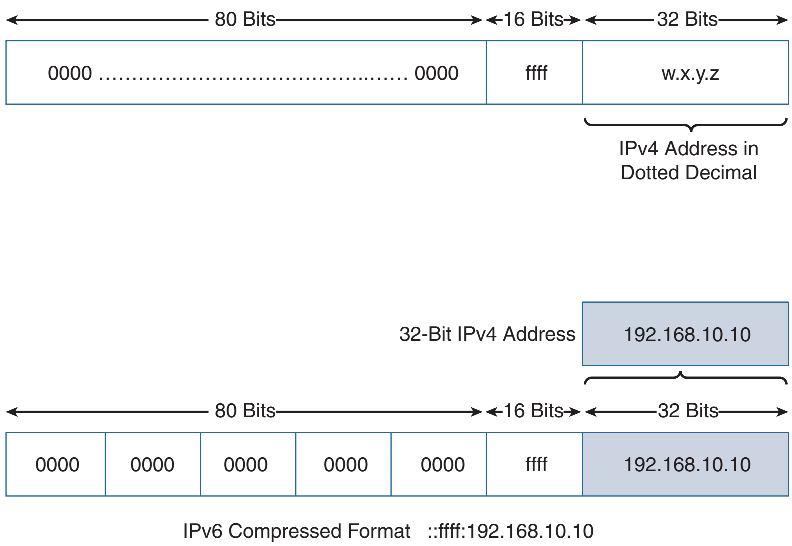


Figure 5-8 IPv4-Mapped IPv6 Address

> **NOTE:** This is a transition technique for moving from IPv4 to IPv6 addressing. This should not be used as a permanent solution. The end goal should always be native end-to-end IPv6 connectivity.

Multicast Addresses

Multicast is a technique in which a device sends a single packet to multiple destinations simultaneously (one-to-many transmission). Multiple destinations can actually be multiple interfaces on the same device, but they are typically different devices.

An IPv6 multicast address defines a group of devices known as a multicast group. IPv6 addresses use the prefix ff00::/8, which is equivalent to the IPv4 multicast address 224.0.0.0/4. A packet sent to a multicast group always has a unicast source address; a multicast address can never be the source address.

Unlike IPv4, there is no broadcast address in IPv6. Instead, IPv6 uses multicast.

Table 5-6 shows IPv6 multicast address representation.

TABLE 5-6 IPv6 Multicast Address Representation

Representation	**IPv6 Multicast Address**
Preferred	ff00:0000:0000:0000:0000:0000:0000:0000/8
Leading 0s omitted	ff00:0:0:0:0:0:0:0/8
Compressed	ff00::/8

The structure of an IPv6 multicast is shown in Figure 5-9; the first 8 bits are 1-bits (ff) followed by 4 bits for flags and a 4-bit Scope field. The next 112 bits represent the Group ID.

8 Bits	**4 Bits**	**4 Bits**	**112 Bits**
1111 1111	Flags	Scope	Group ID

Figure 5-9 IPv6 Multicast Address

Although there are many different types of multicast addresses, this book defines only two of them:

- Well-known multicast addresses
- Solicited-node multicast addresses

Well-Known Multicast Addresses

Well-known multicast addresses have the prefix ff00::/12. Well-known multicast addresses are predefined or reserved multicast addresses for assigned groups of devices. These addresses are equivalent to IPv4 well-known multicast addresses in the range 224.0.0.0 to 239.255.255.255. Some examples of IPv6 well-known multicast addresses include the following:

Address	**Use**
ff02::1	All IPv6 devices
ff02::2	All IPv6 routers
ff02::5	All OSPFv3 routers
ff02::6	All OSPFv3 DR routers
ff02::9	All RIPng routers
ff02:a	All EIGRPv6 routers
ff02::1:2	All DHCPv6 servers and relay agents

Solicited-Node Multicast Addresses

Solicited-node multicast addresses are used as a more efficient approach to IPv4's broadcast address. A more detailed description is beyond the scope of this book.

Anycast Addresses

An IPv6 anycast address is an address that can be assigned to more than one interface (typically on different devices). In other words, multiple devices can have the same anycast address. A packet sent to an anycast address is routed to the "nearest" interface having that address, according to the router's routing table.

Figure 5-10 shows an example of anycast addressing.

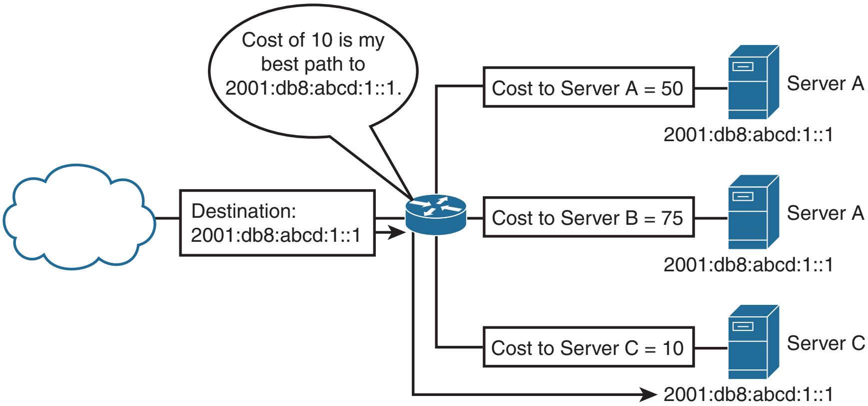


Figure 5-10 Example of Anycast Addressing

> **NOTE:** IPv6 anycast addressing is still somewhat in the experimental stages and beyond the scope of this book.

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