The book makes a big transition at this point. Part I gave you a broad introduction to networking, and Parts II and III went into some detail about the dominant LAN technology today: Ethernet. Part IV transitions from Ethernet to the network layer details that sit above Ethernet and WAN technology, specifically IP version 4 (IPv4).

Thinking about the network layer requires engineers to shift how they think about addressing. Ethernet allows the luxury of using universal MAC addresses, assigned by the manufacturers, with no need to plan or configure addresses. Although the network engineer needs to understand MAC addresses, MAC already exists on each Ethernet NIC, and switches learn the Ethernet MAC addresses dynamically without even needing to be configured to do so. As a result, most people operating the network can ignore the specific MAC address values for most tasks.

Conversely, IP addressing gives you flexibility and allows choice; however, those features require planning, along with a much deeper understanding of the internal structure of the addresses. People operating the network must be more aware of the network layer addresses when doing many tasks. To better prepare you for these Layer 3 addressing details, this part breaks down the addressing details into five chapters, with an opportunity to learn more in preparation for the CCNP Enterprise certification.

Part IV examines most of the basic details of IPv4 addressing and subnetting, mostly from the perspective of operating an IP network. Chapter 11 takes a grand tour of IPv4 addressing as implemented inside a typical enterprise network. Chapters 12 through 15 look at some of the specific questions people must ask themselves when operating an IPv4 network.

This section includes all the details you need to learn for the CCNA 200-301 V1.1 blueprint's IPv4 addressing and subnetting exam topics. Many people have learned subnetting from these chapters over the years; however, some people have asked for video and more practice with subnetting—and understandably so. If that's you, consider these additional products as well, both of which can be found at ciscopress.com:

- IP Subnetting: From Beginning to Mastery (Video Course)
- IP Subnetting Practice Question Kit (Practice Questions Product)

We mention these here before you begin Part IV because, if you decide to use them, you might want to use them alongside the chapters in this part.

Part IV

IPv4 Addressing

CHAPTER 11

Perspectives on IPv4 Subnetting

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.6 Configure and verify IPv4 addressing and subnetting

1.7 Describe private IPv4 addressing

Most entry-level networking jobs require you to operate and troubleshoot a network using a preexisting IP addressing and subnetting plan. The CCNA exam assesses your readiness to use preexisting IP addressing and subnetting information to perform typical operations tasks, such as monitoring the network, reacting to possible problems, configuring addresses for new parts of the network, and troubleshooting those problems.

However, you also need to understand how networks are designed and why. Anyone monitoring a network must ask the question, "Is the network working *as designed*?" If a problem exists, you must consider questions such as "What happens when the network works normally, and what is different right now?" Both questions require you to understand the intended design of the network, including details of the IP addressing and subnetting design.

This chapter provides some perspectives and answers for the bigger issues in IPv4 addressing. What addresses can be used so that they work properly? What addresses should be used? When told to use certain numbers, what does that tell you about the choices made by some other network engineer? How do these choices impact the practical job of configuring switches, routers, hosts, and operating the network on a daily basis? This chapter helps to answer these questions while revealing details of how IPv4 addresses work.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 11-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Analyze Subnetting and Addressing Needs	1–3
Make Design Choices	4–7

1. Host A is a PC, connected to switch SW1 and assigned to VLAN 1. Which of the following are typically assigned an IP address in the same subnet as host A? (Choose two answers.)
   - **a.** The local router's WAN interface
   - **b.** The local router's LAN interface
   - **c.** All other hosts attached to the same switch
   - **d.** Other hosts attached to the same switch and also in VLAN 1
2. Why does the formula for the number of hosts per subnet ($2^H - 2$) require the subtraction of two hosts?
   - **a.** To reserve two addresses for redundant default gateways (routers)
   - **b.** To reserve the two addresses required for DHCP operation
   - **c.** To reserve addresses for the subnet ID and default gateway (router)
   - **d.** To reserve addresses for the subnet broadcast address and subnet ID
3. A Class B network needs to be subnetted such that it supports 100 subnets and 100 hosts/subnet. Which of the following answers list a workable combination for the number of network, subnet, and host bits? (Choose two answers.)
   - **a.** Network = 16, subnet = 7, host = 7
   - **b.** Network = 16, subnet = 8, host = 8
   - **c.** Network = 16, subnet = 9, host = 7
   - **d.** Network = 8, subnet = 7, host = 17
4. Which of the following are private IP networks? (Choose two answers.)
   - **a.** 172.31.0.0
   - **b.** 172.32.0.0
   - **c.** 192.168.255.0
   - **d.** 192.1.168.0
   - **e.** 11.0.0.0
5. Which of the following are public IP networks? (Choose three answers.)
   - **a.** 9.0.0.0
   - **b.** 172.30.0.0
   - **c.** 192.168.255.0
   - **d.** 192.1.168.0
   - **e.** 1.0.0.0
6. Before Class B network 172.16.0.0 is subnetted by a network engineer, what parts of the structure of the IP addresses in this network already exist, with a specific size? (Choose two answers.)
   - **a.** Network
   - **b.** Subnet
   - **c.** Host
   - **d.** Broadcast

7. Consider the size of the network, subnet, and host parts of the address structure for Class B network 172.16.0.0 without any subnetting. Compare that to an updated plan that subnets the network using one mask for all subnets. Which answer describes what changed in the network, subnet, or host fields for the new plan that uses subnetting in comparison to the earlier plan that does not?
   a. The subnet part got smaller.
   b. The host part got smaller.
   c. The network part got smaller.
   d. The host part was removed.
   e. The network part was removed.

Foundation Topics

Introduction to Subnetting

Say you just happened to be at the sandwich shop when it was selling the world's longest sandwich. You're pretty hungry, so you go for it. Now you have one sandwich, but because it's over 2 kilometers long, you realize it's a bit more than you need for lunch all by yourself. To make the sandwich more useful (and more portable), you chop the sandwich into meal-size pieces and give the pieces to other folks around you who are also ready for lunch.

Huh? Well, subnetting, at least the main concept, is similar to this sandwich story. You start with one network, but it is just one large network. As a single large entity, it might not be useful, and it is probably far too large. To make it useful, you chop it into smaller pieces, called **subnets**, and assign those subnets to be used in different parts of the enterprise internetwork.

This short first section of the chapter introduces IP subnetting. First, it shows the general ideas behind a completed subnet design that indeed chops (or subnets) one **network** into subnets. The rest of this section describes the many design steps that you would take to create just such a subnet design. By the end of this section, you should have the right context to then read through the subnetting design steps introduced throughout the rest of this chapter.

NOTE All the chapters from this chapter up until Chapter 25, "Fundamentals of IP Version 6," focus on IPv4 rather than IPv6. All references to *IP* refer to IPv4 unless otherwise stated.

Subnetting Defined Through a Simple Example

An IP network—in other words, a Class A, B, or C network—is simply a set of consecutively numbered IP addresses that follow some preset rules. These Class A, B, and C rules define that for a given network, all the addresses in the network have the same value in some of the octets of the addresses. For example, Class B network 172.16.0.0 consists of all IP addresses that begin with 172.16: 172.16.0.0, 172.16.0.1, 172.16.0.2, and so on, through 172.16.255.255. Another example: Class A network 10.0.0.0 includes all addresses that begin with 10.

An IP subnet is simply a subset of a Class A, B, or C network. If fact, the word *subnet* is a shortened version of the phrase *subdivided network*. For example, one subnet of Class B network 172.16.0.0 could be the set of all IP addresses that begin with 172.16.1, and would include 172.16.1.0, 172.16.1.1, 172.16.1.2, and so on, up through 172.16.1.255. Another subnet of that same Class B network could be all addresses that begin with 172.16.2.

To give you a general idea, Figure 11-1 shows some basic documentation from a completed subnet design that could be used when an engineer subnets Class B network 172.16.0.0.

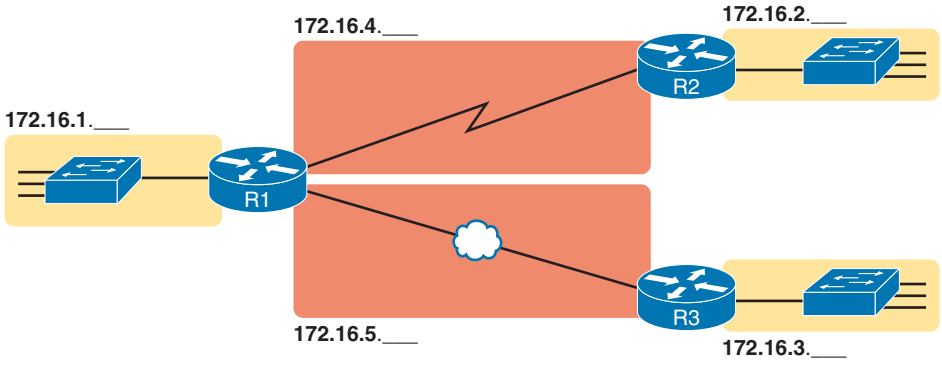


Figure 11-1 *Subnet Plan Document*

The design shows five subnets—one for each of the three LANs and one each for the two WAN links. The small text note shows the rationale used by the engineer for the subnets: each subnet includes addresses that have the same value in the first three octets. For example, for the LAN on the left, the number shows 172.16.1.__, meaning "all addresses that begin with 172.16.1." Also, note that the design, as shown, does not use all the addresses in Class B network 172.16.0.0, so the engineer has left plenty of room for growth.

Operational View Versus Design View of Subnetting

Most IT jobs require you to work with subnetting from an operational view. That is, someone else, before you got the job, designed how IP addressing and subnetting would work for that particular enterprise network. You need to interpret what someone else has already chosen.

To fully understand IP addressing and subnetting, you need to think about subnetting from both a design and operational perspective. For example, Figure 11-1 simply states that in all these subnets, the first three octets must be equal. Why was that convention chosen? What alternatives exist? Would those alternatives be better for your internetwork today? All these questions relate more to subnetting design rather than to operation.

To help you see both perspectives, this chapter focuses more on design issues by moving through the entire design process for the purpose of introducing the bigger picture of IP subnetting. The next three chapters each examine one topic from this chapter from an operational perspective, with the final chapter in this part returning to subnet design for a closer look.

The remaining three main sections of this chapter examine each of the steps listed in Figure 11-2, in sequence.

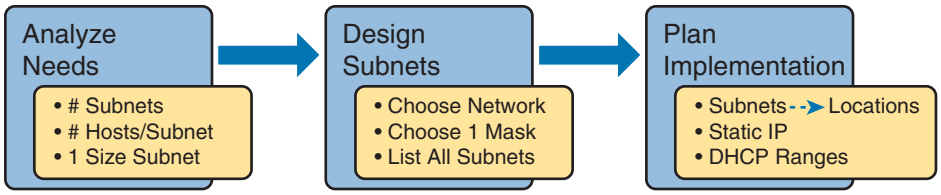


Figure 11-2 *Subnet Planning, Design, and Implementation Tasks*

Analyze Subnetting and Addressing Needs

This section discusses the meaning of four basic questions that can be used to analyze the addressing and subnetting needs for any new or changing enterprise network:

1. Which hosts should be grouped together into a subnet?
2. How many subnets does this internetwork require?
3. How many host IP addresses does each subnet require?
4. Will we use a single subnet size for simplicity, or not?

Rules About Which Hosts Are in Which Subnet

Every device that connects to an IP internetwork needs to have an IP address. These devices include computers used by end users, servers, mobile phones, laptops, IP phones, tablets, and networking devices like routers, switches, and firewalls. In short, any device that uses IP to send and receive packets needs an IP address.

NOTE In a discussion of IP addressing, the term *network* has specific meaning: a Class A, B, or C IP network. To avoid confusion with that use of the term *network*, this book uses the terms *internetwork* and *enterprise network* when referring to a collection of hosts, routers, switches, and so on.

The IP addresses must be assigned according to some basic rules—and for good reasons. To make routing work efficiently, IP addressing rules group addresses into groups called subnets. The rules are as follows:

Key Topic

- Addresses in the same subnet are not separated by a router.
- Addresses in different subnets are separated by at least one router.

Figure 11-3 shows the general concept, with hosts A and B in one subnet and host C in another. In particular, note that hosts A and B are not separated from each other by any routers. However, host C, separated from A and B by at least one router, must be in a different subnet.

The idea that hosts on the same link must be in the same subnet is much like the postal code concept. All mailing addresses in the same town use the same postal code (ZIP codes in the United States). Addresses in another town, whether relatively nearby or on the other side of the country, have a different postal code. The postal code gives the postal service a better ability to automatically sort the mail to deliver it to the right location. For the same general reasons, hosts on the same LAN are in the same subnet, and hosts in different LANs are in different subnets.

Answers to the "Do I Know This Already?" quiz:

1 B, D **2** D **3** B, C **4** A, C **5** A, D, E **6** A, C **7** B

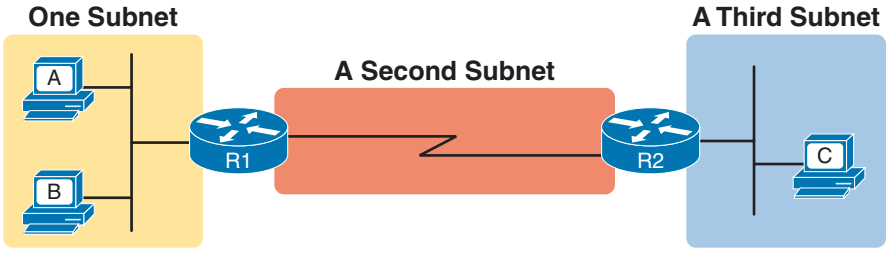


Figure 11-3 *PC A and B in One Subnet and PC C in a Different Subnet*

Note that the point-to-point WAN link in the figure also needs a subnet. Figure 11-3 shows Router R1 connected to the LAN subnet on the left and to a WAN subnet on the right. Router R2 connects to that same WAN subnet. To do so, both R1 and R2 will have IP addresses on their WAN interfaces, and the addresses will be in the same subnet. (An Ethernet WAN link has the same IP addressing needs, with each of the two routers having an IP address in the same subnet.)

The Ethernet LANs in Figure 11-3 also show a slightly different style of drawing, using simple lines with no Ethernet switch. Drawings of Ethernet LANs when the details of the LAN switches do not matter simply show each device connected to the same line, as shown in Figure 11-3. (This kind of drawing mimics the original Ethernet cabling before switches and hubs existed.)

Finally, because the routers' main job is to forward packets from one subnet to another, routers typically connect to multiple subnets. For example, in this case, Router R1 connects to one LAN subnet on the left and one WAN subnet on the right. To do so, R1 will be configured with two different IP addresses, one per interface. These addresses will be in different subnets because the interfaces connect the router to different subnets.

Determining the Number of Subnets

To determine the number of subnets required, the engineer must think about the internetwork as documented and count the locations that need a subnet. To do so, the engineer requires access to network diagrams, VLAN configuration details, and details about WAN links. For the types of links discussed in this book, you should plan for one subnet for every one of the following:

Key Topic

- VLAN
- Point-to-point serial link
- Ethernet WAN (Ethernet Line Service)

NOTE Other WAN technologies outside the scope of the CCNA exam topics allow subnetting options other than one subnet per pair of routers on the WAN (as shown here). However, this book only uses point-to-point WAN technologies—serial links and Ethernet WAN links—that have one subnet for each point-to-point WAN connection between two routers.

For example, imagine that the network planner has only Figure 11-4 on which to base the subnet design.

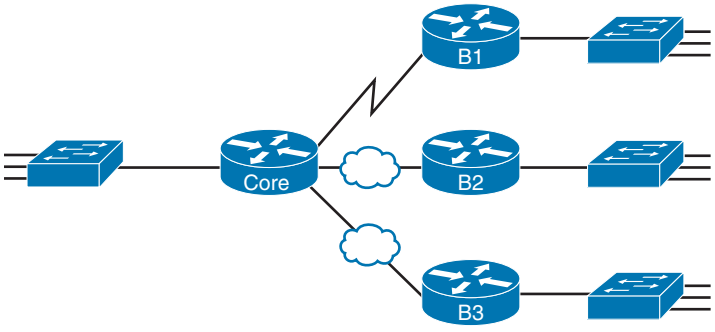


Figure 11-4 *Four-Site Internetwork with Small Central Site*

The number of subnets required cannot be fully predicted with only this figure. Certainly, three subnets will be needed for the WAN links, one per link. However, each LAN switch can be configured with a single VLAN or with multiple VLANs. You can be certain that you need at least one subnet for the LAN at each site, but you might need more.

Next, consider the more detailed version of the same figure as shown in Figure 11-5. In this case, the figure shows VLAN counts in addition to the same Layer 3 topology (the routers and the links connected to the routers). It also shows that the central site has many more switches, but the key fact on the left, regardless of how many switches exist, is that the central site has a total of 12 VLANs. Similarly, the figure lists each branch as having two VLANs. Along with the same three WAN subnets, this internetwork requires 21 subnets.

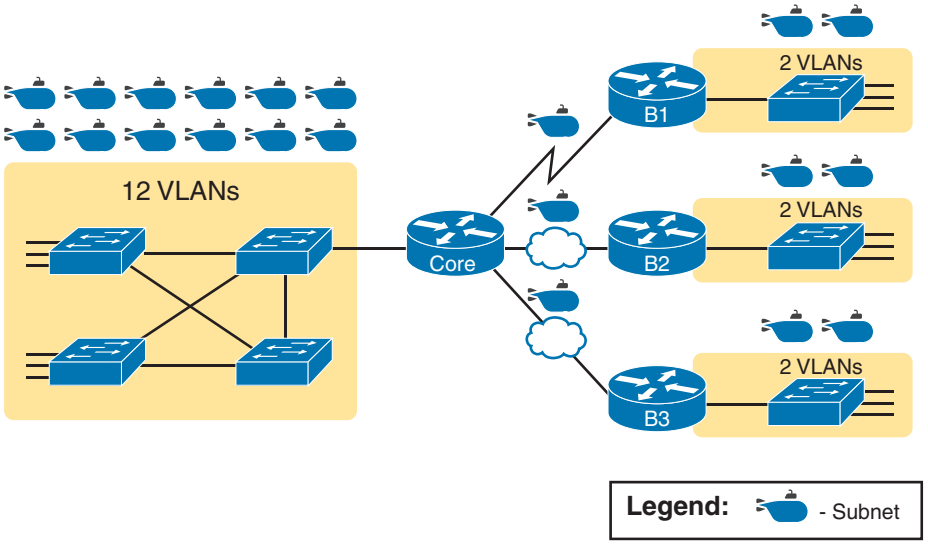


Figure 11-5 *Four-Site Internetwork with Larger Central Site*

Finally, in a real job, you would consider the needs today as well as how much growth you expect in the internetwork over time. Any subnetting plan should include a reasonable estimate of the number of subnets you need to meet future needs.

Determining the Number of Hosts per Subnet

Determining the number of hosts per subnet requires knowing a few simple concepts and then doing a lot of research and questioning. Every device that connects to a subnet needs an IP address. For a totally new network, you can look at business plans—numbers of people at the site, devices on order, and so on—to get some idea of the possible devices. When expanding an existing network to add new sites, you can use existing sites as a point of comparison and then find out which sites will get bigger or smaller. And don't forget to count the router interface IP address in each subnet and the switch IP address used to remotely manage the switch.

Instead of gathering data for each and every site, planners often just use a few typical sites for planning purposes. For example, maybe you have some large sales offices and some small sales offices. You might dig in and learn a lot about only one large sales office and only one small sales office. Add that analysis to the fact that point-to-point links need a subnet with just two addresses, plus any analysis of more one-of-a-kind subnets, and you have enough information to plan the addressing and subnetting design.

For example, in Figure 11-6, the engineer has built a diagram that shows the number of hosts per LAN subnet in the largest branch, B1. For the two other branches, the engineer did not bother to dig to find out the number of required hosts. As long as the number of required IP addresses at sites B2 and B3 stays below the estimate of 50, based on larger site B1, the engineer can plan for 50 hosts in each branch LAN subnet and have plenty of addresses per subnet.

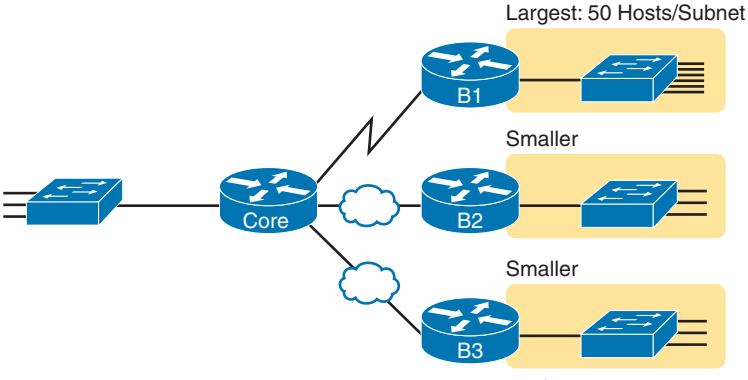


Figure 11-6 *Large Branch B1 with 50 Hosts/Subnet*

One Size Subnet Fits All—Or Not

The final choice in the initial planning step is to decide whether you will use a simpler design by using a one-size-subnet-fits-all philosophy. A subnet's size, or length, is simply the number of usable IP addresses in the subnet. A subnetting design can either use one size subnet or varied sizes of subnets, with pros and cons for each choice.

Defining the Size of a Subnet

Before you finish this book, you will learn all the details of how to determine the size of the subnet. For now, you just need to know a few specific facts about the size of subnets. Chapter 12, "Analyzing Classful IPv4 Networks," and Chapter 13, "Analyzing Subnet Masks," give you a progressively deeper knowledge of the details.

The engineer assigns each subnet a **subnet mask**, and that mask, among other things, defines the size of that subnet. The mask sets aside a number of *host bits* whose purpose is to number different host IP addresses in that subnet. Because you can number 2^x things with x bits, if the mask defines H host bits, the subnet contains 2^H unique numeric values.

However, the subnet's size is not 2^H. It's $2^H - 2$ because two numbers in each subnet are reserved for other purposes. Each subnet reserves the numerically lowest value for the *subnet number* and the numerically highest value as the *subnet broadcast address*. As a result, the number of usable IP addresses per subnet is $2^H - 2$.

NOTE The terms *subnet number*, *subnet ID*, and *subnet address* all refer to the number that represents or identifies a subnet.

Figure 11-7 shows the general concept behind the three-part structure of an IP address (as defined by the subnet mask), focusing on the host part and the resulting subnet size.

Key Topic

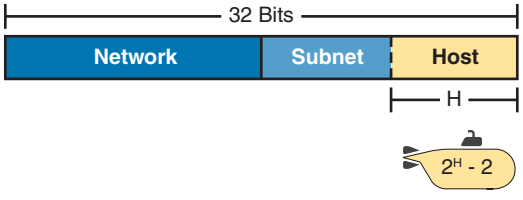


Figure 11-7 *Subnet Size Concepts*

One Size Subnet Fits All

To choose to use a single-size subnet in an enterprise network, you must use the same mask for all subnets because the mask defines the size of the subnet. But which mask?

One requirement to consider when choosing that one mask is this: that one mask must provide enough host IP addresses to support the largest subnet. To do so, the number of host bits (H) defined by the mask must be large enough so that $2^H - 2$ is larger than (or equal to) the number of host IP addresses required in the largest subnet.

For example, consider Figure 11-8. It shows the required number of hosts per LAN subnet. (The figure ignores the subnets on the WAN links, which require only two IP addresses each.) The branch LAN subnets require only 50 host addresses, but the main site LAN subnet requires 200 host addresses. To accommodate the largest subnet, you need at least 8 host bits. Seven host bits would not be enough because $2^7 - 2 = 126$. Eight host bits would be enough because $2^8 - 2 = 254$, which is more than enough to support 200 hosts in a subnet.

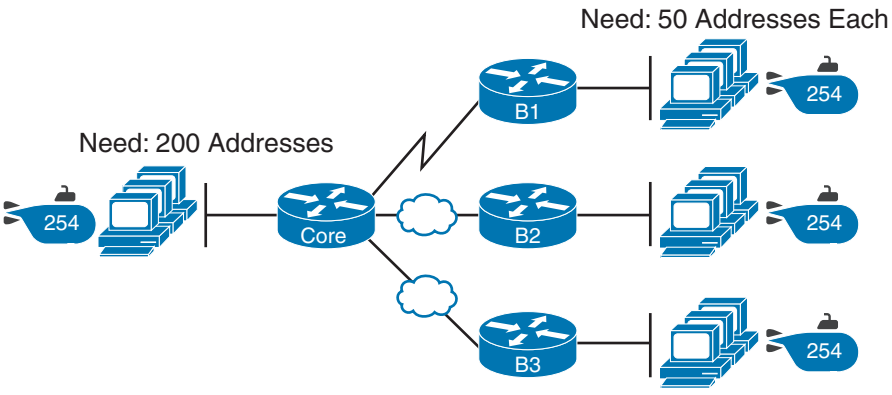


Figure 11-8 *Network Using One Subnet Size*

What's the big advantage when using a single-size subnet? Operational simplicity. In other words, keeping it simple. Everyone on the IT staff who has to work with networking can get used to working with one mask—and one mask only. Staff members will be able to answer all subnetting questions more easily because everyone gets used to doing subnetting math with that one mask.

The big disadvantage for using a single-size subnet is that it wastes IP addresses. For example, in Figure 11-8, all the branch LAN subnets support 254 addresses, while the largest branch subnet needs only 50 addresses. The WAN subnets need only two IP addresses, but each supports 254 addresses, again wasting more IP addresses.

The wasted IP addresses do not actually cause a problem in most cases, however. Most organizations use private IP networks in their enterprise internetworks, and a single Class A or Class B private network can supply plenty of IP addresses, even with the waste.

Multiple Subnet Sizes (Variable-Length Subnet Masks)

To create multiple sizes of subnets in one Class A, B, or C network, the engineer must create some subnets using one mask, some with another, and so on. Different masks mean different numbers of host bits, and a different number of hosts in some subnets based on the $2^H - 2$ formula.

For example, consider the requirements listed earlier in Figure 11-8. It showed one LAN subnet on the left that needs 200 host addresses, three branch subnets that need 50 addresses, and three WAN links that need two addresses. To meet those needs, but waste fewer IP addresses, three subnet masks could be used, creating subnets of three different sizes, as shown in Figure 11-9.

The smaller subnets now waste fewer IP addresses compared to the design shown earlier in Figure 11-8. The subnets on the right that need 50 IP addresses have subnets with 6 host bits, for $2^6 - 2 = 62$ available addresses per subnet. The WAN links use masks with 2 host bits, for $2^2 - 2 = 2$ available addresses per subnet.

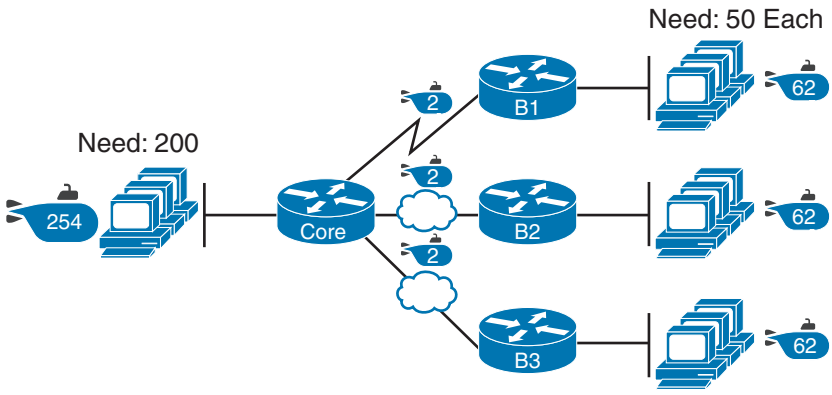


Figure 11-9 *Three Masks, Three Subnet Sizes*

However, some are still wasted because you cannot set the size of the subnet as some arbitrary size. All subnets will be a size based on the $2^H - 2$ formula, with H being the number of host bits defined by the mask for each subnet.

One Mask for All Subnets, or More Than One

For the most part, this book explains subnetting using designs that use a single mask, creating a single subnet size for all subnets. Why? First, it makes the process of learning subnetting easier. Second, some types of analysis that you can do about a network—specifically, calculating the number of subnets in the classful network—make sense only when a single mask is used.

However, you still need to be ready to work with designs that use more than one mask in different subnets of the same Class A, B, or C network. In fact, a design that does just that is said to be using **variable-length subnet masks (VLSM)**. For example, the internetwork in Figure 11-10 shows 11 subnets: two with a mask of /30 and nine with a mask of /24. By using more than one mask among all the subnets of one Class A network (10.0.0.0), the design uses VLSM.

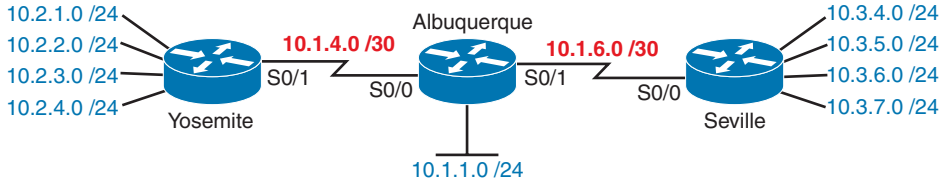


Figure 11-10 *Internetwork with VLSM: Network 10.0.0.0, >1 Mask*

Although VLSM causes problems when using some older IP routing protocols, the CCNA 200-301 V1.1 blueprint includes only the OSPF routing protocol, and VLSM causes no problems with OSPF. Just be aware of the term and what it means and that it should not impact the features included in the current CCNA exam.

NOTE VLSM has been featured in the CCNA exam topics in the past. If you want to read a little more about VLSM, check out Appendix M, "Variable-Length Subnet Masks," on the companion website for this book.

Make Design Choices

Now that you know how to analyze the IP addressing and subnetting needs, the next major step examines how to apply the rules of IP addressing and subnetting to those needs and make some choices. In other words, now that you know how many subnets you need and how many host addresses you need in the largest subnet, how do you create a useful subnetting design that meets those requirements? The short answer is that you need to do the three tasks shown on the right side of Figure 11-11.

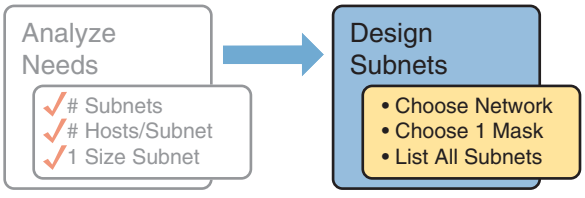


Figure 11-11 *Input to the Design Phase, and Design Questions to Answer*

Choose a Classful Network

In the original design for what we know of today as the Internet, companies used registered *public* **classful IP networks** when implementing TCP/IP inside the company. By the mid-1990s, an alternative became more popular: **private IP networks**. This section discusses the background behind these two choices because it impacts the choice of what IP network a company will then subnet and implement in its enterprise internetwork.

Public IP Networks

The original design of the Internet required that any company that connected to the Internet had to use a *registered* **public IP network**. To do so, the company would complete some paperwork, describing the enterprise's internetwork and the number of hosts existing, plus plans for growth. After submitting the paperwork, the company would receive an assignment of either a Class A, B, or C network.

Public IP networks—and the administrative processes surrounding them—ensure that all the companies that connect to the Internet use unique IP addresses. In particular, after a public IP network is assigned to a company, only that company should use the addresses in that network. That guarantee of uniqueness means that Internet routing can work well because there are no duplicate public IP addresses.

For example, consider the example shown in Figure 11-12. Company 1 has been assigned public Class A network 1.0.0.0, and company 2 has been assigned public Class A network 2.0.0.0. Per the original intent for public addressing in the Internet, after these public network assignments have been made, no other companies can use addresses in Class A networks 1.0.0.0 or 2.0.0.0.

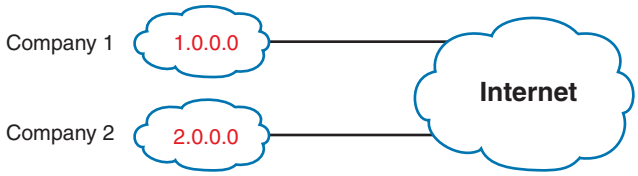


Figure 11-12 *Two Companies with Unique Public IP Networks*

This original address assignment process ensured unique IP addresses across the entire planet. The idea is much like the fact that your telephone number should be unique in the universe, your postal mailing address should also be unique, and your email address should also be unique. If someone calls you, your phone rings, but no one else's phone rings. Similarly, if company 1 is assigned Class A network 1.0.0.0, and the engineers at Company 1 assign address 1.1.1.1 to a particular PC, that address should be unique in the universe. A packet sent through the Internet to destination 1.1.1.1 should arrive only at this one PC inside company 1, instead of being delivered to some other host.

Growth Exhausts the Public IP Address Space

By the early 1990s, the world was running out of public IP networks that could be assigned. During most of the 1990s, the number of hosts newly connected to the Internet was growing at a double-digit pace *per month*. Companies kept following the rules, asking for public IP networks, and it was clear that the current address-assignment scheme could not continue without some changes. Simply put, the number of Class A, B, and C networks supported by the 32-bit address in IP version 4 (IPv4) was not enough to support one public classful network per organization, while also providing enough IP addresses in each company.

NOTE The universe has run out of public IPv4 addresses in a couple of significant ways. IANA, which assigns public IPv4 address blocks to the five Regional Internet Registries (RIR) around the globe, assigned the last of the IPv4 address spaces in early 2011. By 2015, ARIN, the RIR for North America, exhausted its supply of IPv4 addresses, so companies must return unused public IPv4 addresses to ARIN before they have more to assign to new companies. Try an online search for "ARIN depletion" to see pages about the current status of available IPv4 address space for just one RIR example.

The Internet community worked hard during the 1990s to solve this problem, coming up with several solutions, including the following:

Key Topic

- A new version of IP (IPv6), with much larger addresses (128 bit)
- Assigning a subset of a public IP network to each company, instead of an entire public IP network, to reduce waste, using a feature called classless interdomain routing (CIDR)
- Network Address Translation (NAT), which allows the use of private IP networks

These three solutions matter to real networks today. However, to stay focused on the topic of subnet design, this chapter focuses on the third option, and in particular, the private IP networks that can be used by an enterprise when also using NAT. (Be aware that Chapter 14, "Network Address Translation," in the *CCNA 200-301 Official Cert Guide, Volume 2*,

Second Edition, gives more detail about the last two bullets in the list, while Part VII of this book discusses the first bullet item (IPv6) in more depth.

Focusing on the third item in the bullet list, NAT allows multiple companies to use the exact same *private IP network*, using the same IP addresses as other companies while still connecting to the Internet. For example, Figure 11-13 shows the same two companies connecting to the Internet as in Figure 11-12, but now with both using the same private Class A network 10.0.0.0.

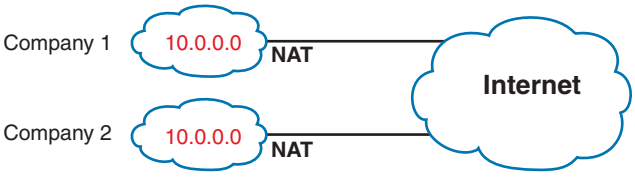


Figure 11-13 *Reusing the Same Private Network 10.0.0.0 with NAT*

Both companies use the same classful IP network (10.0.0.0). Both companies can implement their subnet design internal to their respective enterprise internetworks, without discussing their plans. The two companies can even use the exact same IP addresses inside network 10.0.0.0. And amazingly, at the same time, both companies can even communicate with each other through the Internet.

The technology called Network Address Translation makes it possible for companies to reuse the same IP networks, as shown in Figure 11-13. NAT does this by translating the IP addresses inside the packets as they go from the enterprise to the Internet, using a small number of public IP addresses to support tens of thousands of private IP addresses. That one bit of information is not enough to understand how NAT works; however, to keep the focus on subnetting, the book defers the discussion of how NAT works until *CCNA 200-301 Official Cert Guide, Volume 2*, Second Edition. For now, accept that most companies use NAT, and therefore, they can use private IP networks for their internetworks.

Private IP Networks

When using NAT—and almost every organization that connects to the Internet uses NAT—the company can simply pick one or more of the private IP networks from the list of reserved private IP network numbers. RFC 1918 defines the list of available private IP networks, which is summarized in Table 11-2.

Table 11-2 RFC 1918 Private Address Space

Class of Networks	Private IP Networks	Number of Networks
A	10.0.0.0	1
B	172.16.0.0 through 172.31.0.0	16
C	192.168.0.0 through 192.168.255.0	256

NOTE In each class I teach online, I survey students about who uses network 10.0.0.0 in their company, with an average response of 60–70 percent using private class A network 10.0.0.0.

From the perspective of making IPv4 work for the entire world, private IP networks have helped preserve and extend IPv4 and its use in every enterprise and throughout the Internet. In particular, private networks have improved IPv4's implementation worldwide by

- **Avoiding using another organization's public address range for private networks:** Some organizations have a part of their networks that need zero Internet access. The hosts in that part of their network need IP addresses. RFC 1918 suggests that truly private networks—that is, networks with no need for Internet connectivity—use addresses from the RFC 1918 list of private networks.
- **Delaying IPv4 address exhaustion:** To delay the day in which all public IPv4 addresses were assigned to organizations as public addresses, RFC 1918 calls for the use of NAT along with private networks for the addresses internal to an organization.
- **Reducing Internet routers' routing table size:** Using private networks also helps reduce the size of the IP routing tables in Internet routers. For instance, routers in the Internet do not need routes for the private IP networks used inside organizations (in fact, ISPs filter those routes).

Choosing an IP Network During the Design Phase

Today, most organizations use private IP networks along with NAT, which requires a small CIDR block of public addresses. Some companies use a public address block, like a public Class A, B, or C network, per the original plan that would allow each company to have its own unique public network. Some smaller number of companies might use a public CIDR block for all addresses—in effect a subset of a Class A, B, or C network—and subnet that block.

For the purposes of this book, most examples use private IP network numbers. For the design step to choose a network number, just choose a private Class A, B, or C network from the list of RFC 1918 private networks. Regardless, the subnetting math works the same whether you begin with a public or private IP network.

After the choice to use a private IP network has been made, just pick one that has enough IP addresses. You can have a small internetwork and still choose to use private Class A network 10.0.0.0. It might seem wasteful to choose a Class A network that has over 16 million IP addresses, especially if you need only a few hundred. However, there's no penalty or problem with using a private network that is too large for your current or future needs.

Choose the Mask

If design engineers followed the topics in this chapter so far, in order, they would know the following:

- The number of subnets required
- The number of hosts/subnet required
- That a choice was made to use only one mask for all subnets so that all subnets are the same size (same number of hosts/subnet)
- The classful IP network number that will be subnetted

This section completes the design process, at least the parts described in this chapter, by discussing how to choose that one mask to use for all subnets. First, this section examines default masks, used when a network is not subnetted, as a point of comparison. Next, the concept of borrowing host bits to create subnet bits is explored. Finally, this section ends with an example of how to create a subnet mask based on the analysis of the requirements.

Classful IP Networks Before Subnetting

Before an engineer subnets a classful network, the network is a single group of addresses. In other words, the engineer has not yet subdivided the network into many smaller subsets called *subnets*.

When thinking about an unsubnetted classful network, the addresses in a network have only two parts: the **network part** and **host part**. Comparing any two addresses in the classful network:

- The addresses have the same value in the network part.
- The addresses have different values in the host part.

The actual sizes of the network and host parts of the addresses in a network can be easily predicted, as shown in Figure 11-14.

Key Topic

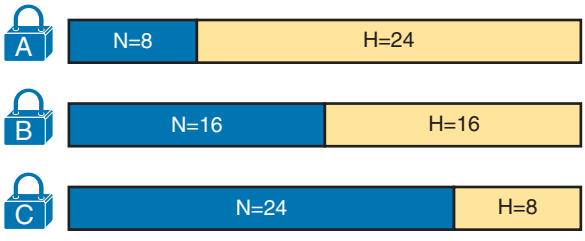


Figure 11-14 *Format of Unsubnetted Class A, B, and C Networks*

In Figure 11-14, N and H represent the number of network and host bits, respectively. Class rules define the number of network octets (1, 2, or 3) for Classes A, B, and C, respectively; the figure shows these values as a number of bits. The number of host octets is 3, 2, or 1, respectively.

Continuing the analysis of a classful network before subnetting, the number of addresses in one classful IP network can be calculated with the same $2^H - 2$ formula previously discussed. In particular, the size of an unsubnetted Class A, B, or C network is as follows:

- **Class A:** $2^{24} - 2 = 16{,}777{,}214$
- **Class B:** $2^{16} - 2 = 65{,}534$
- **Class C:** $2^8 - 2 = 254$

Borrowing Host Bits to Create Subnet Bits

To subnet a network, the designer thinks about the network and host parts, as shown in Figure 11-15, and then the engineer adds a third part in the middle: the **subnet part**. However, the designer cannot change the size of the network part or the size of the entire

address (32 bits). To create a subnet part of the address structure, the engineer borrows bits from the host part. Figure 11-15 shows the general idea.

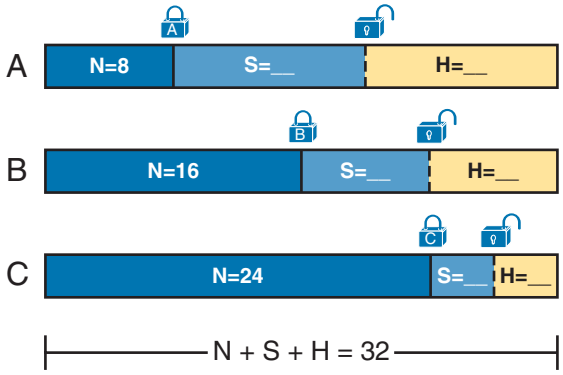


Figure 11-15 *Concept of Borrowing Host Bits*

Figure 11-15 shows a rectangle that represents the subnet mask. N, representing the number of network bits, remains locked at 8, 16, or 24, depending on the class. Conceptually, the designer moves a (dashed) dividing line into the host field, with subnet bits (S) between the network and host parts, and the remaining host bits (H) on the right. The three parts must add up to 32 because IPv4 addresses consist of 32 bits.

Choosing Enough Subnet and Host Bits

The design process requires a choice of where to place the dashed line shown in Figure 11-15. But what is the right choice? How many subnet and host bits should the designer choose? The answers hinge on the requirements gathered in the early stages of the planning process:

- Number of subnets required
- Number of hosts/subnet

The bits in the subnet part create a way to uniquely number the different subnets that the design engineer wants to create. With 1 subnet bit, you can number 2^1 or 2 subnets. With 2 bits, 2^2 or 4 subnets; with 3 bits, 2^3 or 8 subnets; and so on. The number of subnet bits must be large enough to uniquely number all the subnets, as determined during the planning process.

At the same time, the remaining number of host bits must also be large enough to number the host IP addresses in the largest subnet. Remember, in this chapter, we assume the use of a single mask for all subnets. This single mask must support both the required number of subnets and the required number of hosts in the largest subnet. Figure 11-16 shows the concept.

Figure 11-16 shows the idea of the designer choosing a number of subnet (S) and host (H) bits and then checking the math. 2^S must be more than the number of required subnets, or the mask will not supply enough subnets in this IP network. Also, $2^H - 2$ must be more than the required number of hosts/subnet.

Key Topic

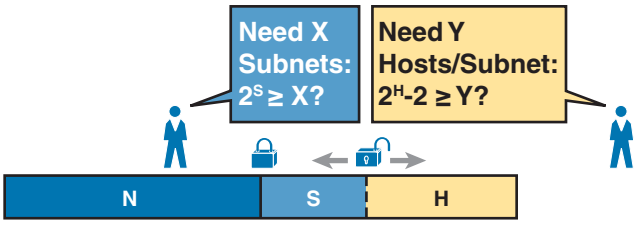


Figure 11-16 *Borrowing Enough Subnet and Host Bits*

NOTE The idea of calculating the number of subnets as 2^S applies only in cases where a single mask is used for all subnets of a single classful network, as is being assumed in this chapter.

To effectively design masks, or to interpret masks that were chosen by someone else, you need a good working memory of the powers of 2. Appendix A, "Numeric Reference Tables," lists a table with powers of 2 up through 2^{32} for your reference.

Example Design: 172.16.0.0, 200 Subnets, 200 Hosts

To help make sense of the theoretical discussion so far, consider an example that focuses on the design choice for the subnet mask. In this case, the planning and design choices so far tell us the following:

- Use a single mask for all subnets.
- Plan for 200 subnets.
- Plan for 200 host IP addresses per subnet.
- Use private Class B network 172.16.0.0.

To choose the mask, the designer asks this question:

How many subnet (S) bits do I need to number 200 subnets?

You can see that S = 7 is not large enough ($2^7 = 128$), but S = 8 is enough ($2^8 = 256$). So, you need *at least* 8 subnet bits.

Next, the designer asks a similar question, based on the number of hosts per subnet:

How many host (H) bits do I need to number 200 hosts per subnet?

The math is basically the same, but the formula subtracts 2 when counting the number of hosts/subnet. You can see that H = 7 is not large enough ($2^7 - 2 = 126$), but H = 8 is enough ($2^8 - 2 = 254$).

Only one possible mask meets all the requirements in this case. First, the number of network bits (N) must be 16 because the design uses a Class B network. The requirements tell us that the mask needs at least 8 subnet bits and at least 8 host bits. The mask has only 32 bits in it; Figure 11-17 shows the resulting mask.

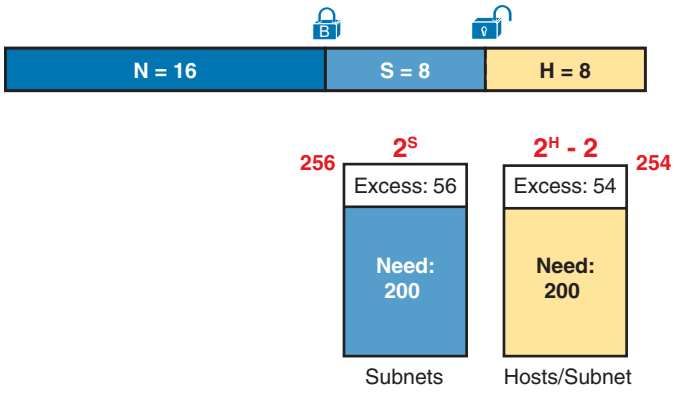


Figure 11-17 *Example Mask Choice, N = 16, S = 8, H = 8*

Masks and Mask Formats

Although engineers think about IP addresses in three parts when making design choices (network, subnet, and host), the subnet mask gives the engineer a way to communicate those design choices to all the devices in the subnet.

The subnet mask is a 32-bit binary number with a number of binary 1s on the left and with binary 0s on the right. By definition, the number of binary 0s equals the number of host bits; in fact, that is exactly how the mask communicates the idea of the size of the host part of the addresses in a subnet. The beginning bits in the mask equal binary 1, with those bit positions representing the combined network and subnet parts of the addresses in the subnet.

Because the network part always comes first, then the subnet part, and then the host part, the subnet mask, in binary form, cannot have interleaved 1s and 0s. Each subnet mask has one unbroken string of binary 1s on the left, with the rest of the bits as binary 0s.

After the engineer chooses the classful network and the number of subnet and host bits in a subnet, creating the binary subnet mask is easy. Just write down N 1s, S 1s, and then H 0s (assuming that N, S, and H represent the number of network, subnet, and host bits). Figure 11-18 shows the mask based on the previous example, which subnets a Class B network by creating 8 subnet bits, leaving 8 host bits.

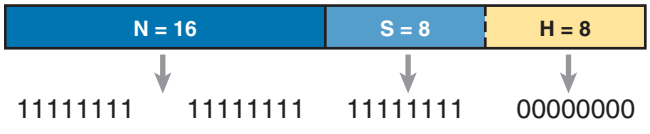


Figure 11-18 *Creating the Subnet Mask—Binary—Class B Network*

In addition to the binary mask shown in Figure 11-18, masks can also be written in two other formats: the familiar **dotted-decimal notation** (DDN) seen in IP addresses and an even briefer *prefix* notation. Chapter 13 discusses these formats and how to convert between the different formats.

Build a List of All Subnets

Building a list of all subnets, the final task of the subnet design step, determines the actual subnets that can be used, based on all the earlier choices. The earlier design work

determined the Class A, B, or C network to use, and the (one) subnet mask to use that supplies enough subnets and enough host IP addresses per subnet. But what are those subnets? How do you identify or describe a subnet? This section answers these questions.

A subnet consists of a group of consecutive numbers. Most of these numbers can be used as IP addresses by hosts. However, each subnet reserves the first and last numbers in the group, and these two numbers cannot be used as IP addresses. In particular, each subnet contains the following:

Key Topic

- **Subnet number:** Also called the *subnet ID* or *subnet address*, this number identifies the subnet. It is the numerically smallest number in the subnet. It cannot be used as an IP address by a host.
- **Subnet broadcast:** Also called the *subnet broadcast address* or *directed broadcast address*, this is the last (numerically highest) number in the subnet. It also cannot be used as an IP address by a host.
- **IP addresses:** All the numbers between the subnet ID and the subnet broadcast address can be used as a host IP address.

For example, consider the earlier case in which the design results were as follows:

Network	172.16.0.0 (Class B)
Mask	255.255.255.0 (for all subnets)

With some math, the facts about each subnet that exists in this Class B network can be calculated. In this case, Table 11-3 shows the first ten such subnets. It then skips many subnets and shows the last two (numerically largest) subnets.

Table 11-3 First Ten Subnets, Plus the Last Few, from 172.16.0.0, 255.255.255.0

Subnet Number	IP Addresses	Broadcast Address
172.16.0.0	172.16.0.1 – 172.16.0.254	172.16.0.255
172.16.1.0	172.16.1.1 – 172.16.1.254	172.16.1.255
172.16.2.0	172.16.2.1 – 172.16.2.254	172.16.2.255
172.16.3.0	172.16.3.1 – 172.16.3.254	172.16.3.255
172.16.4.0	172.16.4.1 – 172.16.4.254	172.16.4.255
172.16.5.0	172.16.5.1 – 172.16.5.254	172.16.5.255
172.16.6.0	172.16.6.1 – 172.16.6.254	172.16.6.255
172.16.7.0	172.16.7.1 – 172.16.7.254	172.16.7.255
172.16.8.0	172.16.8.1 – 172.16.8.254	172.16.8.255
172.16.9.0	172.16.9.1 – 172.16.9.254	172.16.9.255
Skipping many…		
172.16.254.0	172.16.254.1 – 172.16.254.254	172.16.254.255
172.16.255.0	172.16.255.1 – 172.16.255.254	172.16.255.255

After you have the network number and the mask, calculating the subnet IDs and other details for all subnets requires some math. In real life, most people use subnet calculators or

subnet-planning tools. For the CCNA exam, you need to be ready to find this kind of information, as discussed in Chapter 15, "Subnet Design."

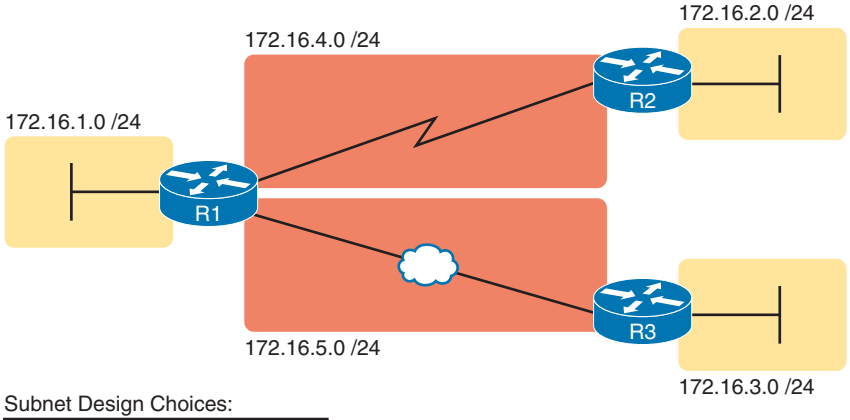
Plan the Implementation

The next step, planning the implementation, is the last step before actually configuring the devices to create a subnet. The engineer first needs to choose where to use each subnet. For example, at a branch office in a particular city, which subnet from the subnet planning chart (Table 11-3) should be used for each VLAN at that site? Also, for any interfaces that require static IP addresses, which addresses should be used in each case? Finally, what range of IP addresses from inside each subnet should be configured in the DHCP server, to be dynamically leased to hosts for use as their IP address? Figure 11-19 summarizes the list of implementation planning tasks.

Figure 11-19 *Facts Supplied to the Plan Implementation Step*

Assigning Subnets to Different Locations

The job is simple: Look at your network diagram, identify each location that needs a subnet, and pick one from the table you made of all the possible subnets. Then, track it so that you know which ones you use where, using a spreadsheet or some other purpose-built subnet-planning tool. That's it! Figure 11-20 shows a sample of a completed design using Table 11-3, which happens to match the initial design sample shown way back in Figure 11-1.



Subnet Design Choices:

Class B 172.16.0.0 /24 (255.255.255.0)

Figure 11-20 *Example of Subnets Assigned to Different Locations*

Although this design could have used any five subnets from Table 11-3, in real networks, engineers usually give more thought to some strategy for assigning subnets. For example, you might assign all LAN subnets lower numbers and WAN subnets higher numbers. Or you might slice off large ranges of subnets for different divisions of the company. Or you might follow that same strategy but ignore organizational divisions in the company, paying more attention to geographies.

For example, for a U.S.-based company with a smaller presence in both Europe and Asia, you might plan to reserve ranges of subnets based on continent. This kind of choice is particularly useful when later trying to use a feature called route summarization. Figure 11-21 shows the general benefit of placing addressing in the network for easier route summarization, using the same subnets from Table 11-3 again.

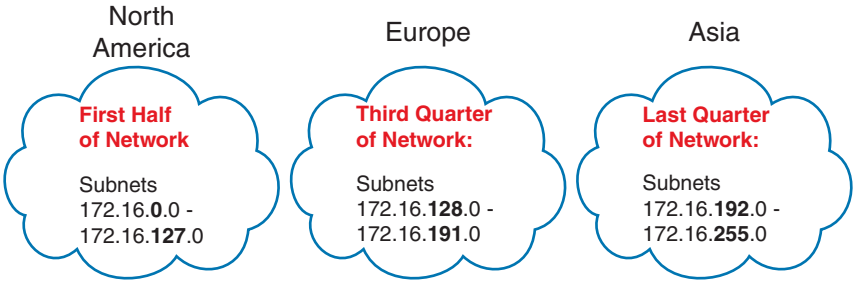


Figure 11-21 *Reserving 50 Percent of Subnets for North America and 25 Percent Each for Europe and Asia*

Choose Static and Dynamic Ranges per Subnet

Devices receive their IP address and mask assignment in one of two ways: dynamically by using Dynamic Host Configuration Protocol (DHCP) or statically through configuration. For DHCP to work, the network engineer must tell the DHCP server the subnets for which it must assign IP addresses. In addition, that configuration limits the DHCP server to only a subset of the addresses in the subnet. For static addresses, you simply configure the device to tell it what IP address and mask to use.

To keep things as simple as possible, most shops use a strategy to separate the static IP addresses on one end of each subnet, and the DHCP-assigned dynamic addresses on the other. It does not really matter whether the static addresses sit on the low end of the range of addresses or the high end.

For example, imagine that the engineer decides that, for the LAN subnets in Figure 11-20, the DHCP pool comes from the high end of the range, namely, addresses that end in .101 through .254. (The address that ends in .255 is, of course, reserved.) The engineer also assigns static addresses from the lower end, with addresses ending in .1 through .100. Figure 11-22 shows the idea.

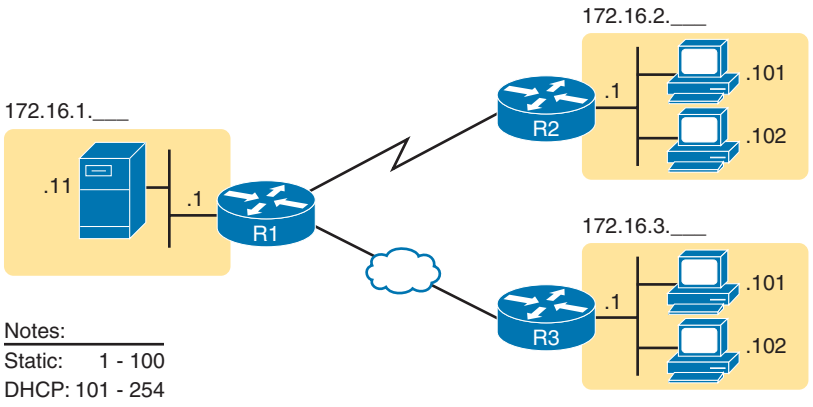


Figure 11-22 *Static from the Low End and DHCP from the High End*

Figure 11-22 shows all three routers with statically assigned IP addresses that end in .1. The only other static IP address in the figure is assigned to the server on the left, with address 172.16.1.11 (abbreviated simply as .11 in the figure).

On the right, each LAN has two PCs that use DHCP to dynamically lease their IP addresses. DHCP servers often begin by leasing the addresses at the bottom of the range of addresses, so in each LAN, the hosts have leased addresses that end in .101 and .102, which are at the low end of the range chosen by design.

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 11-4 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 11-4 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Review memory tables		Website

Review All the Key Topics

Key Topic

Table 11-5 Key Topics for Chapter 11

Key Topic Element	Description	Page Number
List	Key facts about subnets	304
List	Rules about what places in a network topology need a subnet	305
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Key Terms You Should Know

classful IP network, dotted-decimal notation, host part, network, network part, private IP network, public IP network, subnet, subnet mask, subnet part, variable-length subnet masks (VLSM)

CHAPTER 12

Analyzing Classful IPv4 Networks

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.6 Configure and verify IPv4 addressing and subnetting

1.7 Describe private IPv4 addressing

When operating a network, you often start investigating a problem based on an IP address and mask. Based on the IP address alone, you should be able to determine several facts about the Class A, B, or C network in which the IP address resides.

This chapter lists the key facts about classful IP networks and explains how to discover these facts. Following that, this chapter lists some practice problems. Before moving to the next chapter, you should practice until you can consistently determine all these facts, quickly and confidently, based on an IP address.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 12-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Classful Network Concepts	1–5

1. Which of the following are not valid Class A network IDs? (Choose two answers.)
   a. 1.0.0.0
   b. 130.0.0.0
   c. 127.0.0.0
   d. 9.0.0.0
2. Which of the following are not valid Class B network IDs?
   a. 130.0.0.0
   b. 191.255.0.0
   c. 128.0.0.0
   d. 150.255.0.0
   e. All are valid Class B network IDs.

3. Which of the following are true about IP address 172.16.99.45's IP network? (Choose two answers.)
   a. The network ID is 172.0.0.0.
   b. The network is a Class B network.
   c. The default mask for the network is 255.255.255.0.
   d. The number of host bits in the unsubnetted network is 16.
4. Which of the following are true about IP address 192.168.6.7's IP network? (Choose two answers.)
   a. The network ID is 192.168.6.0.
   b. The network is a Class B network.
   c. The default mask for the network is 255.255.255.0.
   d. The number of host bits in the unsubnetted network is 16.
5. Which of the following is a network broadcast address?
   a. 10.1.255.255
   b. 192.168.255.1
   c. 224.1.1.255
   d. 172.30.255.255

Foundation Topics

Classful Network Concepts

Imagine that you have a job interview for your first IT job. As part of the interview, you're given an IPv4 address and mask: 10.4.5.99, 255.255.255.0. What can you tell the interviewer about the classful **network** (in this case, the Class A network) in which the IP address resides?

This section, the first of two major sections in this chapter, reviews the concepts of **classful IP networks** (in other words, Class A, B, and C networks). In particular, this chapter examines how to begin with a single IP address and then determine the following facts:

- Class (A, B, or C)
- Default mask
- Number of network octets/bits
- Number of host octets/bits
- Number of host addresses in the network
- Network ID
- Network broadcast address
- First and last usable address in the network

Before getting into this chapter's processes, the text first discusses the context. Analyzing Class A, B, and C networks has a valuable purpose, and it remains an important skill—but it might not be as useful in some networks. This section begins by setting that context

regarding public networks, large public CIDR blocks, and small public CIDR blocks. Then the rest of the section dives into finding all the facts about the classful IP network an address would reside in if the assignment process still assigned the entire Class A, B, or C network.

Setting the Context of Public Networks and CIDR Blocks

As discussed in Chapter 11, "Perspectives on IPv4 Subnetting," the original plan called for every organization to register for and use a public IP network of one of three classes: A, B, or C. That approach existed in the 1980s up through the 2010s when the Regional Internet Registries (RIRs) assigned their final IP **network numbers**. Even with the RIRs exhausting their supply of IPv4 addresses, companies that received assignments for a public Class A, B, or C network continue to use them. Figure 12-1 shows a conceptual diagram with some Class A networks that could still be used today.

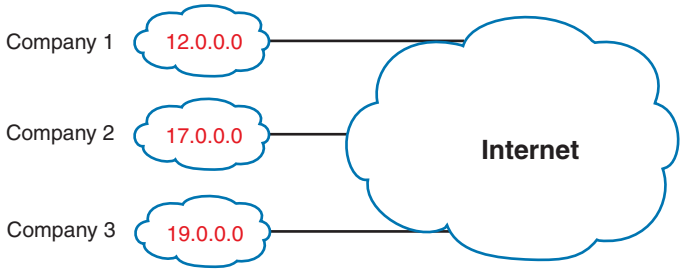


Figure 12-1 *Concept: Companies Using Separate Public Class A Networks*

One of the address conservation options that emerged in the 1990s called for using more than the three set sizes of Class A, B, and C networks, instead allowing for any block size that is a power of 2. Starting in that decade, the Internet Assigned Numbers Authority (IANA), the global owner of the address space, along with the five RIRs, began assigning public *classless interdomain routing (CIDR) blocks*. Doing so allowed companies to receive assignments that did not waste as many addresses.

For instance, instead of assigning public network 1.0.0.0 to one company, an RIR could subdivide that network into smaller blocks that followed some simple rules. For instance, each block has to include a power of 2 number of addresses. Figure 12-2 shows the concept, with three other companies receiving assignments of public CIDR blocks that look like subsets of former Class A network 1.0.0.0.

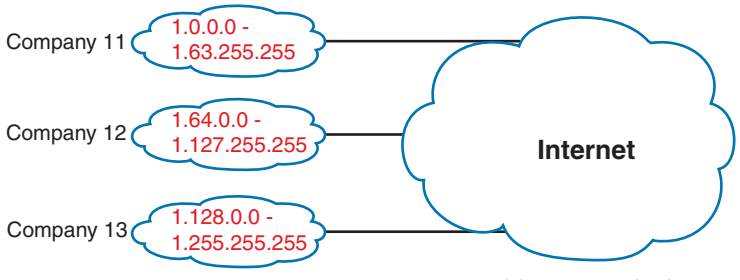


Figure 12-2 *Concept: Companies Using Public CIDR Blocks*

Answers to the "Do I Know This Already?" quiz:

1 B, C **2** E **3** B, D **4** A, C **5** D

A company using a large public **CIDR block** implements it like a public Class A, B, or C network. Whether starting with a public Class A, B, or C network, or a public CIDR block, the company has one large block of public addresses. The company can then create a subnetting plan to subdivide the large block further, picking which subnets to use in each location. All the hosts in the network use an address from the large public address block.

Over time, a third option emerged that used even fewer public addresses—and it became the most popular option. A company uses a private IP network to address all the hosts within the company. The company also needs a small public CIDR block, while using NAT to translate addresses for packets that flow to and from the Internet. Often, a block of 4, 8, or 16 addresses gives even a large company plenty of public IP address capacity to use with NAT. All companies can use any private IP network for hosts inside the company, as shown in Figure 12-3.

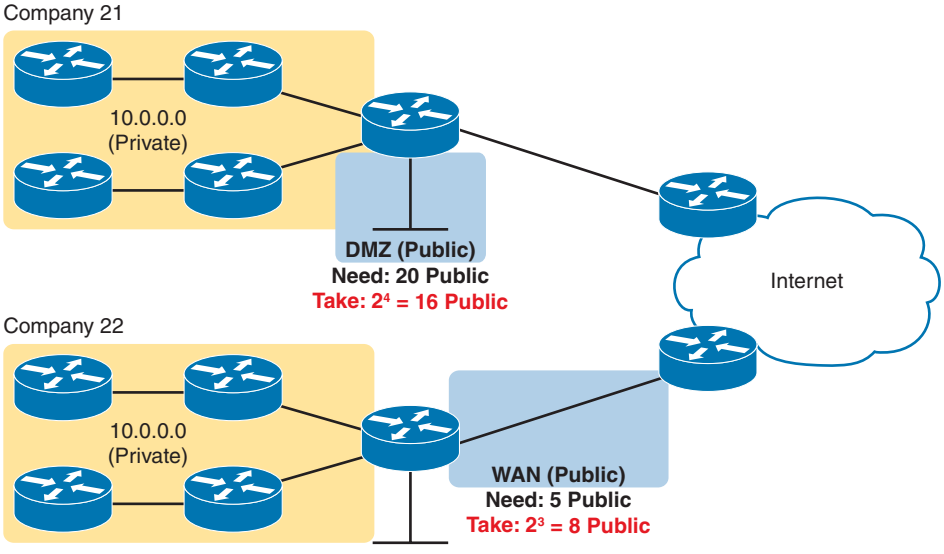


Figure 12-3 *Concept: Small CIDR Block with Private IP Network*

Now back to the main point of this chapter, which focuses on processes to find key facts about Class A, B, and C networks, when starting with a **unicast IP address**. Regardless of whether the address happens to be from a public classful network, a public CIDR block, or a private classful network, learning the processes in this chapter will help you in your journey to understand networks and subnetting math. Most of you will use these foundational skills at your company or your clients' companies, and it helps prepare you for the exam.

To complete the discussion of the context, be aware that if you start with one public IP address, you cannot tell from that address whether it comes from a public classful network or a public CIDR block. However, this chapter focuses on determining the facts about a Class A, B, or C network, assuming it comes from a public IP network rather than a public CIDR block. Now on to the math and processes!

NOTE You can discover if a public unicast address is part of a public classful network assignment, or a public CIDR block, with a search of WHOIS records. As for the process, go to ARIN's WHOIS search page (https://search.arin.net/rdap/), with a search for any public IP address. For example, on that page, a search for 17.1.1.1 reveals an address block of 17.0.0.0/8. As you will learn in this chapter and the next, the 17.0.0.0/8 notation represents Class A network 17.0.0.0, meaning that the 17.1.1.1 address comes from a public Class A assignment.

IPv4 Network Classes and Related Facts

IP version 4 (IPv4) defines five address classes. Three of the classes, Classes A, B, and C, consist of unicast IP addresses. Unicast addresses identify a single host or interface so that the address uniquely identifies the device. Class D addresses serve as multicast addresses, so that one packet sent to a Class D multicast IPv4 address can actually be delivered to multiple hosts. Finally, Class E addresses were originally intended for experimentation but were changed to simply be reserved for future use. The class can be identified based on the value of the first octet of the address, as shown in Table 12-2.

Key Topic

Table 12-2 IPv4 Address Classes Based on First Octet Values

Class	First Octet Values	Purpose
A	1–126	Unicast (large networks)
B	128–191	Unicast (medium-sized networks)
C	192–223	Unicast (small networks)
D	224–239	Multicast
E	240–255	Reserved (formerly experimental)

After you identify the class of a unicast address as either A, B, or C, many other related facts can be derived just through memorization. Table 12-3 lists that information for reference and later study; each of these concepts is described in this chapter.

Key Topic

Table 12-3 Key Facts for Classes A, B, and C

	Class A	Class B	Class C
First octet range	1–126	128–191	192–223
Valid network numbers	1.0.0.0–126.0.0.0	128.0.0.0–191.255.0.0	192.0.0.0–223.255.255.0
Total networks	$2^7 - 2 = 126$	$2^{14} = 16{,}384$	$2^{21} = 2{,}097{,}152$
Hosts per network	$2^{24} - 2$	$2^{16} - 2$	$2^8 - 2$
Octets (bits) in network part	1 (8)	2 (16)	3 (24)
Octets (bits) in host part	3 (24)	2 (16)	1 (8)
Default mask	255.0.0.0	255.255.0.0	255.255.255.0

Note that the address ranges of all addresses that begin with 0 and all addresses that begin with 127 are reserved. Had they not been reserved since the creation of Class A networks, as listed in RFC 791 (published in 1981), then they might have been known as Class A networks

0.0.0.0 and 127.0.0.0. Because they are reserved, however, the address space has 126 Class A networks, and not 128. Also, note that there are no similar reserved ranges to begin/end the Class B and C ranges.

In addition to the reservation of what would be Class A networks 0.0.0.0 and 127.0.0.0 for other purposes, other newer RFCs have also reserved small pieces of the Class A, B, and C address space. So, tables like Table 12-3, with the count of the numbers of Class A, B, and C networks, are a good place to get a sense of the size of the number; however, the number of reserved networks does change slightly over time (albeit slowly) based on these other reserved address ranges.

NOTE If you are interested in seeing all the reserved IPv4 address ranges, just do an Internet search on "IANA IPv4 special-purpose address registry."

The Number and Size of the Class A, B, and C Networks

Table 12-3 lists the range of Class A, B, and C network numbers; however, some key points can be lost just referencing a table of information. This section examines the Class A, B, and C network numbers, focusing on the more important points and the exceptions and unusual cases.

First, the number of networks from each class significantly differs. Only 126 Class A networks exist: network 1.0.0.0, 2.0.0.0, 3.0.0.0, and so on, up through network 126.0.0.0. However, 16,384 Class B networks exist, with more than 2 million Class C networks.

Next, note that the size of networks from each class also significantly differs. Each Class A network is relatively large—over 16 million host IP addresses per network—so they were originally intended to be used by the largest companies and organizations. Class B networks are smaller, with over 65,000 hosts per network. Finally, Class C networks, intended for small organizations, have 254 hosts in each network. Figure 12-4 summarizes those facts.

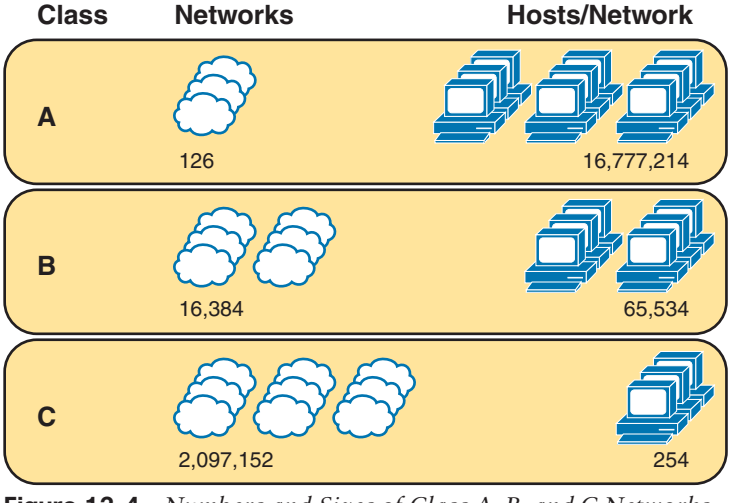


Figure 12-4 *Numbers and Sizes of Class A, B, and C Networks*

Address Formats

In some cases, an engineer might need to think about a Class A, B, or C network as if the network has not been subdivided through the subnetting process. In such a case, the addresses in the classful network have a structure with two parts: the **network part** (sometimes called the *prefix*) and the **host part**. Then, comparing any two IP addresses in one network, the following observations can be made:

Key Topic

The addresses in the same network have the same values in the network part.

The addresses in the same network have different values in the host part.

For example, in Class A network 10.0.0.0, by definition, the network part consists of the first octet. As a result, all addresses have an equal value in the network part, namely a 10 in the first octet. If you then compare any two addresses in the network, the addresses have a different value in the last three octets (the host octets). For example, IP addresses 10.1.1.1 and 10.1.1.2 have the same value (10) in the network part, but different values in the host part.

Figure 12-5 shows the format and sizes (in number of bits) of the network and host parts of IP addresses in Class A, B, and C networks, before any subnetting has been applied.

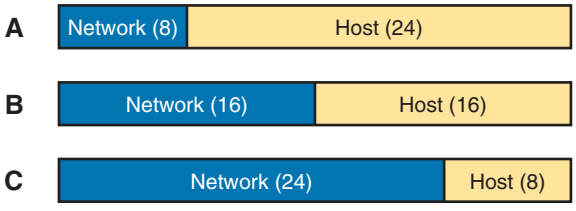


Figure 12-5 *Sizes (Bits) of the Network and Host Parts of Unsubnetted Classful Networks*

Default Masks

Although we humans can easily understand the concepts behind Figure 12-5, computers prefer numbers. To communicate those same ideas to computers, each network class has an associated **default mask** that defines the size of the network and host parts of an unsubnetted Class A, B, and C network. To do so, the mask lists binary 1s for the bits considered to be in the network part and binary 0s for the bits considered to be in the host part.

For example, Class A network 10.0.0.0 has a network part of the first single octet (8 bits) and a host part of the last three octets (24 bits). As a result, the Class A default mask is 255.0.0.0, which in binary is

11111111 00000000 00000000 00000000

Figure 12-6 shows default masks for each network class, both in binary and dotted-decimal format.

NOTE Decimal 255 converts to the binary value 11111111. Decimal 0, converted to 8-bit binary, is 00000000. See Appendix A, "Numeric Reference Tables," for a conversion table.

Key Topic

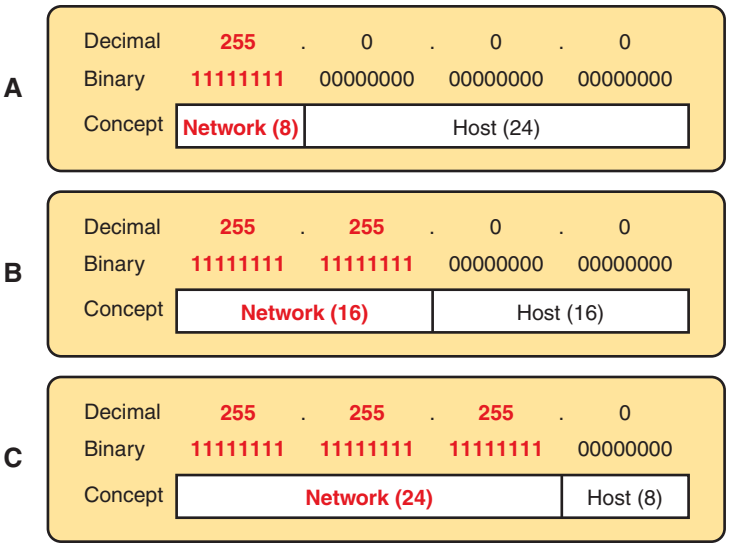


Figure 12-6 *Default Masks for Classes A, B, and C*

Number of Hosts per Network

Calculating the number of hosts per network requires some basic binary math. First, consider a case where you have a single binary digit. How many unique values are there? There are, of course, two values: 0 and 1. With 2 bits, you can make four combinations: 00, 01, 10, and 11. As it turns out, the total combination of unique values you can make with N bits is 2^N.

Host addresses—the IP addresses assigned to hosts—must be unique. The host bits exist for the purpose of giving each host a unique IP address by virtue of having a different value in the host part of the addresses. So, with H host bits, 2^H unique combinations exist.

However, the number of hosts in a network is not 2^H; instead, it is $2^H - 2$. Each network reserves two numbers that would have otherwise been useful as host addresses but have instead been reserved for special use: one for the **network ID** and one for the **network broadcast address**. As a result, the formula to calculate the number of host addresses per Class A, B, or C network is

Key Topic

$$2^H - 2$$

where H is the number of host bits.

Deriving the Network ID and Related Numbers

Each classful network has four key numbers that describe the network. You can derive these four numbers if you start with just one IP address in the network. The numbers are as follows:

- Network number
- First (numerically lowest) usable address
- Last (numerically highest) usable address
- Network broadcast address

First, consider both the network number and first usable IP address. The *network number*, also called the *network ID* or **network address**, identifies the network. By definition, the network number is the numerically lowest number in the network. However, to prevent any ambiguity, the people who made up IP addressing added the restriction that the network number cannot be assigned as an IP address. So, the lowest number in the network is the network ID. Then, the first (numerically lowest) host IP address is *one larger than* the network number.

Next, consider the network broadcast address along with the last (numerically highest) usable IP address. The TCP/IP RFCs define a network broadcast address as a special address in each network. This broadcast address could be used as the destination address in a packet, and the routers would forward a copy of that one packet to all hosts in that classful network. Numerically, a network broadcast address is always the highest (last) number in the network. As a result, the highest (last) number usable as an IP address is the address that is *one less than* the network broadcast address.

Simply put, if you can find the network number and network broadcast address, finding the first and last usable IP addresses in the network is easy. For the exam, you should be able to find all four values with ease; the process is as follows:

Key Topic

Step 1. Determine the class (A, B, or C) based on the first octet.

Step 2. Mentally divide the network and host octets based on the class.

Step 3. To find the network number, change the IP address's host octets to 0.

Step 4. To find the first address, add 1 to the fourth octet of the network ID.

Step 5. To find the broadcast address, change the network ID's host octets to 255.

Step 6. To find the last address, subtract 1 from the fourth octet of the network broadcast address.

The written process actually looks harder than it is. Figure 12-7 shows an example of the process, using Class A IP address 10.17.18.21, with the circled numbers matching the process.

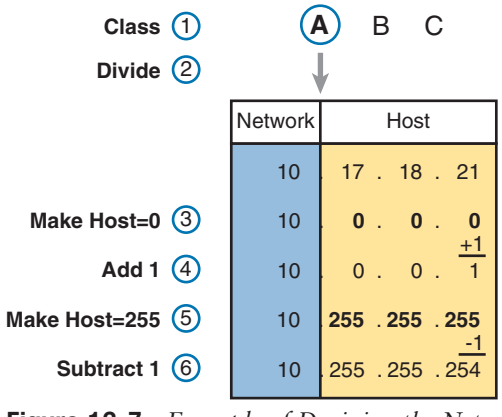


Figure 12-7 *Example of Deriving the Network ID and Other Values from 10.17.18.21*

Figure 12-7 shows the identification of the class as Class A (Step 1) and the number of network/host octets as 1 and 3, respectively. So, to find the network ID at Step 3, the figure copies only the first octet, setting the last three (host) octets to 0. At Step 4, just copy the network ID and add 1 to the fourth octet. Similarly, to find the broadcast address at Step 5, copy the network octets but set the host octets to 255. Then, at Step 6, subtract 1 from the fourth octet to find the last (numerically highest) usable IP address.

Just to show an alternative example, consider IP address 172.16.8.9. Figure 12-8 shows the process applied to this IP address.

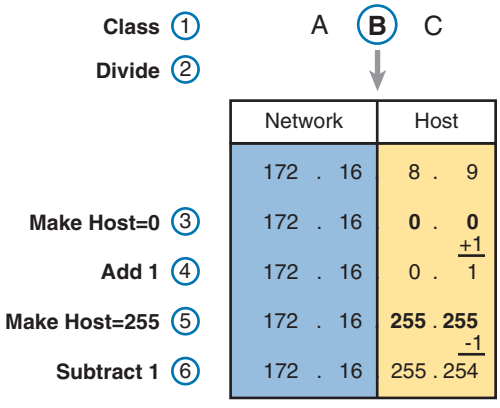


Figure 12-8 *Example Deriving the Network ID and Other Values from 172.16.8.9*

Figure 12-8 shows the identification of the class as Class B (Step 1) and the number of network/host octets as 2 and 2, respectively. So, to find the network ID at Step 3, the figure copies only the first two octets, setting the last two (host) octets to 0. Similarly, Step 5 shows the same action, but with the last two (host) octets being set to 255.

Unusual Network IDs and Network Broadcast Addresses

Some of the more unusual numbers in and around the range of Class A, B, and C network numbers can cause some confusion. This section lists some examples of numbers that make many people make the wrong assumptions about the meaning of the number.

For Class A, the first odd fact is that the range of values in the first octet omits the numbers 0 and 127. As it turns out, what would be Class A network 0.0.0.0 was originally reserved for some broadcasting requirements, so all addresses that begin with 0 in the first octet are reserved. What would be Class A network 127.0.0.0 is still reserved because of a special address used in software testing, called the loopback address (127.0.0.1).

For Class B (and C), some of the network numbers can look odd, particularly if you fall into a habit of thinking that 0s at the end mean the number is a network ID, and 255s at the end mean it's a network broadcast address. First, Class B network numbers range from 128.0.0.0 to 191.255.0.0, for a total of 2^{14} networks. However, even the first (lowest number) Class B network number (128.0.0.0) looks a little like a Class A network number because it ends with three 0s. However, the first octet is 128, making it a Class B network with a two-octet network part (128.0).

For another Class B example, the high end of the Class B range also might look strange at first glance (191.255.0.0), but this is indeed the numerically highest of the valid Class B network numbers. This network's broadcast address, 191.255.255.255, might look a little like a Class A broadcast address because of the three 255s at the end, but it is indeed the broadcast address of a Class B network.

Similarly to Class B networks, some of the valid Class C network numbers do look strange. For example, Class C network 192.0.0.0 looks a little like a Class A network because of the last three octets being 0, but because it is a Class C network, it consists of all addresses that begin with three octets equal to 192.0.0. Similarly, 223.255.255.0, another valid Class C network, consists of all addresses that begin with 223.255.255.

Practice with Classful Networks

As with all areas of IP addressing and subnetting, you need to practice to be ready for the CCNA exam. You should practice some while reading this chapter to make sure that you understand the processes. At that point, you can use your notes and this book as a reference, with a goal of understanding the process. After that, keep practicing this and all the other subnetting processes. Before you take the exam, you should be able to always get the right answer, and with speed. Table 12-4 summarizes the key concepts and suggestions for this two-phase approach.

Table 12-4 Keep-Reading and Take-Exam Goals for This Chapter's Topics

Time Frame	After Reading This Chapter	Before Taking the Exam
Focus on…	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	10 seconds

Practice Deriving Key Facts Based on an IP Address

Practice finding the various facts that can be derived from an IP address, as discussed throughout this chapter. To do so, complete Table 12-5.

Table 12-5 Practice Problems: Find the Network ID and Network Broadcast

	IP Address	Class	Network Octets	Host Octets	Network ID	Network Broadcast Address
1	1.1.1.1					
2	128.1.6.5					
3	200.1.2.3					
4	192.192.1.1					
5	126.5.4.3					
6	200.1.9.8					
7	192.0.0.1					
8	191.255.1.47					
9	223.223.0.1					

The answers are listed in the section "Answers to Earlier Practice Problems," later in this chapter.

Practice Remembering the Details of Address Classes

Tables 12-2 and 12-3, shown earlier in this chapter, summarized some key information about IPv4 address classes. Tables 12-6 and 12-7 show sparse versions of these same tables. To practice recalling those key facts, particularly the range of values in the first octet that identifies the address class, complete these tables. Then, refer to Tables 12-2 and 12-3 to check your answers. Repeat this process until you can recall all the information in the tables.

Table 12-6 Sparse Study Table Version of Table 12-2

Class	First Octet Values	Purpose
A		
B		
C		
D		
E		

Table 12-7 Sparse Study Table Version of Table 12-3

	Class A	Class B	Class C
First octet range			
Valid network numbers			
Total networks			
Hosts per network			
Octets (bits) in network part			
Octets (bits) in host part			
Default mask			

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 12-8 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 12-8 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Review memory tables		Website

Review Element	Review Date(s)	Resource Used
Practice analyzing classful IPv4 networks		Website, Appendix D
Watch video		Website

Review All the Key Topics

Key Topic

Table 12-9 Key Topics for Chapter 12

Key Topic Elements	Description	Page Number
Table 12-2	Address classes	328
Table 12-3	Key facts about Class A, B, and C networks	328
List	Comparisons of network and host parts of addresses in the same classful network	330
Figure 12-6	Default masks	331
Paragraph	Function to calculate the number of hosts per network	331
List	Steps to find information about a classful network	332

Key Terms You Should Know

CIDR block, classful IP network, default mask, host part, network, network address, network broadcast address, network ID, network number, network part, unicast IP address

Additional Practice for This Chapter's Processes

For additional practice with analyzing classful networks, you may do a set of practice problems using your choice of tools:

Application: From the companion website, in the section titled "Memory Tables and Practice Exercises," use the "Practice Exercise: Analyzing Classful IPv4 Networks."

PDF: Practice the same problems using companion website Appendix D, "Practice for Chapter 12: Analyzing Classful IPv4 Networks."

Answers to Earlier Practice Problems

Table 12-5, shown earlier, listed several practice problems. Table 12-10 lists the answers.

Table 12-10 Practice Problems: Find the Network ID and Network Broadcast

	IP Address	Class	Network Octets	Host Octets	Network ID	Network Broadcast
1	1.1.1.1	A	1	3	1.0.0.0	1.255.255.255
2	128.1.6.5	B	2	2	128.1.0.0	128.1.255.255
3	200.1.2.3	C	3	1	200.1.2.0	200.1.2.255
4	192.192.1.1	C	3	1	192.192.1.0	192.192.1.255
5	126.5.4.3	A	1	3	126.0.0.0	126.255.255.255

	IP Address	Class	Network Octets	Host Octets	Network ID	Network Broadcast
6	200.1.9.8	C	3	1	200.1.9.0	200.1.9.255
7	192.0.0.1	C	3	1	192.0.0.0	192.0.0.255
8	191.255.1.47	B	2	2	191.255.0.0	191.255.255.255
9	223.223.0.1	C	3	1	223.223.0.0	223.223.0.255

The class, number of network octets, and number of host octets all require you to look at the first octet of the IP address to determine the class. If a value is between 1 and 126, inclusive, the address is a Class A address, with one network and three host octets. If a value is between 128 and 191 inclusive, the address is a Class B address, with two network and two host octets. If a value is between 192 and 223, inclusive, it is a Class C address, with three network octets and one host octet.

The last two columns can be found based on Table 12-3, specifically the number of network and host octets along with the IP address. To find the network ID, copy the IP address, but change the host octets to 0. Similarly, to find the network broadcast address, copy the IP address, but change the host octets to 255.

The last three problems can be confusing and were included on purpose so that you could see an example of these unusual cases, as follows.

Answers to Practice Problem 7 (from Table 12-5)

Consider IP address 192.0.0.1. First, 192 is on the lower edge of the first octet range for Class C; as such, this address has three network octets and one host octet. To find the network ID, copy the address, but change the single host octet (the fourth octet) to 0, for a network ID of 192.0.0.0. It looks strange, but it is indeed the network ID.

The network broadcast address choice for problem 7 can also look strange. To find the broadcast address, copy the IP address (192.0.0.1), but change the last octet (the only host octet) to 255, for a broadcast address of 192.0.0.255. In particular, if you decide that the broadcast should be 192.255.255.255, you might have fallen into the trap of logic, like "Change all 0s in the network ID to 255s," which is not the correct logic. Instead, change all host octets in the IP address (or network ID) to 255s.

Answers to Practice Problem 8 (from Table 12-5)

The first octet of problem 8 (191.255.1.47) sits on the upper edge of the Class B range for the first octet (128–191). As such, to find the network ID, change the last two octets (host octets) to 0, for a network ID of 191.255.0.0. This value sometimes gives people problems because they are used to thinking that 255 somehow means the number is a broadcast address.

The broadcast address, found by changing the two host octets to 255, means that the broadcast address is 191.255.255.255. It looks more like a broadcast address for a Class A network, but it is actually the broadcast address for Class B network 191.255.0.0.

Answers to Practice Problem 9 (from Table 12-5)

Problem 9, with IP address 223.223.0.1, is near the high end of the Class C range. As a result, only the last (host) octet is changed to 0 to form the network ID 223.223.0.0. It looks a little like a Class B network number at first glance because it ends in two octets of 0. However, it is indeed a Class C network ID (based on the value in the first octet).

CHAPTER 13

Analyzing Subnet Masks

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.6 Configure and verify IPv4 addressing and subnetting

The subnet mask used in one or many subnets in an IP internetwork says a lot about the intent of the subnet design. First, the mask divides addresses into two parts: *prefix* and *host*, with the host part defining the size of the subnet (that is, the number of hosts in the subnet). Then, the class (A, B, or C) further divides the structure of addresses in a subnet, breaking the prefix part into the *network* and *subnet* parts. The subnet part defines the number of subnets that could exist inside one classful IP network, assuming that one mask is used throughout the classful network.

The subnet mask holds the key to understanding several important subnetting design points. However, to analyze a subnet mask, you first need some basic math skills with masks. The math converts masks between the three different formats used to represent a mask:

- Binary
- Dotted-decimal notation (DDN)
- Prefix (also called classless interdomain routing [CIDR])

This chapter has two major sections. The first focuses on the mask formats and the math used to convert between the three formats. The second section explains how to take an IP address and its subnet mask and analyze those values. In particular, it shows how to determine the three-part format of the IPv4 address and describes the facts about the subnetting design that are implied by the mask.

NOTE The majority of the chapter assumes subnetting of a Class A, B, or C network. The end of the chapter provides some discussion of the similar case of subnetting a public CIDR block.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 13-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Subnet Mask Conversion	1–3
Identifying Subnet Design Choices Using Masks	4–7

1. Which of the following answers lists the prefix (CIDR) format equivalent of 255.255.254.0?
   - **a.** /19
   - **b.** /20
   - **c.** /23
   - **d.** /24
   - **e.** /25
2. Which of the following answers lists the prefix (CIDR) format equivalent of 255.255.255.240?
   - **a.** /26
   - **b.** /28
   - **c.** /27
   - **d.** /30
   - **e.** /29
3. Which of the following answers lists the dotted-decimal notation (DDN) equivalent of /30?
   - **a.** 255.255.255.192
   - **b.** 255.255.255.252
   - **c.** 255.255.255.240
   - **d.** 255.255.254.0
   - **e.** 255.255.255.0
4. Working at the help desk, you receive a call and learn a user's PC IP address and mask (10.55.66.77, mask 255.255.255.0). When thinking about this using classful logic, you determine the number of network (N), subnet (S), and host (H) bits. Which of the following is true in this case?
   - **a.** N=12
   - **b.** S=12
   - **c.** H=8
   - **d.** S=8
   - **e.** N=24
5. Working at the help desk, you receive a call and learn a user's PC IP address and mask (192.168.9.1/27). When thinking about this using classful logic, you determine the number of network (N), subnet (S), and host (H) bits. Which of the following is true in this case?
   - **a.** N=24
   - **b.** S=24

c. H=8

d. H=7

6. Which of the following statements is true about classless IP addressing concepts?
   a. Uses a 128-bit IP address
   b. Applies only for Class A and B networks
   c. Separates IP addresses into network, subnet, and host parts
   d. Ignores Class A, B, and C network rules
7. Which of the following masks, when used as the only mask within a Class B network, would supply enough subnet bits to support 100 subnets? (Choose two answers.)
   a. /24
   b. 255.255.255.252
   c. /20
   d. 255.255.252.0

Foundation Topics

Subnet Mask Conversion

This section describes how to convert between different formats for the subnet mask. You can then use these processes when you practice. If you already know how to convert from one format to the other, go ahead and move to the section "Practice Converting Subnet Masks," later in this chapter.

Three Mask Formats

Subnet masks can be written as 32-bit binary numbers, but not just any binary number. In particular, the binary subnet mask must follow these rules:

- The value must not interleave 1s and 0s.
- If 1s exist, they are on the left.
- If 0s exist, they are on the right.

For example, the following values would be illegal. The first is illegal because the value interleaves 0s and 1s, and the second is illegal because it lists 0s on the left and 1s on the right:

```
10101010 01010101 11110000 00001111
00000000 00000000 00000000 11111111
```

The following two binary values meet the requirements, in that they have all 1s on the left, followed by all 0s, with no interleaving of 1s and 0s:

```
11111111 00000000 00000000 00000000
11111111 11111111 11111111 00000000
```

Two alternative subnet mask formats exist so that we humans do not have to work with 32-bit binary numbers. One format, **dotted-decimal notation (DDN)**, converts each set of 8 bits into the decimal equivalent. For example, the two previous binary masks would convert to the following DDN subnet masks because binary 11111111 converts to decimal 255, and binary 00000000 converts to decimal 0:

255.0.0.0

255.255.255.0

Although the DDN format has been around since the beginning of IPv4 addressing, the third mask format was added later, in the early 1990s: the *prefix* format. This format takes advantage of the rule that the subnet mask starts with some number of 1s, and then the rest of the digits are 0s. Prefix format lists a slash (/) followed by the number of binary 1s in the **binary mask**. Using the same two examples as earlier in this section, the prefix format equivalent masks are as follows:

/8

/24

Note that although the terms *prefix* or **prefix mask** can be used, the terms **CIDR mask** or *slash mask* can also be used. This newer prefix style mask was created around the same time as the classless interdomain routing (CIDR) specification back in the early 1990s, and the acronym CIDR grew to be used for anything related to CIDR, including prefix-style masks. In addition, the term *slash mask* is sometimes used because the value includes a slash mark (/).

You need to get comfortable working with masks in different formats. The rest of this section examines how to convert between the three formats.

Converting Between Binary and Prefix Masks

Converting between binary and prefix masks should be relatively intuitive after you know that the prefix value is simply the number of binary 1s in the binary mask. For the sake of completeness, the processes to convert in each direction are

Key Topic

Binary to prefix: Count the number of binary 1s in the binary mask, and write the total, in decimal, after a /.

Prefix to binary: Write P binary 1s, where P is the prefix value, followed by as many binary 0s as required to create a 32-bit number.

Tables 13-2 and 13-3 show some examples.

Table 13-2 Example Conversions: Binary to Prefix

Binary Mask	Logic	Prefix Mask
11111111 11111111 11000000 00000000	Count 8 + 8 + 2 = 18 binary 1s	/18
11111111 11111111 11111111 11110000	Count 8 + 8 + 8 + 4 = 28 binary 1s	/28
11111111 11111000 00000000 00000000	Count 8 + 5 = 13 binary 1s	/13

Table 13-3 Example Conversions: Prefix to Binary

Prefix Mask	Logic	Binary Mask
/18	Write 18 1s, then 14 0s, total 32	11111111 11111111 11000000 00000000
/28	Write 28 1s, then 4 0s, total 32	11111111 11111111 11111111 11110000
/13	Write 13 1s, then 19 0s, total 32	11111111 11111000 00000000 00000000

Converting Between Binary and DDN Masks

By definition, a dotted-decimal number (DDN) used with IPv4 addressing contains four decimal numbers, separated by dots. Each decimal number represents 8 bits. So, a single DDN shows four decimal numbers that together represent some 32-bit binary number.

Conversion from a DDN mask to the binary equivalent is relatively simple to describe but can be laborious to perform. First, to do the conversion, the process is as follows:

For each octet, perform a decimal-to-binary conversion.

However, depending on your comfort level with doing decimal-to-binary conversions, that process can be difficult or time-consuming. If you want to think about masks in binary for the exam, consider picking one of the following methods to do the conversion and practicing until you can do it quickly and accurately:

- Do the decimal-binary conversions, but practice your decimal-binary conversions to get fast. If you choose this path, consider the Cisco Binary Game, which you can find by searching its name at the Cisco Learning Network (CLN), or try this link: https://learningnetwork.cisco.com/s/binary-game.
- Use the decimal-binary conversion chart in Appendix A, "Numeric Reference Tables." This lets you find the answer more quickly now, but you cannot use the chart on exam day.
- Memorize the nine possible decimal values that can be in a **decimal mask**, and practice using a reference table with those values.

The third method, which is the method recommended in this book, takes advantage of the fact that any and every DDN mask octet must be one of only nine values. Why? Well, remember how a binary mask cannot interleave 1s and 0s, and the 0s must be on the right? It turns out that only nine different 8-bit binary numbers conform to these rules. Table 13-4 lists the values, along with other relevant information.

Key Topic

Table 13-4 Nine Possible Values in One Octet of a Subnet Mask

Binary Mask Octet	Decimal Equivalent	Number of Binary 1s
00000000	0	0
10000000	128	1
11000000	192	2
11100000	224	3

Answers to the "Do I Know This Already?" quiz:

1 C **2** B **3** B **4** C **5** A **6** D **7** A, B

Binary Mask Octet	Decimal Equivalent	Number of Binary 1s
11110000	240	4
11111000	248	5
11111100	252	6
11111110	254	7
11111111	255	8

Many subnetting processes can be done with or without binary math. Some of those processes—mask conversion included—use the information in Table 13-4. You should plan to memorize the information in the table. I recommend making a copy of the table to keep handy while you practice. (You will likely memorize the contents of this table simply by practicing the conversion process enough to get both good and fast at the conversion.)

Using the table, the conversion processes in each direction with binary and decimal masks are as follows:

Key Topic

Binary to decimal: Organize the bits into four sets of eight. For each octet, find the binary value in the table and write down the corresponding decimal value.

Decimal to binary: For each octet, find the decimal value in the table and write down the corresponding 8-bit binary value.

Tables 13-5 and 13-6 show some examples.

Table 13-5 Conversion Example: Binary to Decimal

Binary Mask	Logic	Decimal Mask
11111111 11111111 11000000 00000000	11111111 maps to 255 11000000 maps to 192 00000000 maps to 0	255.255.192.0
11111111 11111111 11111111 11110000	11111111 maps to 255 11110000 maps to 240	255.255.255.240
11111111 11111000 00000000 00000000	11111111 maps to 255 11111000 maps to 248 00000000 maps to 0	255.248.0.0

Table 13-6 Conversion Examples: Decimal to Binary

Decimal Mask	Logic	Binary Mask
255.255.192.0	255 maps to 11111111 192 maps to 11000000 0 maps to 00000000	11111111 11111111 11000000 00000000
255.255.255.240	255 maps to 11111111 240 maps to 11110000	11111111 11111111 11111111 11110000

Decimal Mask	Logic	Binary Mask
255.248.0.0	255 maps to 11111111 248 maps to 11111000 0 maps to 00000000	11111111 11111000 00000000 00000000

Converting Between Prefix and DDN Masks

When you are learning, the best way to convert between the prefix and decimal formats is to first convert to binary. For example, to move from decimal to prefix, first convert decimal to binary and then from binary to prefix.

For the exams, set a goal to master these conversions doing the math in your head. While learning, you will likely want to use paper. To train yourself to do all this without writing it down, instead of writing each octet of binary, just write the number of binary 1s in that octet.

Figure 13-1 shows an example with a prefix-to-decimal conversion. The left side shows the conversion to binary as an interim step. For comparison, the right side shows the binary interim step in shorthand that just lists the number of binary 1s in each octet of the binary mask.

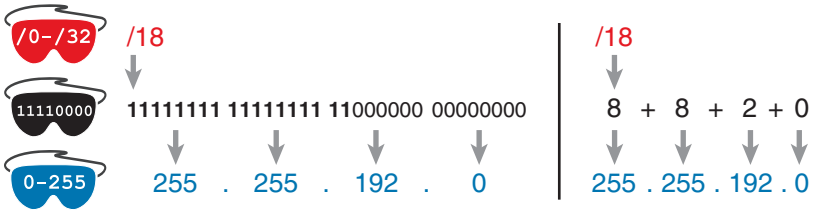


Figure 13-1 *Conversion from Prefix to Decimal: Full Binary Versus Shorthand*

Similarly, when converting from decimal to prefix, mentally convert to binary along the way, and as you improve, just think of the binary as the number of 1s in each octet. Figure 13-2 shows an example of such a conversion.

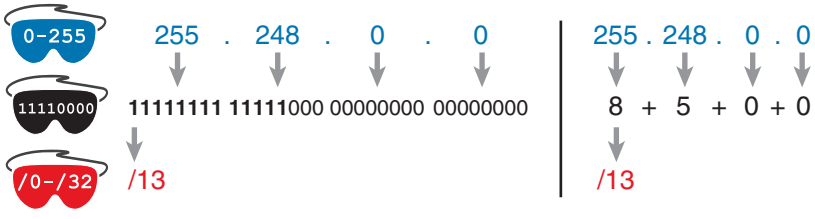


Figure 13-2 *Conversion from Decimal to Prefix: Full Binary Versus Shorthand*

Note that Appendix A has a table that lists all 33 legal subnet masks, with all three formats shown.

Practice Converting Subnet Masks

Before moving to the second half of this chapter, and thinking about what these subnet masks mean, first do some practice. Practice the processes discussed in this chapter until you get the right answer most of the time. Later, before taking the exam, practice more until

you master the topics in this chapter and can move pretty fast, as outlined in the right column of Table 13-7.

Table 13-7 Keep-Reading and Take-Exam Goals for This Chapter's Topics

Time Frame	Before Moving to the Next Section	Before Taking the Exam
Focus On…	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	10 seconds

Table 13-8 lists eight practice problems. The table has three columns, one for each mask format. Each row lists one mask, in one format. Your job is to find the mask's value in the other two formats for each row. Table 13-12, located in the section "Answers to Earlier Practice Problems," later in this chapter, lists the answers.

Table 13-8 Practice Problems: Find the Mask Values in the Other Two Formats

Prefix	Binary Mask	Decimal
	11111111 11111111 11000000 00000000	
		255.255.255.252
/25		
/16		
		255.0.0.0
	11111111 11111111 11111100 00000000	
		255.254.0.0
/27		

Identifying Subnet Design Choices Using Masks

Subnet masks have many purposes. In fact, if ten experienced network engineers were independently asked, "What is the purpose of a subnet mask?" the engineers would likely give a variety of true answers. The subnet mask plays several roles.

This chapter focuses on one particular use of a subnet mask: defining the prefix part of the IP addresses in a subnet. The prefix part must be the same value for all addresses in a subnet. In fact, a single subnet can be defined as all IPv4 addresses that have the same value in the prefix part of their IPv4 addresses.

While the previous paragraph might sound a bit formal, the idea is relatively basic, as shown in Figure 13-3. The right side of the figure shows a subnet of all addresses that begin with 172.16.2 and another subnet made of all addresses that begin with 172.16.3. In this example, the prefix—the part that has the same value in all the addresses in the subnet—is the first three octets.

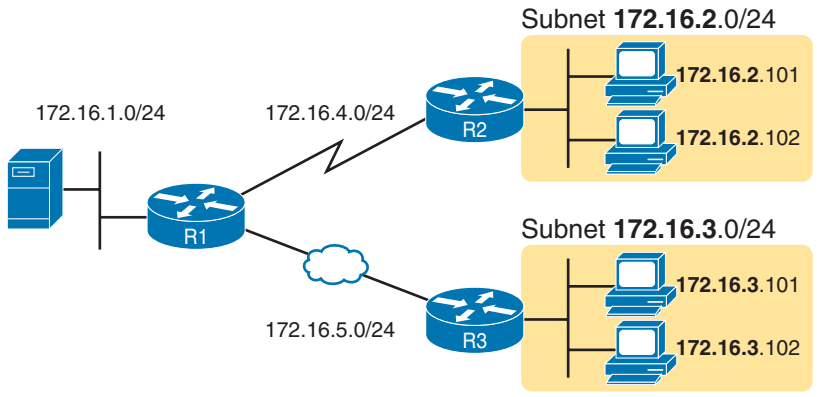


Figure 13-3 *Simple Subnet Design, with Mask /24*

While people can sit around a conference table and talk about how a prefix is three octets long, computers communicate that same concept using a subnet mask. In this case, the subnets use a subnet mask of /24, which means that the prefix part of the addresses is 24 bits (3 octets) long.

This section explains more about how to use a subnet mask to understand this concept of a prefix part of an IPv4 address, along with these other uses for a subnet mask. Note that this section discusses the first five items in the list.

Key Topic

- Defines the size of the prefix (combined network and subnet) part of the addresses in a subnet
- Defines the size of the host part of the addresses in the subnet
- Can be used to calculate the number of hosts in the subnet
- Provides a means for the network designer to communicate the design details—the number of subnet and host bits—to the devices in the network
- Under certain assumptions, can be used to calculate the number of subnets in the entire classful network
- Can be used in binary calculations of both the subnet ID and the subnet broadcast address

Masks Divide the Subnet's Addresses into Two Parts

The subnet mask subdivides the IP addresses in a subnet into two parts: the *prefix*, or *subnet part*, and the *host part*.

The prefix part identifies the addresses that reside in the same subnet because all IP addresses in the same subnet have the same value in the prefix part of their addresses. The idea is much like the postal code (ZIP codes in the United States) in mailing addresses. All mailing addresses in the same town have the same postal code. Likewise, all IP addresses in the same subnet have identical values in the prefix part of their addresses.

The host part of an address identifies the host uniquely inside the subnet. If you compare any two IP addresses in the same subnet, their host parts will differ, even though the prefix parts of their addresses have the same value. To summarize these key comparisons:

Key Topic

Prefix (subnet) part: Equal in all addresses in the same subnet

Host part: Different in all addresses in the same subnet

For example, imagine a subnet that, in concept, includes all addresses whose first three octets are 10.1.1. So, the following list shows several addresses in this subnet:

10.1.1.**1**

10.1.1.**2**

10.1.1.**3**

In this list, the prefix or subnet parts (the first three octets of 10.1.1) are equal. The host part (the last octet [in bold]) is different. So, the prefix or subnet part of the address identifies the group, and the host part identifies the specific member of the group.

The subnet mask defines the dividing line between the prefix and the host part. To do so, the mask creates a conceptual line between the binary 1s in the binary mask and the binary 0s in the mask. In short, if a mask has P binary 1s, the prefix part is P bits long and the rest of the bits are host bits. Figure 13-4 shows the concept.

Key Topic

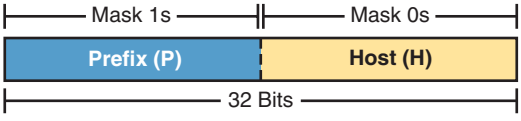


Figure 13-4 *Prefix (Subnet) and Host Parts Defined by Mask 1s and 0s*

Figure 13-5, shows a specific example using mask 255.255.255.0. Mask 255.255.255.0 (/24) has 24 binary 1s, for a prefix length of 24 bits.

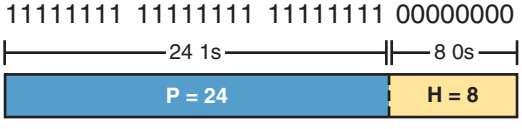


Figure 13-5 *Mask 255.255.255.0: P=24, H=8*

Masks and Class Divide Addresses into Three Parts

In addition to the two-part view of IPv4 addresses, you can also think about IPv4 addresses as having three parts. When subnetting a class A, B, or C network, just apply Class A, B, and C rules to the address format to define the network part at the beginning of the address. This added logic divides the prefix into two parts: the *network* part and the *subnet* part. The class defines the length of the network part, with the subnet part simply being the rest of the prefix. Figure 13-6 shows the idea.

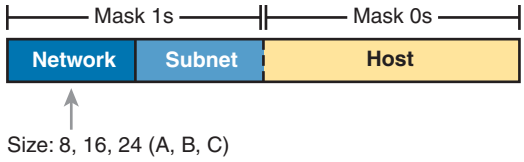


Figure 13-6 *Class Concepts Applied to Create Three Parts*

The combined network and subnet parts act like the prefix because all addresses in the same subnet must have identical values in the network and subnet parts. The size of the host part remains unchanged, whether viewing the addresses as having two parts or three parts.

To be complete, Figure 13-7 shows the same example as in the previous section, with the subnet of "all addresses that begin with 10.1.1." In that example, the subnet uses mask 255.255.255.0, and the addresses are all in Class A network 10.0.0.0. The class defines 8 network bits, and the mask defines 24 prefix bits, meaning that 24 – 8 = 16 subnet bits exist. The host part remains as 8 bits per the mask.

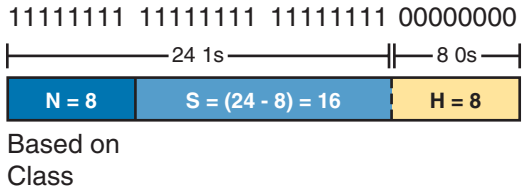


Figure 13-7 *Subnet 10.1.1.0, Mask 255.255.255.0: N=8, S=16, H=8*

Classless and Classful Addressing

The terms **classless addressing** and **classful addressing** refer to the two different ways to think about IPv4 addresses as described so far in this chapter. Classful addressing means that you think about Class A, B, and C rules, so the prefix is separated into the network and subnet parts, as shown in Figures 13-6 and 13-7. Classless addressing means that you ignore the Class A, B, and C rules and treat the prefix part as one part, as shown in Figures 13-4 and 13-5. The following more formal definitions are listed for reference and study:

Classless addressing: The concept that an IPv4 address has two parts—the prefix part plus the host part—as defined by the mask, with *no consideration of the class* (A, B, or C).

Classful addressing: The concept that an IPv4 address has three parts—network, subnet, and host—as defined by the mask *and Class A, B, and C rules*.

NOTE Unfortunately, the networking world uses the terms *classless* and *classful* in a couple of different ways. In addition to the classless and classful addressing described here, each routing protocol can be categorized as either a *classless routing protocol* or a *classful routing protocol*. In another use, the terms *classless routing* and *classful routing* refer to some details of how Cisco routers forward (route) packets using the default route in some cases. As a result, these terms can be easily confused and misused. So, when you see the words *classless* and *classful*, be careful to note the context: addressing, routing, or routing protocols.

Calculations Based on the IPv4 Address Format

After you know how to break an address down using both classless and classful addressing rules, you can easily calculate a couple of important facts using some basic math formulas.

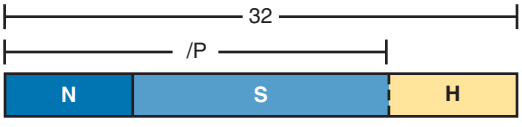
First, for any subnet, after you know the number of host bits, you can calculate the number of host IP addresses in the subnet. Next, if you know the number of subnet bits (using classful addressing concepts) and you know that only one subnet mask is used throughout the network, you can also calculate the number of subnets in the network. The formulas just require that you know the powers of 2:

Hosts in the subnet: $2^H - 2$, where H is the number of host bits.

Subnets in the network: 2^S, where S is the number of subnet bits. Only use this formula if only one mask is used throughout the network.

NOTE The section "Choose the Mask" in Chapter 11, "Perspectives on IPv4 Subnetting," details many concepts related to masks, including comments about this assumption of one mask throughout a single Class A, B, or C network.

The sizes of the parts of IPv4 addresses can also be calculated. The math is basic, but the concepts are important. Keeping in mind that IPv4 addresses are 32 bits long, the two parts with classless addressing must add up to 32 (P + H = 32), and with classful addressing, the three parts must add up to 32 (N + S + H = 32). Figure 13-8 shows the relationships.



Class:
A: N = 8
B: N = 16
C: N = 24

Figure 13-8 *Relationship Between /P, N, S, and H*

You often begin with an IP address and mask, both when answering questions on the CCNA exam and when examining problems that occur in real networks. Based on the information in this chapter and earlier chapters, you should be able to find all the information in Figure 13-8 and then calculate the number of hosts/subnet and the number of subnets in the network. For reference, the following process spells out the steps:

Key Topic

Step 1. Convert the mask to prefix format (/P) as needed. (See the earlier section "Practice Converting Subnet Masks" for review.)

Step 2. Determine N based on the class. (See Chapter 12, "Analyzing Classful IPv4 Networks," for review.)

Step 3. Calculate S = P – N.

Step 4. Calculate H = 32 – P.

Step 5. Calculate hosts/subnet: $2^H - 2$.

Step 6. Calculate number of subnets: 2^S.

For example, consider the case of IP address 8.1.4.5 with mask 255.255.0.0 by following this process:

Step 1. 255.255.0.0 = /16, so P=16.

Step 2. 8.1.4.5 is in the range 1–126 in the first octet, so it is Class A; so N=8.

Step 3. S = P – N = 16 – 8 = 8.

Step 4. H = 32 – P = 32 – 16 = 16.

Step 5. $2^{16} - 2$ = 65,534 hosts/subnet.

Step 6. 2^{8} = 256 subnets.

Figure 13-9 shows a visual analysis of the same problem.

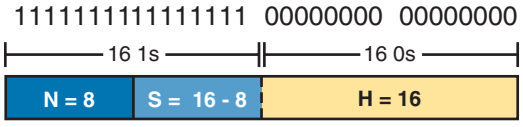


Figure 13-9 *Visual Representation of Problem: 8.1.4.5, 255.255.0.0*

For another example, consider address 200.1.1.1, mask 255.255.255.252 by following this process:

Step 1. 255.255.255.252 = /30, so P=30.

Step 2. 200.1.1.1 is in the range 192–223 in the first octet, so it is Class C; so N=24.

Step 3. S = P – N = 30 – 24 = 6.

Step 4. H = 32 – P = 32 – 30 = 2.

Step 5. $2^{2} - 2$ = 2 hosts/subnet.

Step 6. 2^{6} = 64 subnets.

This example uses a popular mask for serial links because serial links require only two host addresses, and the mask supports only two host addresses.

Practice Analyzing Subnet Masks

As with the other subnetting math in this book, using a two-phase approach may help. Take time now to practice until you feel as though you understand the process. Then, before the exam, make sure you master the math. Table 13-9 summarizes the key concepts and suggestions for this two-phase approach.

Table 13-9 Keep-Reading and Take-Exam Goals for This Chapter's Topics

Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On…	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	15 seconds

On a piece of scratch paper, answer the following questions. In each case:

- Determine the structure of the addresses in each subnet based on the class and mask, using classful IP addressing concepts. In other words, find the size of the network, subnet, and host parts of the addresses.
- Calculate the number of hosts in the subnet.
- Calculate the number of subnets in the network, assuming that the same mask is used throughout.

1. 8.1.4.5, 255.255.254.0
2. 130.4.102.1, 255.255.255.0
3. 199.1.1.100, 255.255.255.0
4. 130.4.102.1, 255.255.252.0
5. 199.1.1.100, 255.255.255.224

The answers are listed in the section "Answers to Earlier Practice Problems," later in this chapter.

Masks and CIDR Blocks

As described in the Introduction, most of this chapter, particularly the second major section, expects the more typical case of subnetting a Class A, B, or C network. However, in some cases, a company will use a large public *CIDR block* instead of a classful public IP network or a classful private IP network. While more common today for enterprises to use private Class A, B, and C IP networks for the addresses for most of their hosts, it still helps to understand how you would subnet if using a large public CIDR block instead.

First, the classless addressing view of the mask need not change. However, the classful view of the mask, which interprets the address structure with a network field length based on Class A, B, and C rules, needs to be adjusted. Thankfully, the concepts are straightforward and do not require new processes or math. In short:

> Formerly, you defined a network field based on Class A, B, and C rules. With a CIDR block, instead, use the prefix length specified by the CIDR block.

To explain a little more, note that a CIDR block assignment lists a prefix ID and length. The prefix ID represents the group, like a network ID or subnet ID, and is the numerically lowest number in the CIDR block. The CIDR block's prefix length acts like the block's default mask. For example, the numbers 1.1.0.0/16 imply "all addresses that begin with 1.1." The /16 mask means that all addresses in the CIDR block have the same value in their first 16 bits.

To summarize using Figure 13-10, instead of using Class A, B, or C rules to create an 8-, 16-, or 24-bit network field, begin with a CIDR field based on the prefix length of the CIDR field (16 bits in the previous example).

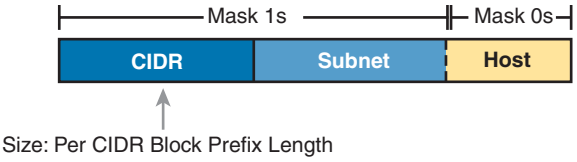


Figure 13-10 *CIDR and Subnet Masks Divide Addresses into Three Parts*

Just as with the classful view of the address structure, when subnetting the CIDR block, the width of the CIDR field remains the same. When you choose a mask, the more binary 1s, the more subnet bits and subnets in the design. The more host bits in the mask, the more hosts/subnet.

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 13-10 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 13-10 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Review memory tables		Website
Practice analyzing subnet masks		Website, Appendix E
Watch video		Website

Review All the Key Topics

Key Topic

Table 13-11 Key Topics for Chapter 13

Key Topic Element	Description	Page Number
List	Rules for binary subnet mask values	340
List	Rules to convert between binary and prefix masks	341
Table 13-4	Nine possible values in a decimal subnet mask	342
List	Rules to convert between binary and DDN masks	343
List	Some functions of a subnet mask	346
List	Comparisons of IP addresses in the same subnet	347
Figure 13-4	Two-part classless view of an IP address	347
Figure 13-6	Three-part classful view of an IP address	348
List	Definitions of classful addressing and classless addressing	348
List	Formal steps to analyze masks and calculate values	349

Key Terms You Should Know

binary mask, CIDR mask, classful addressing, classless addressing, decimal mask, dotted-decimal notation (DDN), prefix mask

Additional Practice for This Chapter's Processes

You can do more practice with the processes in this chapter with a pair of practice sets. One focuses on interpreting existing masks, while the other gives you practice with converting between mask formats. You may do each practice set using the following tools:

Application: From the companion website, in the section titled "Memory Tables and Practice Exercises," use the "Analyzing Subnet Masks" and "Converting Masks" applications, listed under the Chapter Review for this chapter.

PDF: Practice the same problems found in both these apps using companion website Appendix E, "Practice for Chapter 13: Analyzing Subnet Masks."

Answers to Earlier Practice Problems

Table 13-8, shown earlier, listed several practice problems for converting subnet masks; Table 13-12 lists the answers.

Table 13-12 Answers to Problems in Table 13-8

Prefix	Binary Mask	Decimal
/18	11111111 11111111 11000000 00000000	255.255.192.0
/30	11111111 11111111 11111111 11111100	255.255.255.252
/25	11111111 11111111 11111111 10000000	255.255.255.128
/16	11111111 11111111 00000000 00000000	255.255.0.0
/8	11111111 00000000 00000000 00000000	255.0.0.0
/22	11111111 11111111 11111100 00000000	255.255.252.0
/15	11111111 11111110 00000000 00000000	255.254.0.0
/27	11111111 11111111 11111111 11100000	255.255.255.224

Table 13-13 lists the answers to the practice problems from the earlier section "Practice Analyzing Subnet Masks."

Table 13-13 Answers to Problems from Earlier in the Chapter

	Problem	/P	Class	N	S	H	2^S	$2^H - 2$
1	8.1.4.5 255.255.254.0	23	A	8	15	9	32,768	510
2	130.4.102.1 255.255.255.0	24	B	16	8	8	256	254
3	199.1.1.100 255.255.255.0	24	C	24	0	8	N/A	254
4	130.4.102.1 255.255.252.0	22	B	16	6	10	64	1022
5	199.1.1.100 255.255.255.224	27	C	24	3	5	8	30

The following list reviews the problems:

1. For 8.1.4.5, the first octet (8) is in the 1–126 range, so it is a Class A address, with 8 network bits. Mask 255.255.254.0 converts to /23, so P – N = 15, for 15 subnet bits. H can be found by subtracting /P (23) from 32, for 9 host bits.
2. The address 130.4.102.1 is in the 128–191 range in the first octet, making it a Class B address, with N = 16 bits. The 255.255.255.0 converts to /24, so the number of subnet bits is 24 – 16 = 8. With 24 prefix bits, the number of host bits is 32 – 24 = 8.
3. The third problem purposely shows a case where the mask does not create a subnet part of the address. The address, 199.1.1.100, has a first octet between 192 and 223, making it a Class C address with 24 network bits. The prefix version of the mask is /24, so the number of subnet bits is 24 – 24 = 0. The number of host bits is 32 minus the prefix length (24), for a total of 8 host bits. So in this case, the mask shows that the network engineer is using the default mask, which creates no subnet bits and no subnets.
4. With the same address as the second problem, 130.4.102.1 is a Class B address with N = 16 bits. This problem uses a different mask, 255.255.252.0, which converts to /22. This makes the number of subnet bits 22 – 16 = 6. With 22 prefix bits, the number of host bits is 32 – 22 = 10.
5. With the same address as the third problem, 199.1.1.100 is a Class C address with N = 24 bits. This problem uses a different mask, 255.255.255.224, which converts to /27. This makes the number of subnet bits 27 – 24 = 3. With 27 prefix bits, the number of host bits is 32 – 27 = 5.

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CHAPTER 14

Analyzing Existing Subnets

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.6 Configure and verify IPv4 addressing and subnetting

Often, a networking task begins with the discovery of the IP address and mask used by some host. Then, to understand how the internetwork routes packets to that host, you must find key pieces of information about the subnet, specifically the following:

- Subnet ID
- Subnet broadcast address
- Subnet's range of usable unicast IP addresses

This chapter discusses the concepts and math to take a known IP address and mask, and then fully describe a subnet by finding the values in this list. These specific tasks might well be the most important IP skills in the entire IP addressing and subnetting topics in this book because they might be the most commonly used tasks when operating and troubleshooting real networks. Also note that as with the other chapters, this chapter shows examples that subnet a Class A, B, or C network, rather than a CIDR block.

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 14-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Defining a Subnet	1
Analyzing Existing Subnets: Binary	2
Analyzing Existing Subnets: Decimal	3–6

1. When you think about an IP address using classful addressing rules, an address can have three parts: network, subnet, and host. If you examined all the addresses in one subnet, in binary, which of the following answers correctly states which of the three parts of the addresses will be equal among all addresses? (Choose the best answer.)
   - **a.** Network part only
   - **b.** Subnet part only
   - **c.** Host part only
   - **d.** Network and subnet parts
   - **e.** Subnet and host parts
2. Which of the following statements are true regarding the binary subnet ID, subnet broadcast address, and host IP address values in any single subnet? (Choose two answers.)
   - **a.** The host part of the broadcast address is all binary 0s.
   - **b.** The host part of the subnet ID is all binary 0s.
   - **c.** The host part of a usable IP address can have all binary 1s.
   - **d.** The host part of any usable IP address must not be all binary 0s.
3. Which of the following is the resident subnet ID for IP address 10.7.99.133/24?
   - **a.** 10.0.0.0
   - **b.** 10.7.0.0
   - **c.** 10.7.99.0
   - **d.** 10.7.99.128
4. Which of the following is the resident subnet for IP address 192.168.44.97/30?
   - **a.** 192.168.44.0
   - **b.** 192.168.44.64
   - **c.** 192.168.44.96
   - **d.** 192.168.44.128
5. Which of the following is the subnet broadcast address for the subnet in which IP address 172.31.77.201/27 resides?
   - **a.** 172.31.201.255
   - **b.** 172.31.255.255
   - **c.** 172.31.77.223
   - **d.** 172.31.77.207
6. A fellow engineer tells you to configure the DHCP server to lease the last 100 usable IP addresses in subnet 10.1.4.0/23. Which of the following IP addresses could be leased as a result of your new configuration?
   - **a.** 10.1.4.156
   - **b.** 10.1.4.254
   - **c.** 10.1.5.200
   - **d.** 10.1.7.200
   - **e.** 10.1.255.200

Foundation Topics

Defining a Subnet

An IP subnet is a subset of a classful network, created by choice of some network engineer. However, that engineer cannot pick just any arbitrary subset of addresses; instead, the engineer must follow certain rules, such as the following:

Key Topic

- The subnet contains a set of consecutive numbers.
- The subnet holds 2^H numbers, where H is the number of host bits defined by the subnet mask.
- Two special numbers in the range cannot be used as IP addresses:
  - The first (lowest) number acts as an identifier for the subnet (subnet ID).
  - The last (highest) number acts as a *subnet broadcast address*.
- The remaining addresses, whose values sit between the subnet ID and subnet broadcast address, are used as *unicast IP addresses*.

This section reviews and expands the basic concepts of the subnet ID, subnet broadcast address, and range of addresses in a subnet.

An Example with Network 172.16.0.0 and Four Subnets

Imagine that you work at the customer support center, where you receive all initial calls from users who have problems with their computer. You coach the user through finding her IP address and mask: 172.16.150.41, mask 255.255.192.0. One of the first and most common tasks you will do based on that information is to find the subnet ID of the subnet in which that address resides. (In fact, this subnet ID is sometimes called the **resident subnet** because the IP address exists in or resides in that subnet.)

Before getting into the math, examine the mask (255.255.192.0) and classful network (172.16.0.0) for a moment. From the mask, based on what you learned in Chapter 13, "Analyzing Subnet Masks," you can find the structure of the addresses in the subnet, including the number of host and subnet bits. That analysis tells you that two subnet bits exist, meaning that there should be four (2^2) subnets. Figure 14-1 shows the idea.

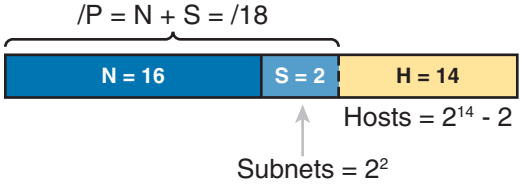


Figure 14-1 *Address Structure: Class B Network, /18 Mask*

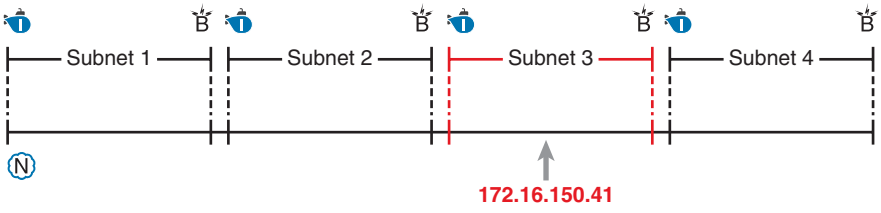
Answers to the "Do I Know This Already?" quiz:

1 D **2** B, D **3** C **4** C **5** C **6** C

NOTE This chapter, like the others in this part of the book, assumes that one mask is used throughout an entire classful network.

Because each subnet uses a single mask, all subnets of this single IP network must be the same size, because all subnets have the same structure. In this example, all four subnets will have the structure shown in the figure, so all four subnets will have $2^{14} - 2$ host addresses.

Next, consider the big picture of what happens with this example subnet design: the one Class B network now has four subnets of equal size. Conceptually, if you represent the entire Class B network as a number line, each subnet consumes one-fourth of the number line, as shown in Figure 14-2. Each subnet has a subnet ID—the numerically lowest number in the subnet—so it sits on the left of the subnet. And each subnet has a **subnet broadcast address**—the numerically highest number in the subnet—so it sits on the right side of the subnet.



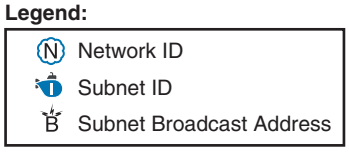
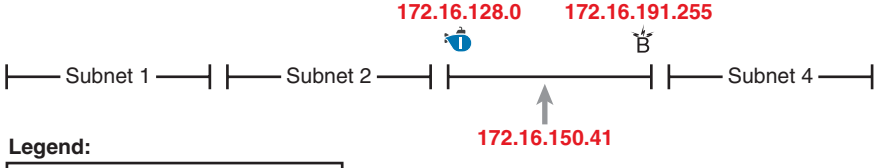


Figure 14-2 *Network 172.16.0.0, Divided into Four Equal Subnets*

The rest of this chapter focuses on how to take one IP address and mask and discover the details about that one subnet in which the address resides. In other words, you see how to find the resident subnet of an IP address. Again, using IP address 172.16.150.41 and mask 255.255.192.0 as an example, Figure 14-3 shows the resident subnet, along with the subnet ID and subnet broadcast address that bracket the subnet.



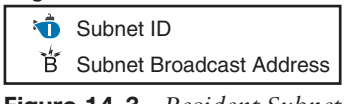


Figure 14-3 *Resident Subnet for 172.16.150.41, 255.255.192.0*

Subnet ID Concepts

A subnet ID is simply a number used to succinctly represent a subnet. When listed along with its matching subnet mask, the subnet ID identifies the subnet and can be used to derive the subnet broadcast address and range of addresses in the subnet. Rather than having to write down all these details about a subnet, you simply need to write down the subnet ID and mask, and you have enough information to fully describe the subnet.

The subnet ID appears in many places, but it is seen most often in IP routing tables. For example, when an engineer configures a router with its IP address and mask, the router calculates the subnet ID and puts a route into its routing table for that subnet. The router typically then advertises the subnet ID/mask combination to neighboring routers with some IP routing protocol. Eventually, all the routers in an enterprise learn about the subnet—again using the subnet ID and subnet mask combination—and display it in their routing tables. (You can display the contents of a router's IP routing table using the **show ip route** command.)

Unfortunately, the terminology related to subnets can sometimes cause problems. First, the terms **subnet ID**, **subnet number**, and **subnet address** are synonyms. In addition, people sometimes simply say *subnet* when referring to both the idea of a subnet and the number that is used as the subnet ID. When talking about routing, people sometimes use the term *prefix* instead of *subnet*. The term *prefix* refers to the same idea as *subnet*; it just uses terminology from the classless addressing way to describe IP addresses, as discussed in Chapter 13's section "Classless and Classful Addressing."

The biggest terminology confusion arises between the terms *network* and *subnet*. In the real world, people often use these terms synonymously, and that is perfectly reasonable in some cases. In other cases, the specific meaning of these terms, and their differences, matter to what is being discussed.

For example, people often might say, "What is the network ID?" when they really want to know the subnet ID. In another case, they might want to know the Class A, B, or C network ID. So, when one engineer asks something like, "What's the net ID for 172.16.150.41 slash 18?" use the context to figure out whether he wants the literal classful network ID (172.16.0.0, in this case) or the literal subnet ID (172.16.128.0, in this case).

For the exams, be ready to notice when the terms *subnet* and *network* are used, and then use the context to figure out the specific meaning of the term in that case.

Table 14-2 summarizes the key facts about the subnet ID, along with the possible synonyms, for easier review and study.

Key Topic

Table 14-2 Summary of Subnet ID Key Facts

Definition	Number that represents the subnet
Numeric Value	First (smallest) number in the subnet
Literal Synonyms	Subnet number, subnet address, prefix, resident subnet
Common-Use Synonyms	Network, network ID, network number, network address
Typically Seen In…	Routing tables, documentation

Subnet Broadcast Address

The subnet broadcast address has two main roles: to be used as a destination IP address for the purpose of sending packets to all hosts in the subnet, and as a means to find the high end of the range of addresses in a subnet.

The original purpose for the subnet broadcast address was to give hosts a way to send one packet to all hosts in a subnet and to do so efficiently. For example, a host in subnet A could send a packet with a destination address of subnet B's subnet broadcast address. The routers would forward this one packet just like a unicast IP packet sent to a host in subnet B. After the packet arrives at the router connected to subnet B, that last router would then forward the packet to all hosts in subnet B, typically by encapsulating the packet in a data-link layer broadcast frame. As a result, all hosts in host B's subnet would receive a copy of the packet.

The subnet broadcast address also helps you find the range of addresses in a subnet because the subnet broadcast address is the last (highest) number in a subnet's range of addresses. To find the low end of the range, calculate the subnet ID; to find the high end of the range, calculate the subnet broadcast address.

Table 14-3 summarizes the key facts about the subnet broadcast address, along with the possible synonyms, for easier review and study.

Key Topic

Table 14-3 Summary of Subnet Broadcast Address Key Facts

Definition	A reserved number in each subnet that, when used as the destination address of a packet, causes the device to forward the packet to all hosts in that subnet
Numeric Value	Last (highest) number in the subnet
Literal Synonyms	Directed broadcast address
Broader-Use Synonyms	Network broadcast
Typically Seen In…	Calculations of the range of addresses in a subnet

Range of Usable Addresses

The engineers implementing an IP internetwork need to know the range of unicast IP addresses in each subnet. Before you can plan which addresses to use as statically assigned IP addresses, which to configure to be leased by the DHCP server, and which to reserve for later use, you need to know the range of usable addresses.

To find the range of usable IP addresses in a subnet, first find the subnet ID and the subnet broadcast address. Then, just add 1 to the fourth octet of the subnet ID to get the first (lowest) usable address, and subtract 1 from the fourth octet of the subnet broadcast address to get the last (highest) usable address in the subnet.

For example, Figure 14-3 showed subnet ID 172.16.128.0, mask /18. The first usable address is simply one more than the subnet ID (in this case, 172.16.128.1). That same figure showed a subnet broadcast address of 172.16.191.255, so the last usable address is one less, or 172.16.191.254.

Now that this section has described the concepts behind the numbers that collectively define a subnet, the rest of this chapter focuses on the math used to find these values.

Analyzing Existing Subnets: Binary

What does it mean to "analyze a subnet"? For this book, it means that you should be able to start with an IP address and mask and then define key facts about the subnet in which that address resides. Specifically, that means discovering the subnet ID, subnet broadcast address, and range of addresses. The analysis can also include the calculation of the number of addresses in the subnet as discussed in Chapter 13, but this chapter does not review those concepts.

Many methods exist to calculate the details about a subnet based on the address/mask. This section begins by discussing some calculations that use binary math, with the next section showing alternatives that use only decimal math. Although many people prefer the decimal method for going fast on the exams, the binary calculations ultimately give you a better understanding of IPv4 addressing. In particular, if you plan to move on to attain Cisco certifications beyond CCNA, you should take the time to understand the binary methods discussed in this section, even if you use the decimal methods for the exams.

Finding the Subnet ID: Binary

The two following statements summarize the logic behind the binary value of any subnet ID:

> All numbers in the subnet (subnet ID, subnet broadcast address, and all usable IP addresses) have the same value in the prefix part of the numbers.
>
> The subnet ID is the lowest numeric value in the subnet, so its host part, in binary, is all 0s.

To find the subnet ID in binary, you take the IP address in binary and change all host bits to binary 0. To do so, you need to convert the IP address to binary. You also need to identify the prefix and host bits, which can be easily done by converting the mask (as needed) to prefix format. Figure 14-4 shows the idea, using the same address/mask as in the earlier examples in this chapter: 172.16.150.41, mask /18.

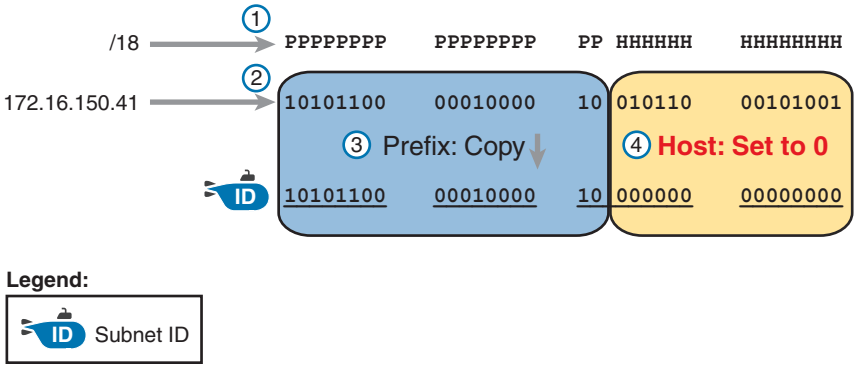


Figure 14-4 *Binary Concept: Convert the IP Address to the Subnet ID*

Starting at the top of Figure 14-4, the format of the IP address is represented with 18 prefix (P) and 14 host (H) bits in the mask (Step 1). The second row (Step 2) shows the binary version of the IP address, converted from the dotted-decimal notation (DDN) value 172.16.150.41.

The next two steps show the action to copy the IP address's prefix bits (Step 3) and give the host bits a value of binary 0 (Step 4). This resulting number is the subnet ID (in binary).

The last step, not shown in Figure 14-4, is to convert the subnet ID from binary to decimal. This book shows that conversion as a separate step, in Figure 14-5, mainly because many people make a mistake at this step in the process. When converting a 32-bit number (like an IP address or IP subnet ID) back to an IPv4 DDN, you must follow this rule:

> Convert 8 bits at a time from binary to decimal, regardless of the line between the prefix and host parts of the number.

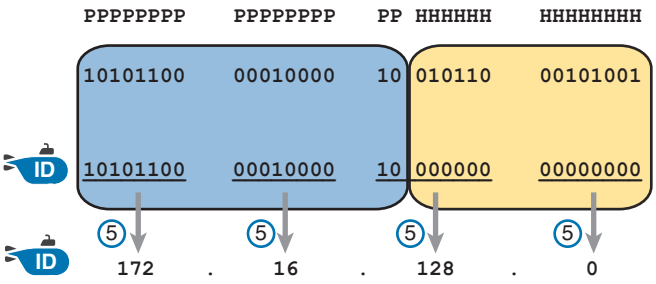


Figure 14-5 *Converting the Subnet ID from Binary to DDN*

Figure 14-5 shows this final step. Note that the third octet (the third set of 8 bits) has 2 bits in the prefix and 6 bits in the host part of the number, but the conversion occurs for all 8 bits.

NOTE You can do the numeric conversions in Figures 14-4 and 14-5 by relying on the conversion table in Appendix A, "Numeric Reference Tables." To convert from DDN to binary, for each octet, find the decimal value in the table and then write down the 8-bit binary equivalent. To convert from binary back to DDN, for each octet of 8 bits, find the matching binary entry in the table and write down the corresponding decimal value. For example, 172 converts to binary 10101100, and 00010000 converts to decimal 16.

Finding the Subnet Broadcast Address: Binary

Finding the subnet broadcast address uses a similar process. To find the subnet broadcast address, use the same binary process used to find the subnet ID, but instead of setting all the host bits to the lowest value (all binary 0s), set the host part to the highest value (all binary 1s). Figure 14-6 shows the concept.

The process in Figure 14-6 demonstrates the same first three steps shown in Figure 14-4. Specifically, it shows the identification of the prefix and host bits (Step 1), the results of converting the IP address 172.16.150.41 to binary (Step 2), and the copying of the prefix bits (first 18 bits, in this case) at Step 3. The difference occurs in the host bits on the right at Step 4, changing all host bits (the last 14, in this case) to the largest possible value (all binary 1s). Step 5 then converts the 32-bit subnet broadcast address to DDN format. Also, remember that with any conversion from DDN to binary or vice versa, the process always converts using 8 bits at a time. In particular, in this case, the entire third octet of binary 10111111 is converted to decimal 191.

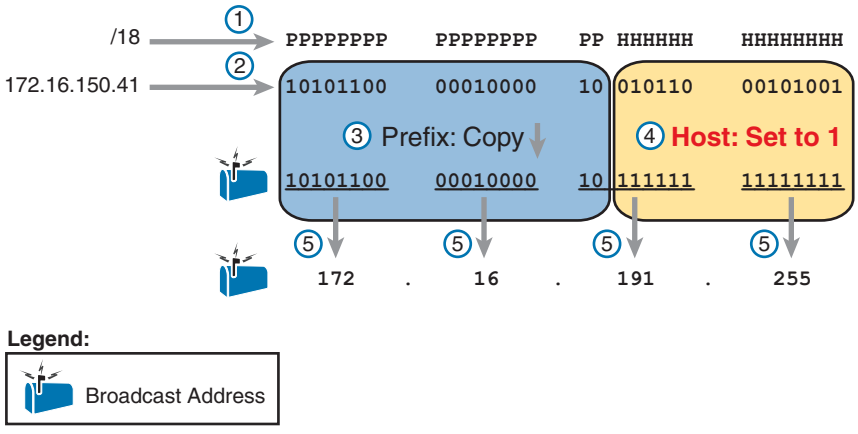


Figure 14-6 *Finding a Subnet Broadcast Address: Binary*

Binary Practice Problems

Figures 14-4 and 14-5 demonstrate a process to find the subnet ID using binary math. The following process summarizes those steps in written form for easier reference and practice:

Key Topic

Step 1. Convert the mask to prefix format to find the length of the prefix (/P) and the length of the host part (32 – P).

Step 2. Convert the IP address to its 32-bit binary equivalent.

Step 3. Copy the prefix bits of the IP address.

Step 4. Write down 0s for the host bits.

Step 5. Convert the resulting 32-bit number, 8 bits at a time, back to decimal.

The process to find the subnet broadcast address is exactly the same, except in Step 4, you set the bits to 1s, as shown in Figure 14-6.

Take a few moments and run through the following five practice problems on scratch paper. In each case, find both the subnet ID and subnet broadcast address. Also, record the prefix style mask:

1. 8.1.4.5, 255.255.0.0
2. 130.4.102.1, 255.255.255.0
3. 199.1.1.100, 255.255.255.0
4. 130.4.102.1, 255.255.252.0
5. 199.1.1.100, 255.255.255.224

Tables 14-4 through 14-8 show the results for the five different examples. The tables show the host bits in bold, and they include the binary version of the address and mask and the binary version of the subnet ID and subnet broadcast address.

Table 14-4 Subnet Analysis for Subnet with Address 8.1.4.5, Mask 255.255.0.0

Prefix Length	/16	11111111 11111111 **00000000 00000000**
Address	8.1.4.5	00001000 00000001 **00000100 00000101**
Subnet ID	8.1.0.0	00001000 00000001 **00000000 00000000**
Broadcast Address	8.1.255.255	00001000 00000001 **11111111 11111111**

Table 14-5 Subnet Analysis for Subnet with Address 130.4.102.1, Mask 255.255.255.0

Prefix Length	/24	11111111 11111111 11111111 **00000000**
Address	130.4.102.1	10000010 00000100 01100110 **00000001**
Subnet ID	130.4.102.0	10000010 00000100 01100110 **00000000**
Broadcast Address	130.4.102.255	10000010 00000100 01100110 **11111111**

Table 14-6 Subnet Analysis for Subnet with Address 199.1.1.100, Mask 255.255.255.0

Prefix Length	/24	11111111 11111111 11111111 **00000000**
Address	199.1.1.100	11000111 00000001 00000001 **01100100**
Subnet ID	199.1.1.0	11000111 00000001 00000001 **00000000**
Broadcast Address	199.1.1.255	11000111 00000001 00000001 **11111111**

Table 14-7 Subnet Analysis for Subnet with Address 130.4.102.1, Mask 255.255.252.0

Prefix Length	/22	11111111 11111111 111111**00 00000000**
Address	130.4.102.1	10000010 00000100 011001**10 00000001**
Subnet ID	130.4.100.0	10000010 00000100 011001**00 00000000**
Broadcast Address	130.4.103.255	10000010 00000100 011001**11 11111111**

Table 14-8 Subnet Analysis for Subnet with Address 199.1.1.100, Mask 255.255.255.224

Prefix Length	/27	11111111 11111111 11111111 111**00000**
Address	199.1.1.100	11000111 00000001 00000001 011**00100**
Subnet ID	199.1.1.96	11000111 00000001 00000001 011**00000**
Broadcast Address	199.1.1.127	11000111 00000001 00000001 011**11111**

Shortcut for the Binary Process

The binary process described in this section so far requires that all four octets be converted to binary and then back to decimal. However, you can easily predict the results in at least three of the four octets, based on the DDN mask. You can then avoid the binary math in all but one octet and reduce the number of binary conversions you need to do.

First, consider an octet, and that octet only, whose DDN mask value is 255. The mask value of 255 converts to binary 11111111, which means that all 8 bits are prefix bits. Thinking through the steps in the process, at Step 2, you convert the address to some number. At Step 3, you copy the number. At Step 4, you convert the same 8-bit number back to decimal. All you did in those three steps, in this one octet, is convert from decimal to binary and convert the same number back to the same decimal value!

In short, for any mask octet of value 255, the subnet ID and subnet broadcast address octet equal the IP address's value in that same octet.

For example, the resident subnet ID for 172.16.150.41, mask 255.255.192.0 is 172.16.128.0. The first two mask octets are 255. Rather than think about the binary math, you could just start by copying the address's value in those two octets: 172.16.

Another shortcut exists for octets whose DDN mask value is decimal 0, or binary 00000000. With a decimal mask value of 0, the math always results in a decimal 0 for the subnet ID, no matter the beginning value in the IP address. Specifically, just look at Steps 4 and 5 in this case: At Step 4, you would write down 8 binary 0s, and at Step 5, you would convert 00000000 back to decimal 0.

The following revised process steps take these two shortcuts into account. However, when the mask is neither 0 nor 255, the process requires the same conversions. At most, you have to do only one octet of the conversions. To find the subnet ID, apply the logic in these steps for each of the four octets:

Key Topic

Step 1. If the mask = 255, copy the decimal IP address for that octet.

Step 2. If the mask = 0, write down a decimal 0 for that octet.

Step 3. If the mask is neither 0 nor 255 in this octet, use the same binary logic as shown in the section "Finding the Subnet ID: Binary," earlier in this chapter.

Figure 14-7 shows an example of this process, again using 172.16.150.41, 255.255.192.0.

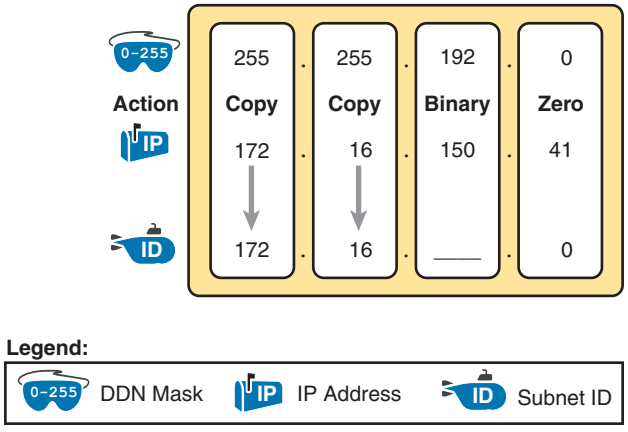


Figure 14-7 *Binary Shortcut Example*

To find the subnet broadcast address, you can use a decimal shortcut similar to the one used to find the subnet ID: for DDN mask octets equal to decimal 0, set the decimal subnet broadcast address value to 255 instead of 0, as noted in the following list:

Key Topic

Step 1. If the mask = 255, copy the decimal IP address for that octet.

Step 2. If the mask = 0, write down a decimal 255 for that octet.

Step 3. If the mask is neither 0 nor 255 in this octet, use the same binary logic as shown in the section "Finding the Subnet Broadcast Address: Binary," earlier in this chapter.

A Brief Note About Boolean Math

So far, this chapter has described how humans can use binary math to find the subnet ID and subnet broadcast address. However, computers typically use an entirely different binary process to find the same values, using a branch of mathematics called *Boolean algebra*. Computers already store the IP address and mask in binary form, so they do not have to do any conversions to and from decimal. Then, certain Boolean operations allow the computers to calculate the subnet ID and subnet broadcast address with just a few CPU instructions.

You do not need to know Boolean math to have a good understanding of IP subnetting. However, in case you are interested, computers use the following Boolean logic to find the subnet ID and subnet broadcast address, respectively:

Perform a *Boolean AND* of the IP address and mask. This process converts all host bits to binary 0s.

Invert the mask and then perform a *Boolean OR* of the IP address and inverted subnet mask. This process converts all host bits to binary 1s.

Finding the Range of Addresses

Finding the range of usable addresses in a subnet, after you know the subnet ID and subnet broadcast address, requires only simple addition and subtraction. To find the first (lowest) usable IP address in the subnet, simply add 1 to the fourth octet of the subnet ID. To find the last (highest) usable IP address, simply subtract 1 from the fourth octet of the subnet broadcast address.

Analyzing Existing Subnets: Decimal

Analyzing existing subnets using the binary process works well. However, some of the math takes time for most people, particularly the decimal-binary conversions. And you need to do the math quickly for the Cisco CCNA exam. For the exam, you really should be able to take an IP address and mask, and calculate the subnet ID and range of usable addresses within about 15 seconds. When using binary methods, most people require a lot of practice to be able to find these answers, even when using the abbreviated binary process.

This section discusses how to find the subnet ID and subnet broadcast address using only decimal math. Most people can find the answers more quickly using this process, at least after a little practice, as compared with the binary process. However, the decimal process does not tell you anything about the meaning behind the math. So, if you have not read the earlier section "Analyzing Existing Subnets: Binary," it is worthwhile to read it for the sake of understanding subnetting. This section focuses on getting the right answer using a method that, after you have practiced, should be faster.

Analysis with Easy Masks

With three easy subnet masks in particular, finding the subnet ID and subnet broadcast address requires only easy logic and literally no math. Three easy masks exist:

255.0.0.0

255.255.0.0

255.255.255.0

These easy masks have only 255 and 0 in decimal. In comparison, difficult masks have one octet that has neither a 255 nor a 0 in the mask, which makes the logic more challenging.

NOTE The terms *easy mask* and *difficult mask* are created for use in this book to describe the masks and the level of difficulty when working with each.

When the problem uses an easy mask, you can quickly find the subnet ID based on the IP address and mask in DDN format. Just use the following process for each of the four octets to find the subnet ID:

Step 1. If the mask octet = 255, copy the decimal IP address.

Step 2. If the mask octet = 0, write a decimal 0.

A similar simple process exists to find the subnet broadcast address, as follows:

Step 1. If the mask octet = 255, copy the decimal IP address.

Step 2. If the mask octet = 0, write a decimal 255.

Before moving to the next section, take some time to fill in the blanks in Table 14-9. Check your answers against Table 14-15 in the section "Answers to Earlier Practice Problems," later in this chapter. Complete the table by listing the subnet ID and subnet broadcast address.

Table 14-9 Practice Problems: Find Subnet ID and Broadcast, Easy Masks

	IP Address	Mask	Subnet ID	Broadcast Address
1	10.77.55.3	255.255.255.0		
2	172.30.99.4	255.255.255.0		
3	192.168.6.54	255.255.255.0		
4	10.77.3.14	255.255.0.0		
5	172.22.55.77	255.255.0.0		
6	1.99.53.76	255.0.0.0		

Predictability in the Interesting Octet

Although three masks are easier to work with (255.0.0.0, 255.255.0.0, and 255.255.255.0), all other subnet masks make the decimal math a little more difficult, so we call these masks *difficult masks*. With difficult masks, one octet has a value of neither a 0 nor a 255. To bring attention to the one octet with the most difficult value, this book refers to that octet as the *interesting octet*.

If you take some time to think about different problems and focus on the interesting octet, you will begin to see a pattern. This section takes you through that examination so that you can learn how to predict the pattern, in decimal, and find the subnet ID.

First, the subnet ID value has a predictable decimal value because of the assumption that a single subnet mask is used for all subnets of a single classful network. The chapters in this part of the book assume that, for a given classful network, the design engineer chooses to use a single subnet mask for all subnets. (See the section "One Size Subnet Fits All—Or Not" in Chapter 11, "Perspectives on IPv4 Subnetting," for more details.)

To see that predictability, consider some planning information written down by a network engineer, as shown in Figure 14-8. The figure shows four different masks the engineer is considering using in an IPv4 network, along with Class B network 172.16.0.0. The figure shows the third-octet values for the subnet IDs that would be created when using masks 255.255.128.0, 255.255.192.0, 255.255.224.0, and 255.255.240.0, from top to bottom in the figure.

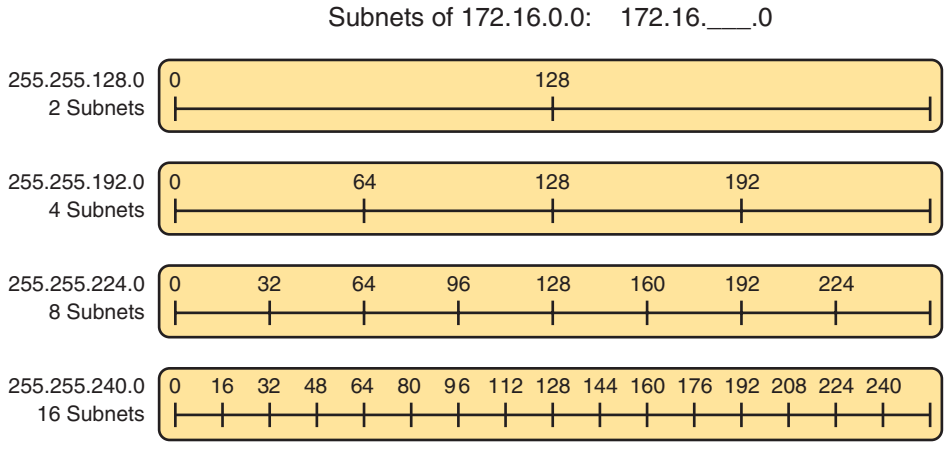


Figure 14-8 *Numeric Patterns in the Interesting Octet*

First, to explain the figure further, look at the top row of the figure. If the engineer uses 255.255.128.0 as the mask, the mask creates two subnets, with subnet IDs 172.16.0.0 and 172.16.128.0. If the engineer uses mask 255.255.192.0, the mask creates four subnets, with subnet IDs 172.16.0.0, 172.16.64.0, 172.16.128.0, and 172.16.192.0.

If you take the time to look at the figure, the patterns become obvious. In this case:

Mask: 255.255.128.0 Pattern: Multiples of 128
Mask: 255.255.192.0 Pattern: Multiples of 64
Mask: 255.255.224.0 Pattern: Multiples of 32
Mask: 255.255.240.0 Pattern: Multiples of 16

To find the subnet ID, you just need a way to figure out what the pattern is. If you start with an IP address and mask, just find the subnet ID closest to the IP address, without going over, as discussed in the next section.

Finding the Subnet ID: Difficult Masks

The following written process lists all the steps to find the subnet ID, using only decimal math. This process adds to the earlier process used with easy masks. For each octet:

Key Topic

Step 1. If the mask octet = 255, copy the decimal IP address.

Step 2. If the mask octet = 0, write a decimal 0.

Step 3. If the mask is neither, refer to this octet as the *interesting octet*:

a. Calculate the *magic number* as 256 – mask.

b. Set the subnet ID's value to the multiple of the magic number that is closest to the IP address without going over.

The process uses two new terms created for this book: *magic number* and *interesting octet*. The term *interesting octet* refers to the octet identified at Step 3 in the process; in other words, it is the octet with the mask that is neither 255 nor 0. Step 3A then uses the term *magic number*, which is derived from the DDN mask. Conceptually, the magic number is the number you add to one subnet ID to get the next subnet ID in order, as shown in Figure 14-8. Numerically, it can be found by subtracting the DDN mask's value, in the interesting octet, from 256, as mentioned in Step 3A.

The best way to learn this process is to see it happen. In fact, if you can, stop reading now, use the companion website for this book, and watch the videos about finding the subnet ID with a difficult mask. These videos demonstrate this process. You can also use the examples on the next few pages that show the process being used on paper. Then follow the practice opportunities outlined in the section "Practice Analyzing Existing Subnets," later in this chapter.

Resident Subnet Example 1

For example, consider the requirement to find the resident subnet for IP address 130.4.102.1, mask 255.255.240.0. The process does not require you to think about prefix bits versus host bits, convert the mask, think about the mask in binary, or convert the IP address to and from binary. Instead, for each of the four octets, choose an action based on the value in the mask. Figure 14-9 shows the results; the circled numbers in the figure refer to the step numbers in the written process to find the subnet ID, as listed in the previous few pages.

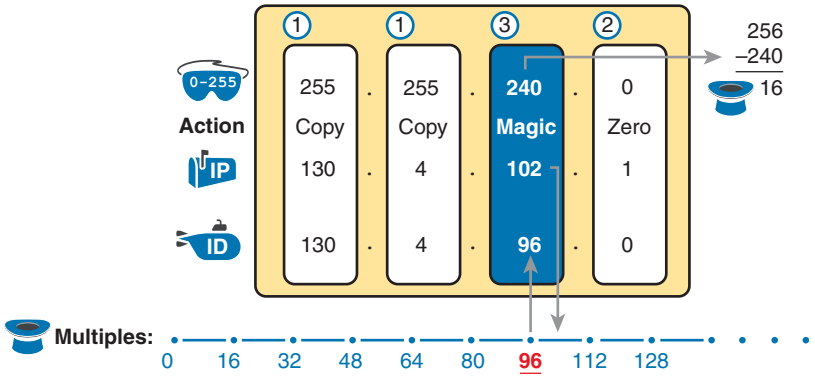


Figure 14-9 *Find the Subnet ID: 130.4.102.1, 255.255.240.0*

First, examine the three uninteresting octets (1, 2, and 4, in this example). The process keys on the mask, and the first two octets have a mask value of 255, so simply copy the IP address to the place where you intend to write down the subnet ID. The fourth octet has a mask value of 0, so write down a 0 for the fourth octet of the subnet ID.

The most challenging logic occurs in the interesting octet, which is the third octet in this example, because of the mask value 240 in that octet. For this octet, Step 3A asks you to calculate the magic number as 256 – mask. That means you take the mask's value in the interesting octet (240, in this case) and subtract it from 256: 256 – 240 = 16. The subnet ID's value in this octet must be a multiple of decimal 16, in this case.

Step 3B then asks you to find the multiples of the magic number (16, in this case) and choose the one closest to the IP address without going over. Specifically, that means that you should

mentally calculate the multiples of the magic number, starting at 0. (Do not forget to start at 0!) Count, starting at 0: 0, 16, 32, 48, 64, 80, 96, 112, and so on. Then, find the multiple closest to the IP address value in this octet (102, in this case), without going over 102. So, as shown in Figure 14-9, you make the third octet's value 96 to complete the subnet ID of 130.4.96.0.

Resident Subnet Example 2

Consider another example: 192.168.5.77, mask 255.255.255.224. Figure 14-10 shows the results.

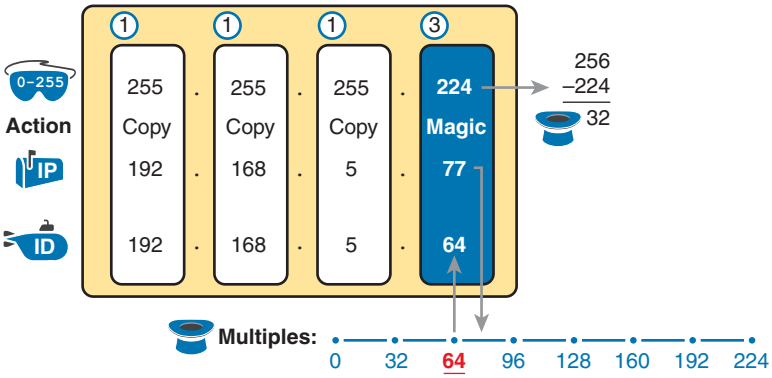


Figure 14-10 *Resident Subnet for 192.168.5.77, 255.255.255.224*

The three uninteresting octets (1, 2, and 3, in this case) require only a little thought. For each octet, each with a mask value of 255, just copy the IP address.

For the interesting octet, at Step 3A, the magic number is 256 – 224 = 32. The multiples of the magic number are 0, 32, 64, 96, and so on. Because the IP address value in the fourth octet is 77, in this case, the multiple must be the number closest to 77 without going over; therefore, the subnet ID ends with 64, for a value of 192.168.5.64.

Resident Subnet Practice Problems

Before moving to the next section, take some time to fill in the blanks in Table 14-10. Check your answers against Table 14-16 in the section "Answers to Earlier Practice Problems," later in this chapter. Complete the table by listing the subnet ID in each case. The text following Table 14-16 also lists explanations for each problem.

Table 14-10 Practice Problems: Find Subnet ID, Difficult Masks

Problem	IP Address	Mask	Subnet ID
1	10.77.55.3	255.248.0.0	
2	172.30.99.4	255.255.192.0	
3	192.168.6.54	255.255.255.252	
4	10.77.3.14	255.255.128.0	
5	172.22.55.77	255.255.254.0	
6	1.99.53.76	255.255.255.248	

Finding the Subnet Broadcast Address: Difficult Masks

To find a subnet's broadcast address, you can use a similar process. For simplicity, this process begins with the subnet ID, rather than the IP address. If you happen to start with an IP address instead, use the processes in this chapter to first find the subnet ID, and then use the following process to find the subnet broadcast address for that same subnet. For each octet:

Key Topic

Step 1. If the mask octet = 255, copy the subnet ID.

Step 2. If the mask octet = 0, write 255.

Step 3. If the mask is neither, identify this octet as the *interesting octet*:

a. Calculate the *magic number* as 256 – mask.

b. Take the subnet ID's value, add the magic number, and subtract 1 (ID + magic – 1).

Subnet Broadcast Example 1

The first example continues the first example from the section "Finding the Subnet ID: Difficult Masks," earlier in this chapter, as demonstrated in Figure 14-9. That example started with the IP address/mask of 130.4.102.1, 255.255.240.0, and showed how to find subnet ID 130.4.96.0. Figure 14-11 now begins with that subnet ID and the same mask.

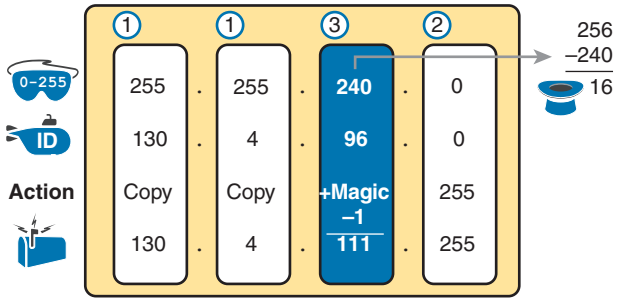


Figure 14-11 *Find the Subnet Broadcast: 130.4.96.0, 255.255.240.0*

First, examine the three uninteresting octets (1, 2, and 4). The process keys on the mask, and the first two octets have a mask value of 255, so simply copy the subnet ID to the place where you intend to write down the subnet broadcast address. The fourth octet has a mask value of 0, so write down a 255 for the fourth octet.

The logic related to the interesting octet occurs in the third octet in this example because of the mask value 240. First, Step 3A asks you to calculate the magic number, as 256 – mask. (If you had already calculated the subnet ID using the decimal process in this book, you should already know the magic number.) At Step 3B, you take the subnet ID's value (96), add the magic number (16), and subtract 1, for a total of 111. That makes the subnet broadcast address 130.4.111.255.

Subnet Broadcast Example 2

Again, this example continues an earlier example, from the section "Resident Subnet Example 2," as demonstrated in Figure 14-10. That example started with the IP address/mask of 192.168.5.77, mask 255.255.255.224 and showed how to find subnet ID 192.168.5.64. Figure 14-12 now begins with that subnet ID and the same mask.

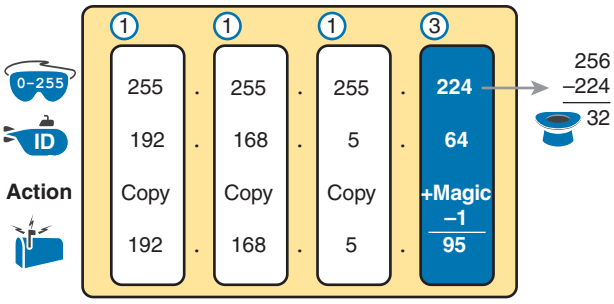


Figure 14-12 *Find the Subnet Broadcast: 192.168.5.64, 255.255.255.224*

First, examine the three uninteresting octets (1, 2, and 3). The process keys on the mask, and the first three octets have a mask value of 255, so simply copy the subnet ID to the place where you intend to write down the subnet broadcast address.

The interesting logic occurs in the interesting octet, the fourth octet in this example, because of the mask value 224. First, Step 3A asks you to calculate the magic number, as 256 – mask. (If you had already calculated the subnet ID, it is the same magic number because the same mask is used.) At Step 3B, you take the subnet ID's value (64), add magic (32), and subtract 1, for a total of 95. That makes the subnet broadcast address 192.168.5.95.

Subnet Broadcast Address Practice Problems

Before moving to the next section, take some time to do several practice problems on a scratch piece of paper. Go back to Table 14-10, which lists IP addresses and masks, and practice by finding the subnet broadcast address for all the problems in that table. Then check your answers against Table 14-17 in the section "Answers to Earlier Practice Problems," later in this chapter.

Practice Analyzing Existing Subnets

As with the other subnetting math in this book, using a two-phase approach may help. Take time now to practice until you feel like you understand the process. Then, before the exam, make sure you master the math. Table 14-11 summarizes the key concepts and suggestions for this two-phase approach.

Table 14-11 Keep-Reading and Take-Exam Goals for This Chapter's Topics

Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On…	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	20–30 seconds

A Choice: Memorize or Calculate

As described in this chapter, the decimal processes to find the subnet ID and subnet broadcast address do require some calculation, including the calculation of the magic number (256 – mask). The processes also use a DDN mask, so if an exam question gives you a prefix-style mask, you need to convert to DDN format before using the process in this book.

Over the years, some people have told me they prefer to memorize a table to find the magic number. These tables could list the magic number for different DDN masks and prefix masks, so you avoid converting from the prefix mask to DDN. Table 14-12 shows an example of such a table. Feel free to ignore this table, use it, or make your own.

Table 14-12 Reference Table: DDN Mask Values, Binary Equivalent, Magic Numbers, and Prefixes

Prefix, interesting octet 2	/9	/10	/11	/12	/13	/14	/15	/16
Prefix, interesting octet 3	/17	/18	/19	/20	/21	/22	/23	/24
Prefix, interesting octet 4	/25	/26	/27	/28	/29	/30		
Magic number	128	64	32	16	8	4	2	1
DDN mask in the interesting octet	128	192	224	240	248	252	254	255

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 14-13 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 14-13 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Review memory tables		Website
Practice mask analysis		Website, Appendix F
Practice analyzing existing subnets		Website, Appendix F
Watch video		Website

Review All the Key Topics

Key Topic

Table 14-14 Key Topics for Chapter 14

Key Topic Element	Description	Page Number
List	Definition of a subnet's key numbers	358
Table 14-2	Key facts about the subnet ID	360
Table 14-3	Key facts about the subnet broadcast address	361
List	Steps to use binary math to find the subnet ID	364
List	General steps to use binary and decimal math to find the subnet ID	366

Key Topic Element	Description	Page Number
List	Steps to use decimal and binary math to find the subnet broadcast address	366
List	Steps to use only decimal math to find the subnet ID	369
List	Steps to use only decimal math to find the subnet broadcast address	372

Key Terms You Should Know

resident subnet, subnet address, subnet broadcast address, subnet ID, subnet number

Additional Practice for This Chapter's Processes

You can do more practice with the processes in this chapter with a pair of practice sets. Both give you practice at analyzing existing subnets. You may do each practice set using the following tools:

Application: From the companion website, in the section titled "Memory Tables and Practice Exercises," use the "Analyzing Existing Subnets" exercises 1 and 2, listed under the Chapter Review for this chapter.

PDF: Practice the same problems found in these apps using companion website Appendix F, "Practice for Chapter 14: Analyzing Existing Subnets."

Answers to Earlier Practice Problems

This chapter includes practice problems spread around different locations in the chapter. The answers are located in Tables 14-15, 14-16, and 14-17.

Table 14-15 Answers to Problems in Table 14-9

	IP Address	Mask	Subnet ID	Broadcast Address
1	10.77.55.3	255.255.255.0	10.77.55.0	10.77.55.255
2	172.30.99.4	255.255.255.0	172.30.99.0	172.30.99.255
3	192.168.6.54	255.255.255.0	192.168.6.0	192.168.6.255
4	10.77.3.14	255.255.0.0	10.77.0.0	10.77.255.255
5	172.22.55.77	255.255.0.0	172.22.0.0	172.22.255.255
6	1.99.53.76	255.0.0.0	1.0.0.0	1.255.255.255

Table 14-16 Answers to Problems in Table 14-10

	IP Address	Mask	Subnet ID
1	10.77.55.3	255.248.0.0	10.72.0.0
2	172.30.99.4	255.255.192.0	172.30.64.0
3	192.168.6.54	255.255.255.252	192.168.6.52
4	10.77.3.14	255.255.128.0	10.77.0.0
5	172.22.55.77	255.255.254.0	172.22.54.0
6	1.99.53.76	255.255.255.248	1.99.53.72

The following list explains the answers for Table 14-16:

1. The second octet is the interesting octet, with magic number 256 – 248 = 8. The multiples of 8 include 0, 8, 16, 24, …, 64, 72, and 80. Here, 72 is closest to the IP address value in that same octet (77) without going over, making the subnet ID 10.72.0.0.
2. The third octet is the interesting octet, with magic number 256 – 192 = 64. The multiples of 64 include 0, 64, 128, and 192. Here, 64 is closest to the IP address value in that same octet (99) without going over, making the subnet ID 172.30.64.0.
3. The fourth octet is the interesting octet, with magic number 256 – 252 = 4. The multiples of 4 include 0, 4, 8, 12, 16, …, 48, 52, and 56. Here, 52 is the closest to the IP address value in that same octet (54) without going over, making the subnet ID 192.168.6.52.
4. The third octet is the interesting octet, with magic number 256 – 128 = 128. Only two multiples exist that matter: 0 and 128. Here, 0 is the closest to the IP address value in that same octet (3) without going over, making the subnet ID 10.77.0.0.
5. The third octet is the interesting octet, with magic number 256 – 254 = 2. The multiples of 2 include 0, 2, 4, 6, 8, and so on—essentially all even numbers. Here, 54 is closest to the IP address value in that same octet (55) without going over, making the subnet ID 172.22.54.0.
6. The fourth octet is the interesting octet, with magic number 256 – 248 = 8. The multiples of 8 include 0, 8, 16, 24, …, 64, 72, and 80. Here, 72 is closest to the IP address value in that same octet (76) without going over, making the subnet ID 1.99.53.72.

Table 14-17 Answers to Problems in the Section "Subnet Broadcast Address Practice Problems"

	Subnet ID	Mask	Broadcast Address
1	10.72.0.0	255.248.0.0	10.79.255.255
2	172.30.64.0	255.255.192.0	172.30.127.255
3	192.168.6.52	255.255.255.252	192.168.6.55
4	10.77.0.0	255.255.128.0	10.77.127.255
5	172.22.54.0	255.255.254.0	172.22.55.255
6	1.99.53.72	255.255.255.248	1.99.53.79

The following list explains the answers for Table 14-17:

1. The second octet is the interesting octet. Completing the three easy octets means that the broadcast address in the interesting octet will be 10.___.255.255. With magic number 256 – 248 = 8, the second octet will be 72 (from the subnet ID), plus 8, minus 1, or 79.
2. The third octet is the interesting octet. Completing the three easy octets means that the broadcast address in the interesting octet will be 172.30.___.255. With magic number 256 – 192 = 64, the interesting octet will be 64 (from the subnet ID), plus 64 (the magic number), minus 1, for 127.

3. The fourth octet is the interesting octet. Completing the three easy octets means that the broadcast address in the interesting octet will be 192.168.6.___. With magic number 256 – 252 = 4, the interesting octet will be 52 (the subnet ID value), plus 4 (the magic number), minus 1, or 55.
4. The third octet is the interesting octet. Completing the three easy octets means that the broadcast address will be 10.77.___.255. With magic number 256 – 128 = 128, the interesting octet will be 0 (the subnet ID value), plus 128 (the magic number), minus 1, or 127.
5. The third octet is the interesting octet. Completing the three easy octets means that the broadcast address will be 172.22.___.255. With magic number 256 – 254 = 2, the broadcast address in the interesting octet will be 54 (the subnet ID value), plus 2 (the magic number), minus 1, or 55.
6. The fourth octet is the interesting octet. Completing the three easy octets means that the broadcast address will be 1.99.53.___. With magic number 256 – 248 = 8, the broadcast address in the interesting octet will be 72 (the subnet ID value), plus 8 (the magic number), minus 1, or 79.

CHAPTER 15

Subnet Design

This chapter covers the following exam topics:

1.0 Network Fundamentals

1.6 Configure and verify IPv4 addressing and subnetting

So far in this book, most of the discussion about IPv4 used examples with the addresses and masks already given. This book has shown many examples already, but the examples so far do not ask you to pick the IP address or pick the mask. Instead, as discussed back in Chapter 11, "Perspectives on IPv4 Subnetting," this book so far has assumed that someone else designed the IP addressing and subnetting plan, and this book shows how to implement it.

This chapter turns that model around. It goes back to the progression of building and implementing IPv4, as discussed in Chapter 11, as shown in Figure 15-1. This chapter picks up the story right after some network engineer has chosen a Class A, B, or C network to use for the enterprise's IPv4 network. And then this chapter discusses the design choices related to picking one subnet mask to use for all subnets (the first major section) and what subnet IDs that choice creates (the second major section).

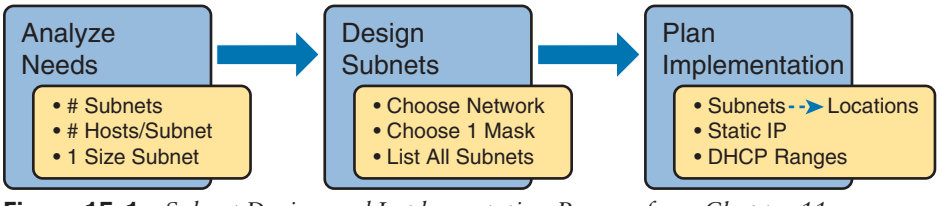


Figure 15-1 *Subnet Design and Implementation Process from Chapter 11*

"Do I Know This Already?" Quiz

Take the quiz (either here or use the PTP software) if you want to use the score to help you decide how much time to spend on this chapter. The letter answers are listed at the bottom of the page following the quiz. Appendix C, found both at the end of the book as well as on the companion website, includes both the answers and explanations. You can also find both answers and explanations in the PTP testing software.

Table 15-1 "Do I Know This Already?" Foundation Topics Section-to-Question Mapping

Foundation Topics Section	Questions
Choosing the Mask(s) to Meet Requirements	1–3
Finding All Subnet IDs	4–6

1. An IP subnetting design effort is under way at a company. So far, the senior engineer has decided to use private Class B network 172.23.0.0. The design calls for 100 subnets, with the largest subnet needing 500 hosts. Management requires that the design accommodate 50 percent growth in the number of subnets and the size of the largest subnet. The requirements also state that a single mask must be used throughout the Class B network. How many masks meet the requirements?
   a. 0
   b. 1
   c. 2
   d. 3+
2. An IP subnetting design requires 200 subnets and 120 hosts/subnet for the largest subnets, and requires that a single mask be used throughout the one private IP network that will be used. The design also requires planning for 20 percent growth in the number of subnets and number of hosts/subnet in the largest subnet. Which of the following answers lists a private IP network and mask that, if chosen, would meet the requirements?
   a. 10.0.0.0/25
   b. 10.0.0.0/22
   c. 172.16.0.0/23
   d. 192.168.7.0/24
3. An engineer has planned to use private Class B network 172.19.0.0 and a single subnet mask throughout the network. The answers list the masks considered by the engineer. Choose the mask that, among the answers, supplies the largest number of hosts per subnet, while also supplying enough subnet bits to support 1000 subnets.
   a. 255.255.255.0
   b. /26
   c. 255.255.252.0
   d. /28
4. An engineer has calculated the list of subnet IDs, in consecutive order, for network 172.30.0.0, assuming that the /22 mask is used throughout the network. Which of the following are true? (Choose two answers.)
   a. Any two consecutive subnet IDs differ by a value of 22 in the third octet.
   b. Any two consecutive subnet IDs differ by a value of 16 in the fourth octet.
   c. The list contains 64 subnet IDs.
   d. The last subnet ID is 172.30.252.0.
5. Which of the following are valid subnet IDs for private network 192.168.9.0, using mask /29, assuming that mask /29 is used throughout the network?
   a. 192.168.9.144
   b. 192.168.9.58
   c. 192.168.9.242
   d. 192.168.9.9

6. Which of the following is not a valid subnet ID for private network 172.19.0.0, using mask /24, assuming that mask /24 is used throughout the network?
   a. 172.19.0.0
   b. 172.19.1.0
   c. 172.19.255.0
   d. 172.19.0.16

Foundation Topics

Choosing the Mask(s) to Meet Requirements

This first major section examines how to find all the masks that meet the stated requirements for the number of subnets and the number of hosts per subnet. To that end, the text assumes that the designer has already determined these requirements and has chosen the network private number to be subnetted. The designer has also made the choice to use a single subnet mask value throughout the classful network.

Armed with the information in this chapter, you can answer questions such as the following, a question that matters both for real engineering jobs and the Cisco exams:

> You are using Class B network 172.16.0.0. You need 200 subnets and 200 hosts/subnet. Which of the following subnet mask(s) meet the requirements? (This question is then followed by several answers that list different subnet masks.)

To begin, this section reviews the concepts in Chapter 11's section "Choose the Mask." That section introduced the main concepts about how an engineer, when designing subnet conventions, must choose the mask based on the requirements.

After reviewing the related concepts from Chapter 11, this section examines this topic in more depth. In particular, this chapter looks at three general cases:

- No masks meet the requirements.
- One and only one mask meets the requirements.
- Multiple masks meet the requirements.

For this last case, the text discusses how to determine all masks that meet the requirements and the tradeoffs related to choosing which one mask to use.

Review: Choosing the Minimum Number of Subnet and Host Bits

The network designer must examine the requirements for the number of subnets and number of hosts/subnet, and then choose a mask. As discussed in detail in Chapter 13, "Analyzing Subnet Masks," a classful view of IP addresses defines the three-part structure of an IP address: network, subnet, and host. The network designer must choose the mask so that the number of subnet and host bits (S and H, respectively, in Figure 15-2) meet the requirements.

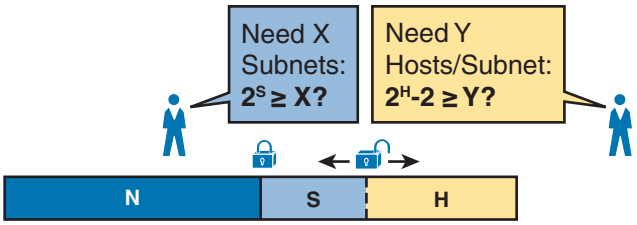


Figure 15-2 *Choosing the Number of Subnet and Host Bits*

Basically, the designer must choose S subnet bits so that the number of subnets that can be uniquely numbered with S bits (2^S) is at least as large as the required number of subnets. The designer applies similar logic to the number of host bits H, while noting that the formula is $2^H - 2$, because of the two reserved numbers in each subnet. So, keeping the powers of 2 handy, as shown in Table 15-2, will be useful when working through these problems.

Table 15-2 Powers of 2 Reference for Designing Masks

Number of Bits	2^X	Number of Bits	2^X	Number of Bits	2^X	Number of Bits	2^X
1	2	5	32	9	512	13	8192
2	4	6	64	10	1024	14	16,384
3	8	7	128	11	2048	15	32,768
4	16	8	256	12	4096	16	65,536

More formally, the process must determine the minimum values for both S and H that meet the requirements. The following list summarizes the initial steps to choose the mask:

Step 1. Determine the number of network bits (N) based on the class.

Step 2. Determine the smallest value of S, so that 2^S => X, where X represents the required number of subnets.

Step 3. Determine the smallest value of H, so that $2^H - 2$ => Y, where Y represents the required number of hosts/subnet.

The next three sections examine how to use these initial steps to choose a subnet mask.

No Masks Meet Requirements

After you determine the required number of subnet and host bits, those bits might not fit into a 32-bit IPv4 subnet mask. Remember, the mask always has a total of 32 bits, with binary 1s in the network and subnet parts and binary 0s in the host part. For the exam, a question might provide a set of requirements that simply cannot be met with 32 total bits.

For example, consider the following sample exam question:

> A network engineer is planning a subnet design. The engineer plans to use Class B network 172.16.0.0. The network has a need for 300 subnets and 280 hosts per subnet. Which of the following masks could the engineer choose?

The three-step process shown in the previous section shows that these requirements mean that a total of 34 bits will be needed, so no mask meets the requirements. First, as a Class B

network, 16 network bits exist, with 16 host bits from which to create the subnet part and to leave enough host bits to number the hosts in each subnet. For the number of subnet bits, S=8 does not work, because $2^8 = 256 < 300$. However, S=9 works, because $2^9 = 512 => 300$. Similarly, because $2^8 - 2 = 254$, which is less than 300, 8 host bits are not enough but 9 host bits ($2^9 - 2 = 510$) are just enough.

These requirements do not leave enough space to number all the hosts and subnet, because the network, subnet, and host parts add up to more than 32:

N=16, because as a Class B network, 16 network bits exist.

The minimum S=9, because S=8 provides too few subnets ($2^8 = 256 < 300$) but S=9 provides $2^9 = 512$ subnets.

The minimum H=9, because H=8 provides too few hosts ($2^8 - 2 = 254 < 280$) but H=9 provides $2^9 - 2 = 510$ hosts/subnet.

Figure 15-3 shows the resulting format for the IP addresses in this subnet, after the engineer has allocated 9 subnet bits on paper. Only 7 host bits remain, but the engineer needs 9 host bits.

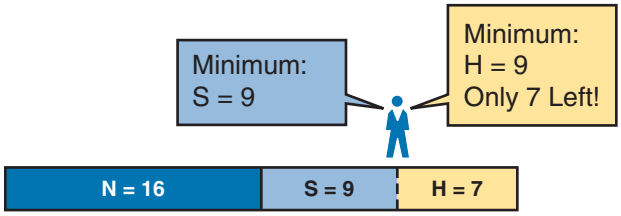


Figure 15-3 *Too Few Bits for the Host Part, Given the Requirements*

One Mask Meets Requirements

The process discussed in this chapter in part focuses on finding the smallest number of subnet bits and the smallest number of host bits to meet the requirements. If the engineer tries to use these minimum values, and the combined network, subnet, and host parts add up to exactly 32 bits, exactly one mask meets the requirements.

For example, consider a revised version of the example in the previous section, with smaller numbers of subnets and hosts, as follows:

A network engineer is planning a subnet design. The engineer plans to use Class B network 172.16.0.0. The network has a need for 200 subnets and 180 hosts per subnet. Which of the following masks could the engineer choose?

The three-step process to determine the numbers of network, minimum subnet, and minimum host bits results in a need for 16, 8, and 8 bits, respectively. As before, with a Class B network, 16 network bits exist. With a need for only 200 subnets, S=8 does work, because $2^8 = 256 => 200$; 7 subnet bits would not supply enough subnets ($2^7 = 128$). Similarly, because $2^8 - 2 = 254 => 180$, 8 host bits meet the requirements; 7 host bits (for 126 total hosts/subnet) would not be enough.

Figure 15-4 shows the resulting format for the IP addresses in this subnet.

Answers to the "Do I Know This Already?" quiz:

1 A **2** B **3** B **4** C, D **5** A **6** D

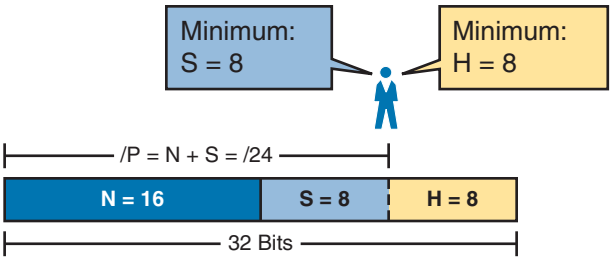


Figure 15-4 *One Mask That Meets the Requirements*

Figure 15-4 shows the mask conceptually. To find the actual mask value, simply record the mask in prefix format (/P), where P = N + S or, in this case, /24.

Multiple Masks Meet Requirements

Depending on the requirements and choice of network, several masks might meet the requirements for the numbers of subnets and hosts/subnet. In these cases, you need to find all the masks that could be used. Then, you have a choice, but what should you consider when choosing one mask among all those that meet your requirements? This section shows how to find all the masks, as well as the facts to consider when choosing one mask from the list.

Finding All the Masks: Concepts

To help you better understand how to find all the subnet masks in binary, this section uses two major steps. In the first major step, you build the 32-bit binary subnet mask on paper. You write down binary 1s for the network bits, binary 1s for the subnet bits, and binary 0s for the host bits, just as always. However, you will use the minimum values for S and H. And when you write down these bits, you will not have 32 bits yet!

For example, consider the following problem, similar to the earlier examples in this chapter but with some changes in the requirements:

> A network engineer is planning a subnet design. The engineer plans to use Class B network 172.16.0.0. The network has a need for 50 subnets and 180 hosts per subnet. Which of the following masks could the engineer choose?

This example is similar to an earlier example, except that only 50 subnets are needed in this case. Again, the engineer is using private IP network 172.16.0.0, meaning 16 network bits. The design requires only 6 subnet bits in this case, because $2^6 = 64 => 50$, and with only 5 subnet bits, $2^5 = 32 < 50$. The design then requires a minimum of 8 host bits.

One way to discuss the concepts and find all the masks that meet these requirements is to write down the bits in the subnet mask: binary 1s for the network and subnet parts and binary 0s for the host part. However, think of the 32-bit mask as 32-bit positions, and when writing the binary 0s, *write them on the far right*. Figure 15-5 shows the general idea.

Figure 15-5 shows 30 bits of the mask, but the mask must have 32 bits. The 2 remaining bits might become subnet bits, being set to binary 1. Alternatively, these 2 bits could be made host bits, being set to binary 0. The engineer simply needs to choose based on whether he would like more subnet bits, to number more subnets, or more host bits, to number more hosts/subnet.

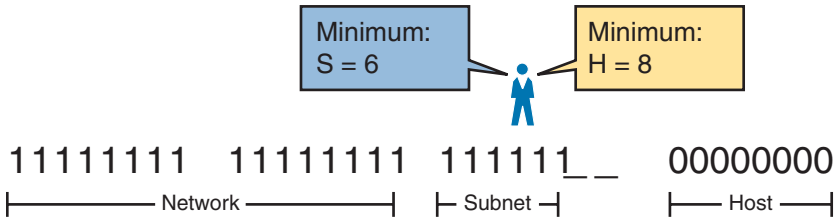


Figure 15-5 *Incomplete Mask with N=16, S=6, and H=8*

Regardless of the requirements, when choosing any IPv4 subnet mask, you must always follow this rule:

Key Topic

A subnet mask begins with all binary 1s, followed by all binary 0s, with no interleaving of 1s and 0s.

With the example shown in Figure 15-5, with 2 open bits, one value (binary 01) breaks this rule. However, the other three combinations of 2 bits (00, 10, and 11) do not break the rule. As a result, three masks meet the requirements in this example, as shown in Figure 15-6.

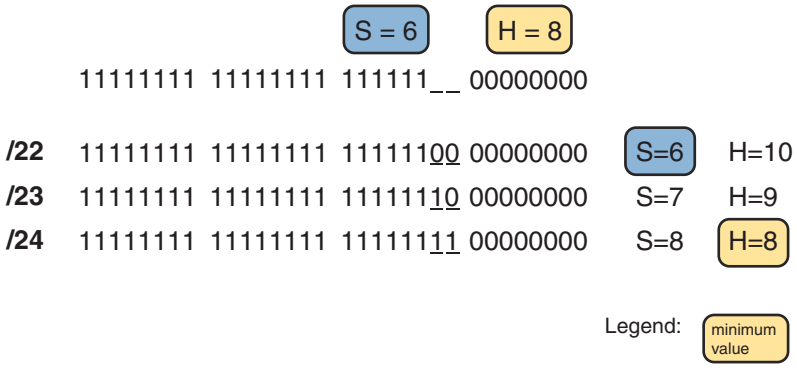


Figure 15-6 *Three Masks That Meet the Requirements*

In the three masks, the first has the least number of subnet bits among the three masks, but therefore has the most number of host bits. So, the first mask maximizes the number of hosts/subnet. The last mask uses the minimum value for the number of host bits, therefore using the most number of subnet bits allowed while still meeting the requirements. As a result, the last mask maximizes the number of subnets allowed.

Finding All the Masks: Math

Although the concepts related to the example shown in Figures 15-5 and 15-6 are important, you can find the range of masks that meets the requirements more easily just using some simple math. The process to find the masks requires only a few steps, after you know N and the minimum values of S and H. The process finds the value of /P when using the least number of subnet bits, and when using the least number of host bits, as follows:

Key Topic

Step 1. Calculate the shortest prefix mask (/P) based on the *minimum value of S*, where P = N + S.

Step 2. Calculate the longest prefix mask (/P) based on the *minimum value of H*, where P = 32 – H.

Step 3. The range of valid masks includes all /P values between the two values calculated in the previous steps.

For example, in the example shown in Figure 15-6, N=16, the minimum S=6, and the minimum H=8. The first step identifies the shortest prefix mask (the /P with the smallest value of P) of /22 by adding N and S (16 + 6). The second step identifies the longest prefix mask that meets the requirements by subtracting the smallest possible value for H (8, in this case) from 32, for a mask of /24. The third step reminds us that the range is from /22 to /24, meaning that /23 is also an option.

Choosing the Best Mask

When multiple possible masks meet the stated requirements, the engineer has a choice of masks. That, of course, begs some questions: Which mask should you choose? Why would one mask be better than the other? The reasons can be summarized into three main options:

Key Topic

To maximize the number of hosts/subnet: To make this choice, use the shortest prefix mask (that is, the mask with the smallest /P value), because this mask has the largest host part.

To maximize the number of subnets: To make this choice, use the longest prefix mask (that is, the mask with the largest /P value), because this mask has the largest subnet part.

To increase both the numbers of supported subnets and hosts: To make this choice, choose a mask in the middle of the range, which gives you both more subnet bits and more host bits.

For example, in Figure 15-6, the range of masks that meet the requirements is /22 – /24. The shortest mask, /22, has the least subnet bits but the largest number of host bits (10) of the three answers, maximizing the number of hosts/subnet. The longest mask, /24, maximizes the number of subnet bits (8), maximizing the number of subnets, at least among the options that meet the original requirements. The mask in the middle, /23, provides some growth in both subnets and hosts/subnet.

The Formal Process

Although this chapter has explained various steps in finding a subnet mask to meet the design requirements, it has not yet collected these concepts into a list for the entire process. The following list collects all these steps into one place for reference. Note that this list does not introduce any new concepts compared to the rest of this chapter; it just puts all the ideas in one place.

Key Topic

Step 1. Find the number of network bits (N) per class rules.

Step 2. Calculate the minimum number of subnet bits (S) so that 2^S => the number of required subnets.

Step 3. Calculate the minimum number of host bits (H) so that $2^H - 2$ => the number of required hosts/subnet.

Step 4. If N + S + H > 32, no mask meets the need.

Step 5. If N + S + H = 32, one mask meets the need. Calculate the mask as /P, where P = N + S.

Step 6. If N + S + H < 32, multiple masks meet the need:

- **a.** Calculate mask /P based on the minimum value of S, where P = N + S. This mask maximizes the number of hosts/subnet.
- **b.** Calculate mask /P based on the minimum value of H, where P = 32 – H. This mask maximizes the number of possible subnets.
- **c.** Note that the complete range of masks includes all prefix lengths between the two values calculated in Steps 6A and 6B.

Practice Choosing Subnet Masks

Take the usual two-phase approach to learning new subnetting math and processes. Take the time now to practice to make sure you understand the fundamentals, using the book and notes as needed. Then, sometime before taking the exam, practice until you can reach the goals in the right column of Table 15-3.

Table 15-3 Keep-Reading and Take-Exam Goals for Choosing a Subnet Mask

Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On…	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	15 seconds

Practice Problems for Choosing a Subnet Mask

The following list shows three separate problems, each with a classful network number and a required number of subnets and hosts/subnet. For each problem, determine the minimum number of subnet and host bits that meet the requirements. If more than one mask exists, note which mask maximizes the number of hosts/subnet and which maximizes the number of subnets. If only one mask meets the requirements, simply list that mask. List the masks in prefix format:

1. Network 10.0.0.0, need 1500 subnets, need 300 hosts/subnet
2. Network 172.25.0.0, need 130 subnets, need 127 hosts/subnet
3. Network 192.168.83.0, need 8 subnets, need 8 hosts/subnet

Table 15-8, found in the later section "Answers to Earlier Practice Problems," lists the answers.

Finding All Subnet IDs

After the person designing the IP subnetting plan has chosen the one mask to use throughout the Class A, B, or C network, that person will soon need to start assigning specific subnet IDs for use in specific VLANs, WAN links, and other places in the internetwork that need a subnet. But what are those subnet IDs? As it turns out, after the network ID and one subnet mask for all subnets have been chosen, finding all the subnet IDs just requires doing a little math. This second major section of this chapter focuses on that math, which focuses on a single question:

> Given a single Class A, B, or C network, and the single subnet mask to use for all subnets, what are all the subnet IDs?

When learning how to answer this question, you can think about the problem in either binary or decimal. This chapter approaches the problem using decimal. Although the process itself requires only simple math, the process requires practice before most people can confidently answer this question.

The decimal process begins by identifying the first, or numerically lowest, subnet ID. After that, the process identifies a pattern in all subnet IDs for a given subnet mask so that you can find each successive subnet ID through simple addition. This section examines the key ideas behind this process first; then you are given a formal definition of the process.

NOTE Some videos included on the companion website describe the same fundamental processes to find all subnet IDs. You can view those videos before or after reading this section, or even instead of reading this section, as long as you learn how to find all subnet IDs. The process step numbering in the videos might not match the steps shown in this edition of the book.

First Subnet ID: The Zero Subnet

The first step in finding all subnet IDs of one network is incredibly simple: Copy the network ID. That is, take the Class A, B, or C network ID—in other words, the classful network ID—and write it down as the first subnet ID. No matter what Class A, B, or C network you use, and no matter what subnet mask you use, the first (numerically lowest) subnet ID is equal to the network ID.

For example, if you begin with classful network 172.20.0.0, no matter what the mask is, the first subnet ID is 172.20.0.0.

This first subnet ID in each network goes by two special names: either **subnet zero** or **zero subnet**. The origin of these names is related to the fact that a network's zero subnet, when viewed in binary, has a subnet part of all binary 0s. In decimal, the zero subnet can be easily identified, because the zero subnet always has the exact same numeric value as the network ID itself.

In the past, engineers avoided using zero subnets because of the ambiguity with one number that could represent the entire classful network, or it could represent one subnet inside the classful network. To help control that, IOS has a global command that can be set one of two ways:

ip subnet-zero, which allows the configuration of addresses in the zero subnet.

no ip subnet-zero, which prevents the configuration of addresses in the zero subnet.

Although most sites use the default setting to allow zero subnets, you can use the **no ip subnet-zero** command to prevent configuring addresses that are part of a zero subnet. Example 15-1 shows how a router rejects an **ip address** command after changing to use **no ip subnet-zero**. Note that the error message does not mention the zero subnet, instead simply stating "bad mask."

Example 15-1 *Effects of* **[no] ip subnet-zero** *on a Local Router*

```
R1# configure terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)# no ip subnet-zero
R1(config)# interface g0/1
R1(config-if)# ip address 10.0.0.1 255.255.255.0
Bad mask /24 for address 10.0.0.1
```

Note that the **no ip subnet-zero** command affects the local router's **ip address** commands, as well as the local router's **ip route** commands (which define static routes). However, it does not affect the local router's routes as learned with a routing protocol.

Finding the Pattern Using the Magic Number

Subnet IDs follow a predictable pattern, at least when using our assumption of a single subnet mask for all subnets of a network. The pattern uses the *magic number*, as discussed in Chapter 14, "Analyzing Existing Subnets." To review, the magic number is 256, minus the mask's decimal value, in a particular octet that this book refers to as the *interesting octet*.

Figure 15-7 shows four examples of these patterns with four different masks. For example, just look at the top of the figure to start. It lists mask 255.255.128.0 on the left. The third octet is the interesting octet, with a mask value other than 0 or 255 in that octet. The left side shows a magic number calculated as 256 – 128 = 128. So, the pattern of subnet IDs is shown in the highlighted number line; that is, the subnet IDs when using this mask will have either a 0 or 128 in the third octet. For example, if using network 172.16.0.0, the subnet IDs would be 172.16.0.0 and 172.16.128.0.

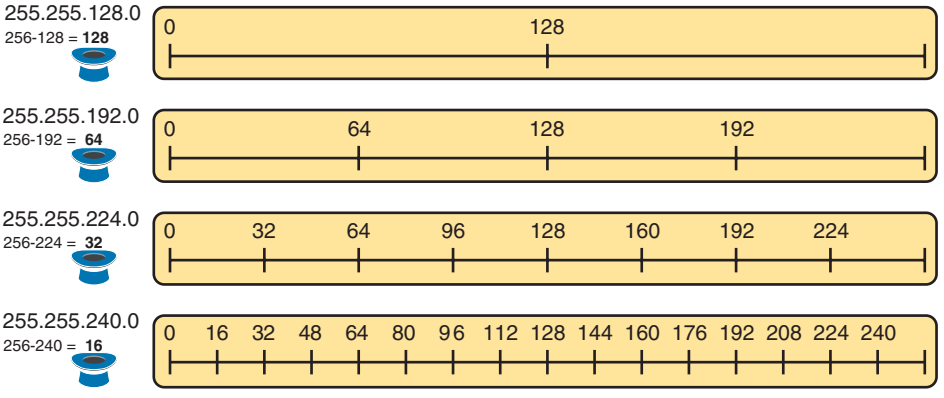


Figure 15-7 *Patterns with Magic Numbers for Masks /17 – /20*

Now focus on the second row, with another example, with mask 255.255.192.0. This row shows a magic number of 64 (256 – 192 = 64), so the subnet IDs will use a value of 0, 64, 128, or 192 (multiples of 64) in the third octet. For example, if used with network 172.16.0.0, the subnet IDs would be 172.16.0.0, 172.16.64.0, 172.16.128.0, and 172.16.192.0.

Looking at the third row/example, the mask is 255.255.224.0, with a magic number of 256 – 224 = 32. So, as shown in the center of the figure, the subnet ID values will be multiples of 32. For example, if used with network 172.16.0.0 again, this mask would tell us that the subnet IDs are 172.16.0.0, 172.16.32.0, 172.16.64.0, 172.16.96.0, and so on.

Finally, for the bottom example, mask 255.255.240.0 makes the magic number, in the third octet, be 16. So, all the subnet IDs will be a multiple of 16 in the third octet, with those values shown in the middle of the figure.

A Formal Process with Fewer Than 8 Subnet Bits

Although it can be easy to see the patterns in Figure 15-7, it might not be as obvious exactly how to apply those concepts to find all the subnet IDs in every case. This section outlines a specific process to find all the subnet IDs.

To simplify the explanations, this section assumes that fewer than 8 subnet bits exist. Later, the section "Finding All Subnets with More Than 8 Subnet Bits," describes the full process that can be used in all cases.

First, to organize your thoughts, you might want to organize the data into a chart like Table 15-4. This book refers to this chart as the list-all-subnets chart.

Table 15-4 Generic List-All-Subnets Chart

Octet	1	2	3	4
Mask				
Magic Number				
Network Number/Zero Subnet				
Next Subnet				
Next Subnet				
Next Subnet				
Broadcast Subnet				
Out of Range—Used by Process				

A formal process to find all subnet IDs, given a network and a single subnet mask, is as follows:

Key Topic

Step 1. Write down the subnet mask, in decimal, in the first empty row of the table.

Step 2. Identify the interesting octet, which is the one octet of the mask with a value other than 255 or 0. Draw a rectangle around the column of the interesting octet.

Step 3. Calculate and write down the magic number by subtracting the *subnet mask's interesting octet* from 256.

Step 4. Write down the classful network number, which is the same number as the zero subnet, in the next empty row of the list-all-subnets chart.

Step 5. To find each successive subnet number:

a. For the three uninteresting octets, copy the previous subnet number's values.

b. For the interesting octet, add the magic number to the previous subnet number's interesting octet.

Step 6. When the sum calculated in Step 5B reaches 256, stop the process. The number with the 256 in it is out of range, and the previous subnet number is the broadcast subnet.

Although the written process is long, with practice, most people can find the answers much more quickly with this decimal-based process than by using binary math. As usual, most people learn this process best by seeing it in action, exercising it, and then practicing it. To that end, review the two following examples, and watch the related videos on the companion website for additional examples.

Example 1: Network 172.16.0.0, Mask 255.255.240.0

To begin this example, focus on the first four of the six steps, when subnetting network 172.16.0.0 using mask 255.255.240.0. Figure 15-8 shows the results of these first four steps:

Step 1. Record mask 255.255.240.0, which was given as part of the problem statement. (Figure 15-8 also shows the network ID, 172.16.0.0, for easy reference.)

Step 2. The mask's third octet is neither 0 nor 255, which makes the third octet interesting.

Step 3. Because the mask's value in the third octet is 240, the magic number = 256 – 240 = 16.

Step 4. Because the network ID is 172.16.0.0, the first subnet ID, the zero subnet, is also 172.16.0.0.

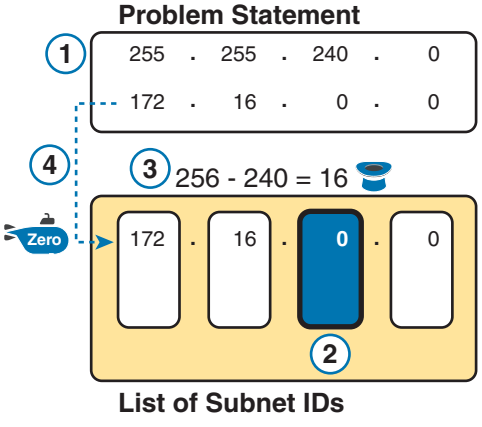


Figure 15-8 *Results of First Four Steps: 172.16.0.0, 255.255.240.0*

These first four steps discover the first subnet (the zero subnet) and get you ready to do the remaining steps by identifying the interesting octet and the magic number. Step 5 in the process tells you to copy the three boring octets and add the magic number (16, in this case) in the interesting octet (octet 3, in this case). Keep repeating this step until the interesting octet value equals 256 (per Step 6). When the total is 256, you have listed all the subnet IDs, and the line with 256 on it is not a correct subnet ID. Figure 15-9 shows the results of the Step 5 actions.

Key Topic

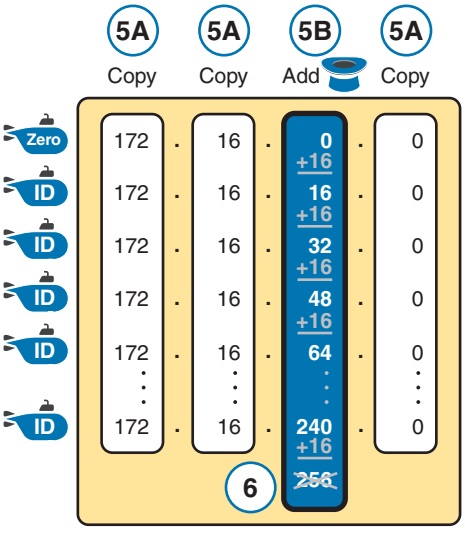


Figure 15-9 *List of Subnet IDs: 172.16.0.0, 255.255.240.0*

NOTE In any list of all the subnet IDs of a network, the numerically highest subnet ID is called the **broadcast subnet**. Decades ago, engineers avoided using the broadcast subnet. However, using the broadcast subnet causes no problems. The term *broadcast subnet* has its origins in the fact that if you determine the subnet broadcast address inside the broadcast subnet, it has the same numeric value as the network-wide broadcast address.

NOTE People sometimes confuse the terms *broadcast subnet* and *subnet broadcast address*. The *broadcast subnet* is one subnet, namely the numerically highest subnet; only one such subnet exists per network. The term *subnet broadcast address* refers to the one number in each and every subnet that is the numerically highest number in that subnet.

Example 2: Network 192.168.1.0, Mask 255.255.255.224

With a Class C network and a mask of 255.255.255.224, this example makes the fourth octet the interesting octet. However, the process works the same, with the same logic, just with the interesting logic applied in a different octet. As with the previous example, the following list outlines the first four steps, with Figure 15-10 showing the results of the first four steps:

Step 1. Record mask 255.255.255.224, which was given as part of the problem statement, and optionally record the network number (192.168.1.0).

Step 2. The mask's fourth octet is neither 0 nor 255, which makes the fourth octet interesting.

Step 3. Because the mask's value in the fourth octet is 224, the magic number = 256 – 224 = 32.

Step 4. Because the network ID is 192.168.1.0, the first subnet ID, the zero subnet, is also 192.168.1.0.

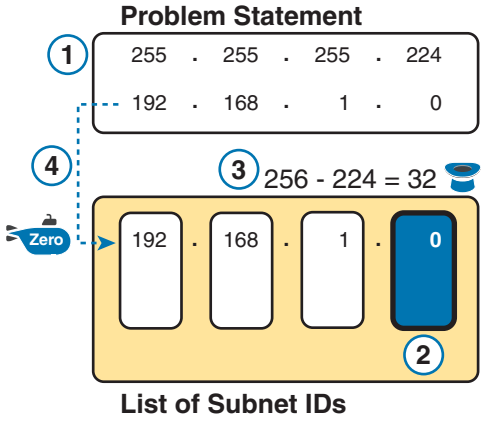


Figure 15-10 *Results of First Four Steps: 192.168.1.0, 255.255.255.224*

From this point, Step 5 in the process tells you to copy the values in the first three octets and then add the magic number (32, in this case) in the interesting octet (octet 4, in this case). Keep doing so until the interesting octet value equals 256 (per Step 6). When the total is 256, you have listed all the subnet IDs, and the line with 256 on it is not a correct subnet ID. Figure 15-11 shows the results of these steps.

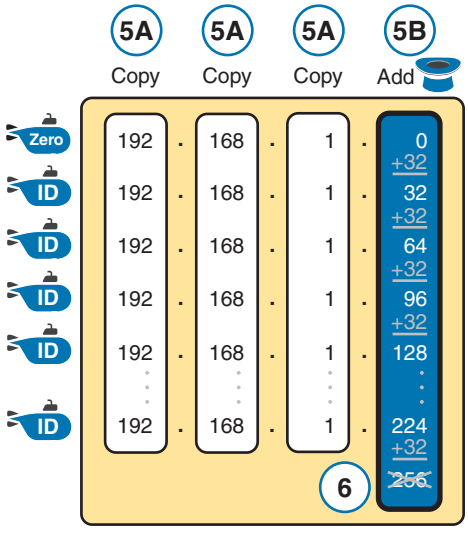


Figure 15-11 *List of Subnet IDs: 192.168.1.0, 255.255.255.224*

Finding All Subnets with Exactly 8 Subnet Bits

The formal process in the earlier section "A Formal Process with Fewer Than 8 Subnet Bits" identified the interesting octet as the octet whose mask value is neither a 255 nor a 0. If the mask defines exactly 8 subnet bits, you must use a different logic to identify the interesting octet; otherwise, the same process can be used. In fact, the actual subnet IDs can be a little more intuitive.

Only two cases exist with exactly 8 subnet bits:

A Class A network with mask 255.255.0.0; the entire second octet contains subnet bits.

A Class B network with mask 255.255.255.0; the entire third octet contains subnet bits.

In each case, use the same process as with less than 8 subnet bits, but identify the interesting octet as the one octet that contains subnet bits. Also, because the mask's value is 255, the magic number will be 256 – 255 = 1, so the subnet IDs are each 1 larger than the previous subnet ID.

For example, for 172.16.0.0, mask 255.255.255.0, the third octet is the interesting octet and the magic number is 256 – 255 = 1. You start with the zero subnet, equal in value to network number 172.16.0.0, and then add 1 in the third octet. For example, the first four subnets are as follows:

172.16.0.0 (zero subnet)

172.16.1.0

172.16.2.0

172.16.3.0

Finding All Subnets with More Than 8 Subnet Bits

Earlier, the section "A Formal Process with Fewer Than 8 Subnet Bits" assumed fewer than 8 subnet bits for the purpose of simplifying the discussions while you learn. In real life, you need to be able to find all subnet IDs with any valid mask, so you cannot assume fewer than 8 subnet bits.

The examples that have at least 9 subnet bits have a minimum of 512 subnet IDs, so writing down such a list would take a lot of time. To conserve space, the examples will use shorthand rather than list hundreds or thousands of subnet IDs.

The process with fewer than 8 subnet bits told you to count in increments of the magic number in one octet. With more than 8 subnet bits, the new expanded process must tell you how to count in multiple octets. So, this section breaks down two general cases: (a) when 9–16 subnet bits exist, which means that the subnet field exists in only two octets, and (b) cases with 17 or more subnet bits, which means that the subnet field exists in three octets.

Process with 9–16 Subnet Bits

To understand the process, you need to know a few terms that the process will use. Figure 15-12 shows the details, with an example that uses Class B network 130.4.0.0 and mask 255.255.255.192. The lower part of the figure details the structure of the addresses per the mask: a network part of two octets because it is a Class B address, a 10-bit subnet part per the mask (/26), and 6 host bits.

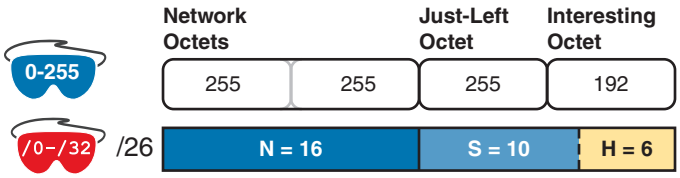


Figure 15-12 *Fundamental Concepts and Terms for the >8 Subnet Bit Process*

In this case, subnet bits exist in two octets: octets 3 and 4. For the purposes of the process, the rightmost of these octets is the interesting octet, and the octet just to the left is the cleverly named *just-left* octet.

The updated process, which makes adjustments for cases in which the subnet field is longer than 1 octet, tells you to count in increments of the magic number in the interesting octet, but count by 1s in the just-left octet. Formally:

Key Topic

Step 1. Calculate subnet IDs using the 8-subnet-bits-or-less process. However, when the total adds up to 256, move to the next step; consider the subnet IDs listed so far as a *subnet block*.

Step 2. Copy the previous subnet block, but add 1 to the just-left octet in all subnet IDs in the new block.

Step 3. Repeat Step 2 until you create the block with a just-left octet of 255, but go no further.

To be honest, the formal concept can cause you problems until you work through some examples, so even if the process remains a bit unclear in your mind, you should work through the following examples instead of rereading the formal process.

First, consider an example based on Figure 15-12, with network 130.4.0.0 and mask 255.255.255.192. Figure 15-12 already showed the structure, and Figure 15-13 shows the subnet ID block created at Step 1.

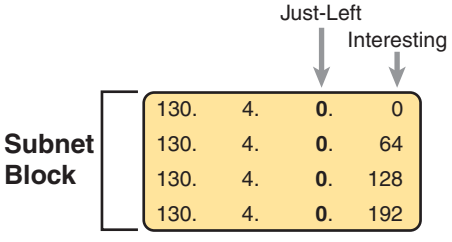


Figure 15-13 *Step 1: Listing the First Subnet ID Block*

The logic at Step 1, to create this subnet ID block of four subnet IDs, follows the same magic number process seen before. The first subnet ID, 130.4.0.0, is the zero subnet. The next three subnet IDs are each 64 bigger, because the magic number, in this case, is 256 – 192 = 64.

Steps 2 and 3 from the formal process tell you how to create 256 subnet blocks, and by doing so, you will list all 1024 subnet IDs. To do so, create 256 total subnet blocks: one with a 0 in the just-left octet, one with a 1 in the just-left octet, and another with a 2 in the just-left octet, up through 255. The process continues through the step at which you create the subnet block with 255 in the just-left octet (third octet, in this case). Figure 15-14 shows the idea, with the addition of the first few subnet blocks.

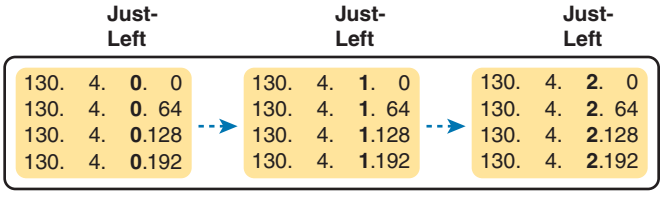


Figure 15-14 *Step 2: Replicating the Subnet Block with +1 in the Just-Left Octet*

This example, with 10 total subnet bits, creates 256 blocks of four subnets each, for a total of 1024 subnets. This math matches the usual method of counting subnets, because $2^{10} = 1024$.

Process with 17 or More Subnet Bits

To create a subnet design that allows 17 or more subnet bits to exist, the design must use a Class A network. In addition, the subnet part will consist of the entire second and third octets, plus part of the fourth octet. That means a lot of subnet IDs: at least 2^{17} (or 131,072) subnets. Figure 15-15 shows an example of just such a structure, with a Class A network and a /26 mask.

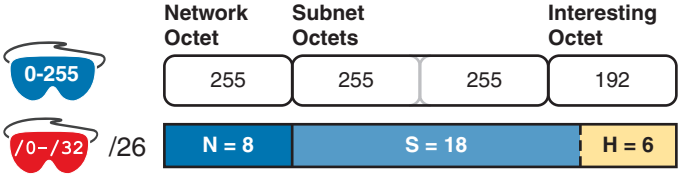


Figure 15-15 *Address Structure with 18 Subnet Bits*

To find all the subnet IDs in this example, you use the same general process as with 9–16 subnet bits, but with many more subnet blocks to create. In effect, you have to create a subnet block for all combinations of values (0–255, inclusive) in both the second and third octets. Figure 15-16 shows the general idea. Note that with only 2 subnet bits in the fourth octet in this example, the subnet blocks will have four subnets each.

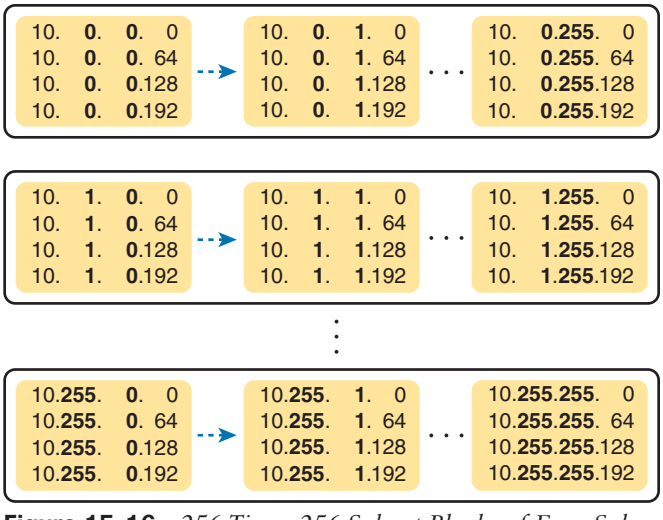


Figure 15-16 *256 Times 256 Subnet Blocks of Four Subnets*

Practice Finding All Subnet IDs

Before moving to the next chapter, practice until you get the right answer most of the time—but use any tools you want and take all the time you need. Then, you can move on with your reading. *Before taking the exam*, practice until you reach the goals in the right column of Table 15-5, which summarizes the key concepts and suggestions for this two-phase approach.

Table 15-5 Keep-Reading and Take-Exam Goals for This Chapter's Topics

Time Frame	Before Moving to the Next Chapter	Before Taking the Exam
Focus On…	Learning how	Being correct and fast
Tools Allowed	All	Your brain and a notepad
Goal: Accuracy	90% correct	100% correct
Goal: Speed	Any speed	45 seconds

Practice Problems for Finding All Subnet IDs

The following list shows three separate problems, each with a classful network number and prefix-style mask. Find all subnet IDs for each problem:

1. 192.168.9.0/27
2. 172.30.0.0/20
3. 10.0.0.0/17

The section "Answers to Earlier Practice Problems," later in this chapter, lists the answers.

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 15-6 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 15-6 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used
Review key topics		Book, website
Review key terms		Book, website
Answer DIKTA questions		Book, PTP
Practice subnet design		Website, Appendix G
Watch video		Website

Review All the Key Topics

Key Topic

Table 15-7 Key Topics for Chapter 15

Key Topic Element	Description	Page Number
Definition	Facts about binary values in subnet masks	384
List	The shorter three-step process to find all prefix masks that meet certain requirements	384
List	Reasons to choose one subnet mask versus another	385
Step list	The complete process for finding and choosing masks to meet certain requirements	385
Step list	Formal steps to find all subnet IDs when fewer than 8 subnet bits exist	389
Figure 15-9	An example of adding the magic number in the interesting octet to find all subnet IDs	391
Step list	Formal steps to find all subnet IDs when more than 8 subnet bits exist	394

Key Terms You Should Know

broadcast subnet, subnet zero, zero subnet

Additional Practice for This Chapter's Processes

For additional practice with subnet mask design and finding all subnet IDs, you may do the same set of practice problems using your choice of tools:

PDF: Practice using online Appendix G, "Practice for Chapter 15: Subnet Design."

Answers to Earlier Practice Problems

Answers to Practice Choosing Subnet Masks

The earlier section "Practice Choosing Subnet Masks" listed three practice problems. The answers are listed here so that the answers are nearby but not visible from the list of problems. Table 15-8 lists the answers, with notes related to each problem following the table.

Table 15-8 Practice Problems: Find the Masks That Meet Requirements

Problem	Class	Minimum Subnet Bits	Minimum Host Bits	Prefix Range	Prefix to Maximize Subnets	Prefix to Maximize Hosts
1	A	11	9	/19 – /23	/23	/19
2	B	8	8	/24	—	—
3	C	3	4	/27 – /28	/28	/27

1. N=8, because the problem lists Class A network 10.0.0.0. With a need for 1500 subnets, 10 subnet bits supply only 1024 subnets (per Table 15-2), but 11 subnet bits (S) would provide 2048 subnets—more than the required 1500. Similarly, the smallest number of host bits would be 9, because $2^8 - 2 = 254$, and the design requires 300 hosts/subnet. The shortest prefix mask would then be /19, found by adding N (8) and the smallest usable number of subnet bits S (11). Similarly, with a minimum H value of 9, the longest prefix mask, maximizing the number of subnets, is 32 – H = /23.
2. N=16, because the problem lists Class B network 172.25.0.0. With a need for 130 subnets, 7 subnet bits supply only 128 subnets (per Table 15-2), but 8 subnet bits (S) would provide 256 subnets—more than the required 130. Similarly, the smallest number of host bits would be 8, because $2^7 - 2 = 126$—close to the required 127, but not quite enough, making H=8 the smallest number of host bits that meets requirements. Note that the network, minimum subnet bits, and minimum host bits add up to 32, so only one mask meets the requirements, namely /24, found by adding the number of network bits (16) to the minimum number of subnet bits (8).
3. N=24, because the problem lists Class C network 192.168.83.0. With a need for 8 subnets, 3 subnet bits supply enough, but just barely. The smallest number of host bits would be 4, because $2^3 - 2 = 6$, and the design requires 8 hosts/subnet. The shortest prefix mask would then be /27, found by adding N (24) and the smallest usable number of subnet bits S (3). Similarly, with a minimum H value of 4, the longest prefix mask, maximizing the number of subnets, is 32 – H = /28.

Answers to Practice Finding All Subnet IDs

The earlier section "Practice Finding All Subnet IDs" listed three practice problems. The answers are listed here so that they are not visible from the same page as the list of problems.

Answer, Practice Problem 1

Problem 1 lists network 192.168.9.0, mask /27. The mask converts to DDN mask 255.255.255.224. When used with a Class C network, which has 24 network bits, only 3 subnet bits exist, and they all sit in the fourth octet. So, this problem is a case of fewer than 8 subnet bits, with the fourth octet as the interesting octet.

To get started listing subnets, first write down the zero subnet and then start adding the magic number in the interesting octet. The zero subnet equals the network ID (192.168.9.0, in this case). The magic number, calculated as 256 – 224 = 32, should be added to the previous subnet ID's interesting octet. Table 15-9 lists the results.

Table 15-9 List-All-Subnets Chart: 192.168.9.0/27

Octet	1	2	3	4
Mask	255	255	255	224
Magic Number	—	—	—	32
Classful Network/Subnet Zero	192	168	9	0
First Nonzero Subnet	192	168	9	32
Next Subnet	192	168	9	64

Octet	1	2	3	4
Next Subnet	192	168	9	96
Next Subnet	192	168	9	128
Next Subnet	192	168	9	160
Next Subnet	192	168	9	192
Broadcast Subnet	192	168	9	224
Invalid—Used by Process	192	168	9	256

Answer, Practice Problem 2

Problem 2 lists network 172.30.0.0, mask /20. The mask converts to DDN mask 255.255.240.0. When used with a Class B network, which has 16 network bits, only 4 subnet bits exist, and they all sit in the third octet. So, this problem is a case of fewer than 8 subnet bits, with the third octet as the interesting octet.

To get started listing subnets, first write down the zero subnet and then start adding the magic number in the interesting octet. The zero subnet equals the network ID (or 172.30.0.0, in this case). The magic number, calculated as 256 – 240 = 16, should be added to the previous subnet ID's interesting octet. Table 15-10 lists the results.

Table 15-10 List-All-Subnets Chart: 172.30.0.0/20

Octet	1	2	3	4
Mask	255	255	240	0
Magic Number	—	—	16	—
Classful Network/Subnet Zero	172	30	0	0
First Nonzero Subnet	172	30	16	0
Next Subnet	172	30	32	0
Next Subnet	172	30	Skipping…	0
Next Subnet	172	30	224	0
Broadcast Subnet	172	30	240	0
Invalid—Used by Process	172	30	256	0

Answer, Practice Problem 3

Problem 3 lists network 10.0.0.0, mask /17. The mask converts to DDN mask 255.255.128.0. When used with a Class A network, which has 8 network bits, 9 subnet bits exist. Using the terms unique to this chapter, octet 3 is the interesting octet, with only 1 subnet bit in that octet, and octet 2 is the just-left octet, with 8 subnet bits.

In this case, begin by finding the first subnet block. The magic number is 256 – 128 = 128. The first subnet (zero subnet) equals the network ID. So, the first subnet ID block includes the following:

10.0.0.0

10.0.128.0

Then, you create a subnet block for all 256 possible values in the just-left octet, or octet 2 in this case. The following list shows the first three subnet ID blocks, plus the last subnet ID block, rather than listing page upon page of subnet IDs:

10.0.0.0 (zero subnet)

10.0.128.0

10.1.0.0

10.1.128.0

10.2.0.0

10.2.128.0

…

10.255.0.0

10.255.128.0 (broadcast subnet)

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Part IV Review

Keep track of your part review progress with the checklist in Table P4-1. Details on each task follow the table.

Table P4-1 Part IV Part Review Checklist

Activity	1st Date Completed	2nd Date Completed
Repeat All DIKTA Questions		
Answer Part Review Questions		
Review Key Topics		
Subnetting Exercises in PDF Appendices on Companion Website		
Interactive Subnetting Exercises on Companion Website		
Watch Video		

Repeat All DIKTA Questions

For this task, use the PTP software to answer the "Do I Know This Already?" questions again for the chapters in this part of the book.

Answer Part Review Questions

For this task, use PTP to answer the Part Review questions for this part of the book.

Review Key Topics

Review all key topics in all chapters in this part, either by browsing the chapters or by using the Key Topics application on the companion website.

Watch Video

The companion website includes a variety of subnetting videos. Some have the familiar common mistake and Q&A format as the other chapters, whereas others simply work through various subnetting processes. Use these videos to challenge your thinking, dig deeper, review topics, and better prepare for the exam. Make sure to bookmark a link to the companion website and use the videos for review whenever you have a few extra minutes.

Subnetting Exercises

Chapters 12 through 15 list some subnetting exercises, along with time and accuracy goals. Now is a good time to work on those goals. Some options include the following:

Practice from this book's appendices or web applications: This book includes four appendices of subnetting practice exercises, all available from the companion website. From that website, to use the static PDFs, look to the section titled "Study Resources." To find the interactive versions of the exercises in those same appendices, look to the section titled "Memory Tables and Practice Exercises." Look for these topics/appendices:

Appendix D, "Practice for Chapter 12: Analyzing Classful IPv4 Networks"

Appendix E, "Practice for Chapter 13: Analyzing Subnet Masks"

Appendix F, "Practice for Chapter 14: Analyzing Existing Subnets"

Appendix G, "Practice for Chapter 15: Subnet Design"

IP Subnetting Practice Question Kit: As mentioned in the Introduction to the book, if you want large amounts of subnetting practice, with explanations that match the processes in the book, consider purchasing the IP Subnetting Practice Question Kit, available at ciscopress.com.

Author's blog: I've written a few dozen subnetting exercises on the blog over the years. Just look at the Questions menu item at the top of the page, and you will see a variety of IPv4 addressing and subnetting question types. Start at https://www.certskills.com.