

Chapter 1

IP Addressing

One of the most important topics in any discussion of TCP/IP is IP addressing. An *IP address* is a numeric identifier assigned to each machine on an IP network. It designates the specific location of a device on the network. An IP address is a software address, not a hardware address—the latter is hard-coded on a network interface card (NIC) and used for finding hosts on a local network. IP addressing was designed to allow hosts on one network to communicate with a host on a different network regardless of the type of LANs the hosts are participating in. Before we get into the more complicated aspects of IP addressing, you need to understand some of the basics. First I'm going to explain some of the fundamentals of IP addressing and its terminology. Then you'll learn about the hierarchical IP addressing scheme and private IP addresses.

1.1 Definition

Throughout this chapter you're being introduced to several important terms that are vital to understanding the Internet Protocol. Here are a few to get you started:

Bit A bit is one digit, either a 1 or a 0.

Byte A byte is 7 or 8 bits, depending on whether parity is used. For the rest of this chapter, always assume a byte is 8 bits.

Octet An octet, made up of 8 bits, is just an ordinary 8-bit binary number. In this chapter, the terms *byte* and *octet* are completely interchangeable.

Network address This is the designation used in routing to send packets to a remote network—for example, 10.0.0.0, 172.16.0.0, and 192.168.10.0.

Broadcast address The address used by applications and hosts to send information to all nodes on a network is called the broadcast address. Examples of layer 3 broadcasts include 255.255.255.255, which is any network, all nodes; 172.16.255.255, which is all subnets and hosts on network 172.16.0.0; and 10.255.255.255, which broadcasts to all subnets and hosts on network 10.0.0.0.

1.2 The Hierarchical IP Addressing Scheme

An IP address consists of 32 bits of information. These bits are divided into four sections, referred to as octets or bytes, with each containing 1 byte (8 bits). You can depict an IP address

using one of three methods:

Dotted-decimal, as in 172.16.30.56

Binary, as in 10101100.00010000.00011110.00111000

Hexadecimal, as in AC.10.1E.38

All these examples represent the same IP address. Pertaining to IP addressing, hexadecimal isn't used as often as dotted-decimal or binary, but you still might find an IP address stored in hexadecimal in some programs.

The 32-bit IP address is a structured or hierarchical address, as opposed to a flat or nonhierarchical address. Although either type of addressing scheme could have been used, *hierarchical addressing* was chosen for a good reason. The advantage of this scheme is that it can handle a large number of addresses, namely 4.3 billion (a 32-bit address space with two possible values for each position—either 0 or 1—gives you 2^{32} , or 4,294,967,296). The disadvantage of the flat addressing scheme, and the reason it's not used for IP addressing, relates to routing. If every address were unique, all routers on the Internet would need to store the address of each and every machine on the Internet. This would make efficient routing impossible, even if only a fraction of the possible addresses were used!

The solution to this problem is to use a two- or three-level hierarchical addressing scheme that is structured by network and host or by network, subnet, and host. This two- or three-level scheme can also be compared to a telephone number. The first section, the area code, designates a very large area. The second section, the prefix, narrows the scope to a local calling area. The final segment, the customer number, zooms in on the specific connection. IP addresses use the same type of layered structure. Rather than all 32 bits being treated as a unique identifier, as in flat addressing, a part of the address is designated as the network address and the other part is designated as either the subnet and host or just the node address. Next, we'll cover IP network addressing and the different classes of address we can use to address our networks.

1.3 Network Addressing

The *network address* (which can also be called the network number) uniquely identifies each network. Every machine on the same network shares that network address as part of its IP address. For example, in the IP address 172.16.30.56, 172.16 is the network address. The *node address* is assigned to, and uniquely identifies, each machine on a network. This part of the address must be unique because it identifies a particular machine—an individual—as opposed to a network, which is a group. This number can also be referred to as a *host address*. In the sample IP address 172.16.30.56, the 30.56 specifies the node address.

The designers of the Internet decided to create classes of networks based on network size. For the small number of networks possessing a very large number of nodes, they created the rank *Class A network*. At the other extreme is the *Class C network*, which is reserved for the numerous networks with a small number of nodes. The class distinction for networks between very large and very small is predictably called the *Class B network*.

Subdividing an IP address into a network and node address is determined by the class designation of one's network. Figure 1.1 summarizes the three classes of networks used to address hosts—a subject I'll explain in much greater detail throughout this chapter.

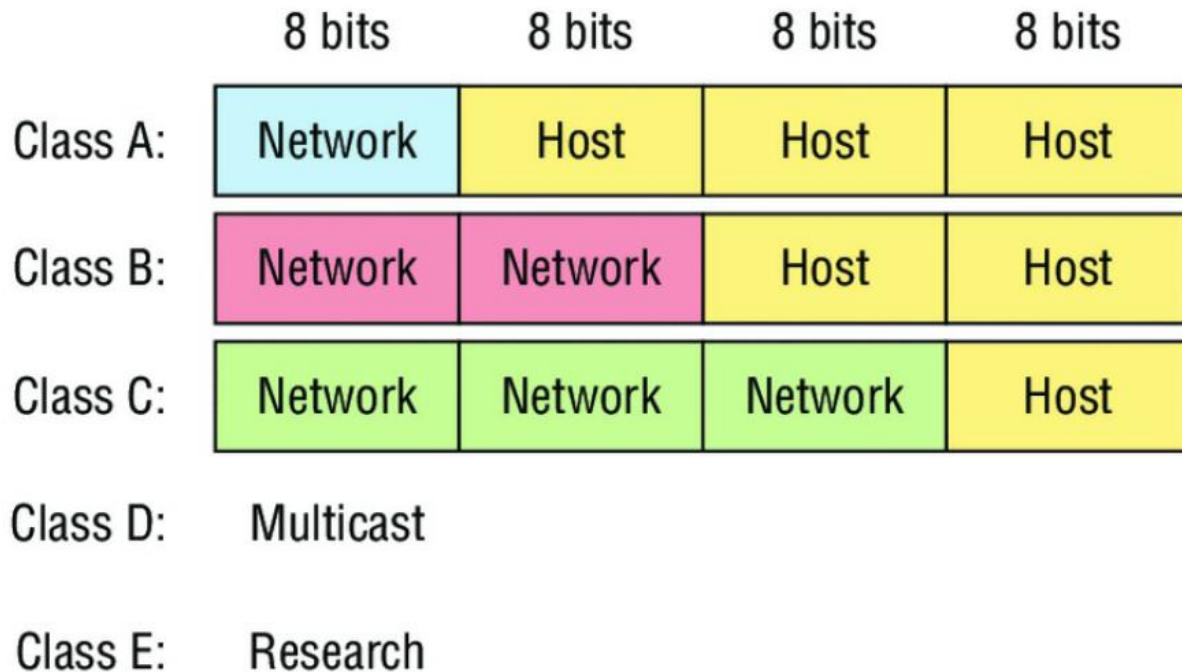


Figure 1.1 Summary of the three classes of networks

To ensure efficient routing, Internet designers defined a mandate for the leading-bits section of the address for each different network class. For example, since a router knows that a Class A network address always starts with a 0, the router might be able to speed a packet on its way after reading only the first bit of its address. This is where the address schemes define the difference between a Class A, a Class B, and a Class C address. Coming up, I'll discuss the differences between these three classes, followed by a discussion of the Class D and Class E addresses. Classes A, B, and C are the only ranges that are used to address hosts in our networks.

Network Address Range: Class A

The designers of the IP address scheme decided that the first bit of the first byte in a Class A network address must always be off, or 0. This means a Class A address must be between 0 and 127 in the first byte, inclusive.

Consider the following network address:

0xxxxxxx

If we turn the other 7 bits all off and then turn them all on, we'll find the Class A range of network addresses:

00000000 = 0

01111111 = 127

So, a Class A network is defined in the first octet between 0 and 127, and it can't be less or more. Understand that 0 and 127 are not valid in a Class A network because they're reserved addresses, which I'll explain soon.

Network Address Range: Class B

In a Class B network, the RFCs state that the first bit of the first byte must always be turned on but the second bit must always be turned off. If you turn the other 6 bits all off and then all on, you will find the range for a Class B network:

10000000 = 128

10111111 = 191

As you can see, a Class B network is defined when the first byte is configured from 128 to 191.

Network Address Range: Class C

For Class C networks, the RFCs define the first 2 bits of the first octet as always turned on, but the third bit can never be on. Following the same process as the previous classes, convert from binary to decimal to find the range. Here's the range for a Class C network:

11000000 = 192

11011111 = 223

So, if you see an IP address that starts at 192 and goes to 223, you'll know it is a Class C IP address.

Network Address Ranges: Classes D and E

The addresses between 224 to 255 are reserved for Class D and E networks. Class D (224–239) is used for multicast addresses and Class E (240–255) for scientific purposes, but I'm not going into these types of addresses because they are beyond the scope of knowledge you need to gain from this book.

Network Addresses: Special Purpose

Some IP addresses are reserved for special purposes, so network administrators can't ever assign these addresses to nodes. Table 1.1 lists the members of this exclusive little club and the reasons why they're included in it.

>Address	>Function
Network address of all 0s	Interpreted to mean "this network or segment."
Network address of all 1s	Interpreted to mean "all networks."
Network 127.0.0.1	Reserved for loopback tests. Designates the local node and allows that node to send a test packet to itself without generating network traffic.

Node address of all 0s	Interpreted to mean “network address” or any host on a specified network.
Node address of all 1s	Interpreted to mean “all nodes” on the specified network; for example, 128.2.255.255 means “all nodes” on network 128.2 (Class B address).
Entire IP address set to all 0s	Used by Cisco routers to designate the default route. Could also mean “any network.”
Entire IP address set to all 1s (same as 255.255.255.255)	Broadcast to all nodes on the current network; sometimes called an “all 1s broadcast” or local broadcast.

Table 1.1 Special purpose addresses

Class A Addresses

In a Class A network address, the first byte is assigned to the network address and the three remaining bytes are used for the node addresses. The Class A format is as follows:

network.node.node.node

For example, in the IP address 49.22.102.70, the 49 is the network address and 22.102.70 is the node address. Every machine on this particular network would have the distinctive network address of 49.

Class A network addresses are 1 byte long, with the first bit of that byte reserved and the 7 remaining bits available for manipulation (addressing). As a result, the maximum number of Class A networks that can be created is 128. Why? Because each of the 7 bit positions can be either a 0 or a 1, thus 2⁷ or 128.

To complicate matters further, the network address of all 0s (0000 0000) is reserved to designate the default route (see Table 1.1 in the previous section). Additionally, the address 127, which is reserved for diagnostics, can’t be used either, which means that you can really only use the numbers 1 to 126 to designate Class A network addresses. This means the actual number of usable Class A network addresses is 128 minus 2, or 126.

Note. The IP address 127.0.0.1 is used to test the IP stack on an individual node and cannot be used as a valid host address. However, the loopback address creates a shortcut method for TCP/IP applications and services that run on the same device to communicate with each other.

Each Class A address has 3 bytes (24-bit positions) for the node address of a machine. This means there are 2²⁴—or 16,777,216—unique combinations and, therefore, precisely that many possible unique node addresses for each Class A network. Because node addresses with the two patterns of all 0s and all 1s are reserved, the actual maximum usable number of nodes for a Class A network

is 22 4 minus 2, which equals 16,777,214. Either way, that's a huge number of hosts on a single network segment!

Class A Valid Host IDs

Here's an example of how to figure out the valid host IDs in a Class A network address:

All host bits off is the network address: 10.0.0.0.

All host bits on is the broadcast address: 10.255.255.255.

The valid hosts are the numbers in between the network address and the broadcast address: 10.0.0.1 through 10.255.255.254. Notice that 0s and 255s can be valid host IDs. All you need to remember when trying to find valid host addresses is that the host bits can't all be turned off or on at the same time.

Class B Addresses

In a Class B network address, the first 2 bytes are assigned to the network address and the remaining 2 bytes are used for node addresses. The format is as follows:

network.network.node.node

For example, in the IP address 172.16.30.56, the network address is 172.16 and the node address is 30.56. With a network address being 2 bytes (8 bits each), you get 21 6 unique combinations. But the Internet designers decided that all Class B network addresses should start with the binary digit 1, then 0. This leaves 14 bit positions to manipulate, therefore 16,384, or 21 4 unique Class B network addresses. A Class B address uses 2 bytes for node addresses. This is 21 6 minus the two reserved patterns of all 0s and all 1s for a total of 65,534 possible node addresses for each Class B network.

Class B Valid Host IDs

Here's an example of how to find the valid hosts in a Class B network:

All host bits turned off is the network address: 172.16.0.0.

All host bits turned on is the broadcast address: 172.16.255.255.

The valid hosts would be the numbers in between the network address and the broadcast address: 172.16.0.1 through 172.16.255.254.

Class C Addresses

The first 3 bytes of a Class C network address are dedicated to the network portion of the address, with only 1 measly byte remaining for the node address. Here's the format:

network.network.network.node

Using the example IP address 192.168.100.102, the network address is 192.168.100 and the node address is 102. In a Class C network address, the first three bit positions are always the binary 110. The calculation is as follows: 3 bytes, or 24 bits, minus 3 reserved positions leaves 21

positions. Hence, there are 2^{24} , or 2,097,152, possible Class C networks. Each unique Class C network has 1 byte to use for node addresses. This leads to 256, minus the two reserved patterns of all 0s and all 1s, for a total of 254 node addresses for each Class C network.

Class C Valid Host IDs

Here's an example of how to find a valid host ID in a Class C network:

All host bits turned off is the network ID: 192.168.100.0.

All host bits turned on is the broadcast address: 192.168.100.255.

The valid hosts would be the numbers in between the network address and the broadcast address: 192.168.100.1 through 192.168.100.254.

1.4 IPv4 Address Types

Most people use the term *broadcast* as a generic term, and most of the time, we understand what they mean—but not always! For example, you might say, “The host broadcasted through a router to a DHCP server,” but, well, it’s pretty unlikely that this would ever really happen. What you probably mean—using the correct technical jargon—is, “The DHCP client broadcasted for an IP address and a router then forwarded this as a unicast packet to the DHCP server.” Oh, and remember that with IPv4, broadcasts are pretty important, but with IPv6, there aren’t any broadcasts sent at all! Okay, I’ve referred to IP addresses throughout the preceding chapters and now all throughout this chapter, and even showed you some examples. But I really haven’t gone into the different terms and uses associated with them yet, and it’s about time I did. So here are the address types that I’d like to define for you:

Loopback (localhost) Used to test the IP stack on the local computer. Can be any address from 127.0.0.1 through 127.255.255.254.

Layer 2 broadcasts These are sent to all nodes on a LAN.

Broadcasts (layer 3) These are sent to all nodes on the network.

Unicast This is an address for a single interface, and these are used to send packets to a single destination host.

Multicast These are packets sent from a single source and transmitted to many devices on different networks. Referred to as “one-to-many.”

Layer 2 Broadcasts

First, understand that layer 2 broadcasts are also known as hardware broadcasts—they only go out on a LAN, but they don’t go past the LAN boundary (router). The typical hardware address is 6

bytes (48 bits) and looks something like 45:AC:24:E3:60:A5. The broadcast would be all 1s in binary, which would be all *F*s in hexadecimal, as in ff:ff:ff:ff:ff:ff and shown in Figure 1.2.

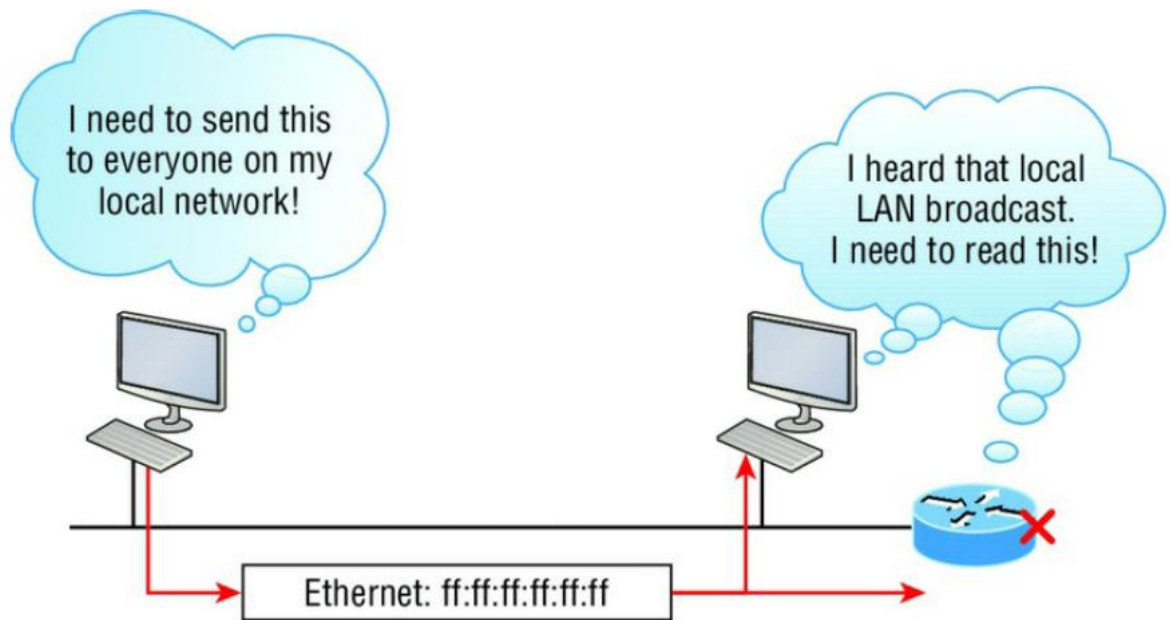


Figure 1.2 Local layer 2 broadcasts

Every network interface card (NIC) will receive and read the frame, including the router, since this was a layer 2 broadcast, but the router would never, ever forward this!

Layer 3 Broadcasts

Then there are the plain old broadcast addresses at layer 3. Broadcast messages are meant to each all hosts on a broadcast domain. These are the network broadcasts that have all host bits on. Here's an example that you're already familiar with: The network address of 172.16.0.0 255.255.0.0 would have a broadcast address of 172.16.255.255—all host bits on. Broadcasts can also be "any network and all hosts," as indicated by 255.255.255.255 and shown in Figure 1.3.

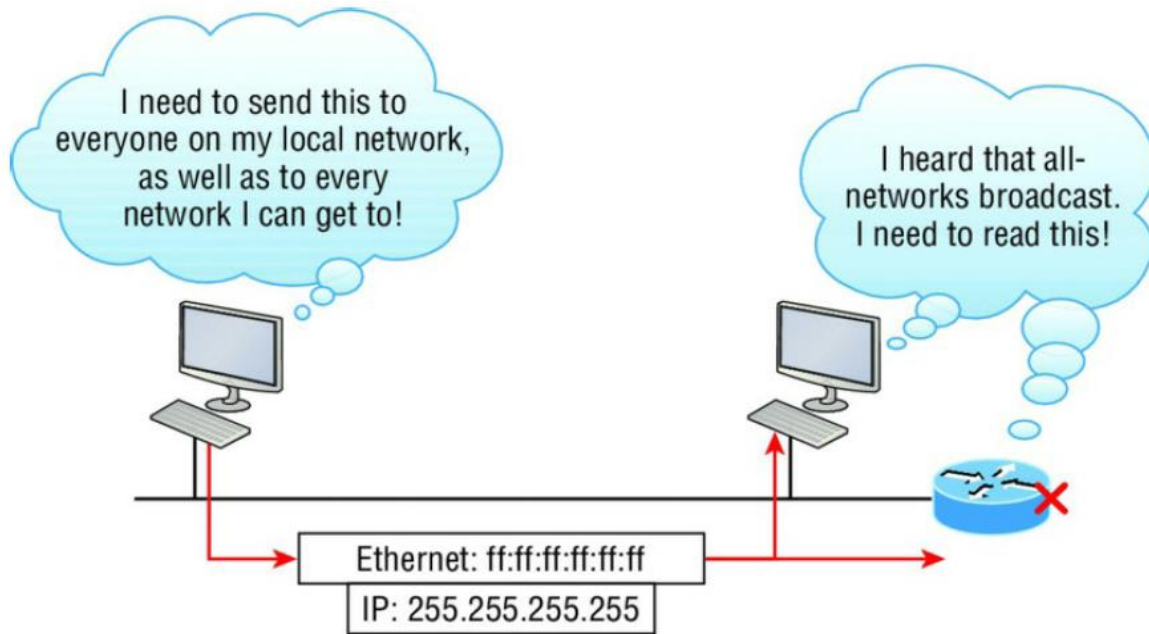


Figure 1.3 Layer 3 broadcasts

In Figure 1.3 all hosts on the LAN will get this broadcast on their NIC, including the router, but by default the router would never forward this packet.

Unicast Address

A unicast is defined as a single IP address that's assigned to a network interface card and is the destination IP address in a packet—in other words, it's used for directing packets to a specific host. In Figure 1.4, both the MAC address and the destination IP address are for a single NIC on the network. All hosts on the broadcast domain would receive this frame and accept it. Only the destination NIC of 10.1.1.2 would accept the packet; the other NICs would discard the packet.

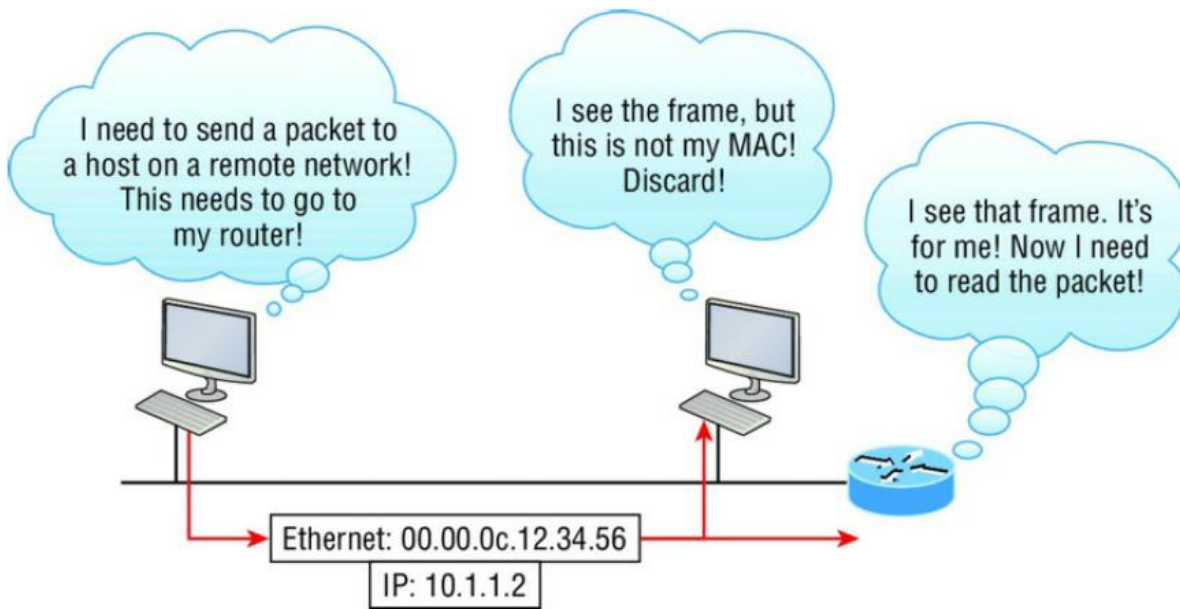


Figure 1.4 Unicast Address

Multicast Address

Multicast is a different beast entirely. At first glance, it appears to be a hybrid of unicast and broadcast communication, but that isn't quite the case. Multicast does allow point-to-multipoint communication, which is similar to broadcasts, but it happens in a different manner. The crux of *multicast* is that it enables multiple recipients to receive messages without flooding the messages to all hosts on a broadcast domain. However, this is not the default behavior—it's what we *can* do with multicasting if it's configured correctly!

Multicast works by sending messages or data to IP *multicast group* addresses. Unlike with Broadcasts, which aren't forwarded, routers then forward copies of the packet out to every interface that has hosts *subscribed* to that group address. This is where multicast differs from broadcast messages—with multicast communication, copies of packets, in theory, are sent only to subscribed hosts. For example, when I say in theory, I mean that the hosts will receive a multicast packet destined for 224.0.0.10. This is an EIGRP packet, and only a router running the EIGRP protocol will read these. All hosts on the broadcast LAN, and Ethernet is a broadcast multi-access LAN technology, will pick up the frame, read the destination address, then immediately discard the frame unless they're in the multicast group. This saves PC processing, not LAN bandwidth. Be warned though—multicasting can cause some serious LAN congestion if it's not implemented carefully! Figure 1.5 shows a Cisco router sending an EIGRP multicast packet on the local LAN and only the other Cisco router will accept and read this packet.

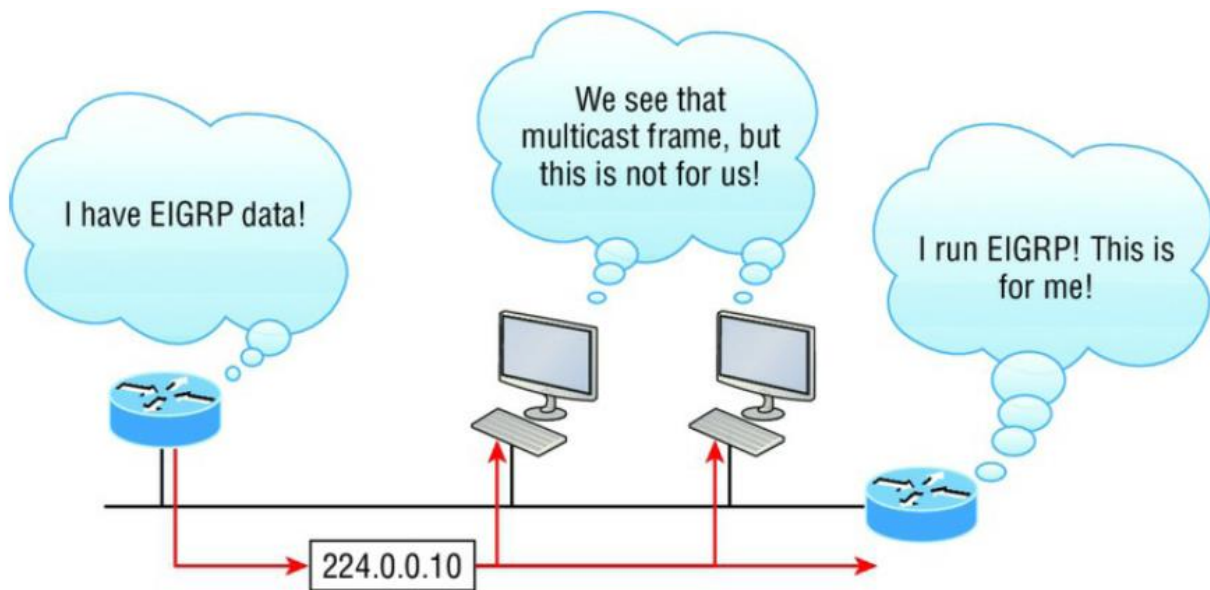


Figure 15 EIGRP Multicast Address

There are several different groups that users or applications can subscribe to. The range of multicast addresses starts with 224.0.0.0 and goes through 239.255.255.255. As you can see, this range of addresses falls within IP Class D address space based on classful IP assignment.