Chapter 6

IP Routing

THE CCNA EXAM TOPICS COVERED IN THIS CHAPTER INCLUDE THE FOLLOWING:

- ✓ **Describe how a network works**
  - Determine the path between two hosts across a network
- ✓ **Configure, verify, and troubleshoot basic router operation and routing on Cisco devices**
  - Describe basic routing concepts (including: packet forwarding, router lookup process)
  - Configure, verify, and troubleshoot RIPv2
  - Access and utilize the router to set basic parameters (including: CLI/SDM)
  - Connect, configure, and verify operation status of a device interface
  - Verify device configuration and network connectivity using ping, traceroute, telnet, SSH or other utilities
  - Perform and verify routing configuration tasks for a static or default route given specific routing requirements
  - Compare and contrast methods of routing and routing protocols
  - Configure, verify, and troubleshoot OSPF
  - Configure, verify, and troubleshoot EIGRP
  - Verify network connectivity (including: using ping, traceroute, and telnet or SSH)
  - Troubleshoot routing issues
  - Verify router hardware and software operation using SHOW & DEBUG commands
  - Implement basic router security

In this chapter, I'm going to discuss the IP routing process. This is an important subject to understand since it pertains to all routers and configurations that use IP. IP routing is the process of moving packets from one network to another network using routers. And as before, by routers I mean Cisco routers, of course!

But before you read this chapter, you must understand the difference between a routing protocol and a routed protocol. A *routing protocol* is used by routers to dynamically find all the networks in the internetwork and to ensure that all routers have the same routing table. Basically, a routing protocol determines the path of a packet through an internetwork. Examples of routing protocols are RIP, RIPv2, EIGRP, and OSPF.

Once all routers know about all networks, a *routed protocol* can be used to send user data (packets) through the established enterprise. Routed protocols are assigned to an interface and determine the method of packet delivery. Examples of routed protocols are IP and IPv6.

I'm pretty sure that I don't have to tell you that this is definitely important stuff to know. You most likely understand that from what I've said so far. IP routing is basically what Cisco routers do, and they do it very well. Again, this chapter is dealing with truly fundamental material—these are things you must know if you want to understand the objectives covered in this book!

In this chapter, I'm going to show you how to configure and verify IP routing with Cisco routers. I'll be covering the following:

- Routing basics
- The IP routing process
- Static routing
- Default routing
- Dynamic routing

In Chapter 7, "Enhanced IGRP (EIGRP) and Open Shortest Path First (OSPF)," I'll be moving into more advanced, dynamic routing with EIGRP and OSPF. But first, you've really got to nail down the basics of how packets actually move through an internetwork, so let's get started!

For up-to-the minute updates for this chapter, please see www.lammle.com and/or www.sybex.com.

Routing Basics

Once you create an internetwork by connecting your WANs and LANs to a router, you'll need to configure logical network addresses, such as IP addresses, to all hosts on the internetwork so that they can communicate across that internetwork.

The term *routing* is used for taking a packet from one device and sending it through the network to another device on a different network. Routers don't really care about hosts—they only care about networks and the best path to each network. The logical network address of the destination host is used to get packets to a network through a routed network, and then the hardware address of the host is used to deliver the packet from a router to the correct destination host.

If your network has no routers, then it should be apparent that you are not routing. Routers route traffic to all the networks in your internetwork. To be able to route packets, a router must know, at a minimum, the following:

- Destination address
- Neighbor routers from which it can learn about remote networks
- Possible routes to all remote networks
- The best route to each remote network
- How to maintain and verify routing information

The router learns about remote networks from neighbor routers or from an administrator. The router then builds a routing table (a map of the internetwork) that describes how to find the remote networks. If a network is directly connected, then the router already knows how to get to it.

If a network isn't directly connected to the router, the router must use one of two ways to learn how to get to the remote network: static routing, meaning that someone must hand-type all network locations into the routing table, or something called dynamic routing.

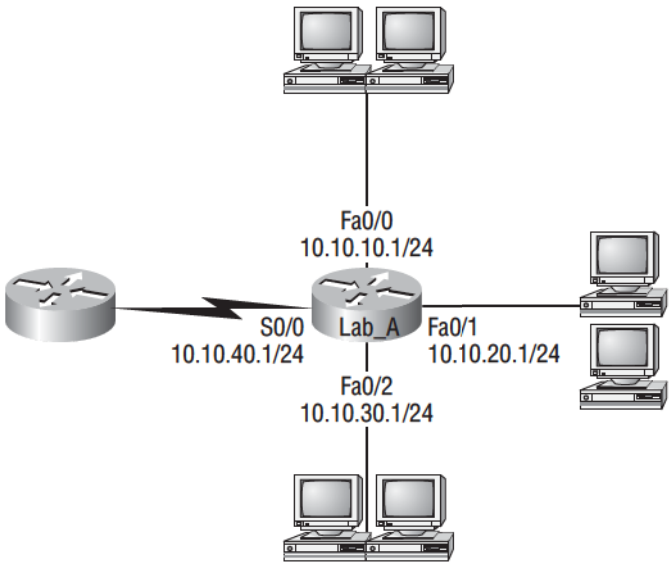
In *dynamic routing*, a protocol on one router communicates with the same protocol running on neighbor routers. The routers then update each other about all the networks they know about and place this information into the routing table. If a change occurs in the network, the dynamic routing protocols automatically inform all routers about the event. If *static routing* is used, the administrator is responsible for updating all changes by hand into all routers. Typically, in a large network, a combination of both dynamic and static routing is used.

Before we jump into the IP routing process, let's take a look at a simple example that demonstrates how a router uses the routing table to route packets out of an interface. We'll be going into a more detailed study of the process in the next section.

Figure 6.1 shows a simple two-router network. Lab_A has one serial interface and three LAN interfaces.

Looking at Figure 6.1, can you see which interface Lab_A will use to forward an IP datagram to a host with an IP address of 10.10.10.10?

FIGURE 6.1 A simple routing example



By using the command **show ip route**, we can see the routing table (map of the internetwork) that Lab_A uses to make forwarding decisions:

```
Lab_A#sh ip route
[output cut]
Gateway of last resort is not set
C       10.10.10.0/24 is directly connected, FastEthernet0/0
C       10.10.20.0/24 is directly connected, FastEthernet0/1
C       10.10.30.0/24 is directly connected, FastEthernet0/2
C       10.10.40.0/24 is directly connected, Serial 0/0
```

The C in the routing table output means that the networks listed are "directly connected," and until we add a routing protocol—something like RIP, EIGRP, etc.—to the routers in our internetwork (or use static routes), we'll have only directly connected networks in our routing table.

So let's get back to the original question: By looking at the figure and the output of the routing table, can you tell what IP will do with a received packet that has a destination IP address of 10.10.10.10? The router will packet-switch the packet to interface FastEthernet 0/0, and this interface will frame the packet and then send it out on the network segment.

Because we can, let's do another example: Based on the output of the next routing table, which interface will a packet with a destination address of 10.10.10.14 be forwarded from?

```
Lab_A#sh ip route
[output cut]
Gateway of last resort is not set
C       10.10.10.16/28 is directly connected, FastEthernet0/0
```

```
C       10.10.10.8/29 is directly connected, FastEthernet0/1
C       10.10.10.4/30 is directly connected, FastEthernet0/2
C       10.10.10.0/30 is directly connected, Serial 0/0
```

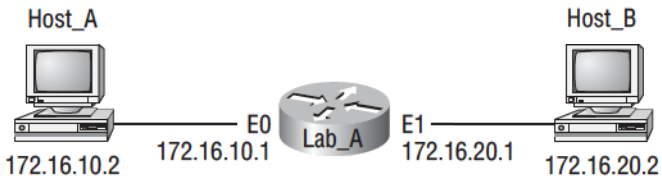
First, you can see that the network is subnetted and each interface has a different mask. And I have to tell you—you just can't answer this question if you can't subnet! 10.10.10.14 would be a host in the 10.10.10.8/29 subnet connected to the FastEthernet0/1 interface. Don't freak out if you don't get it. Just go back and reread Chapter 3 if you're struggling, and this should make perfect sense to you afterward.

For everyone who's ready to move on, let's get into this process in more detail.

The IP Routing Process

The IP routing process is fairly simple and doesn't change, regardless of the size of your network. For an example, we'll use Figure 6.2 to describe step-by-step what happens when Host_A wants to communicate with Host_B on a different network.

FIGURE 6.2 IP routing example using two hosts and one router



In this example, a user on Host_A pings Host_B's IP address. Routing doesn't get simpler than this, but it still involves a lot of steps. Let's work through them:

1. Internet Control Message Protocol (ICMP) creates an echo request payload (which is just the alphabet in the data field).
2. ICMP hands that payload to Internet Protocol (IP), which then creates a packet. At a minimum, this packet contains an IP source address, an IP destination address, and a Protocol field with 01h. (Remember that Cisco likes to use *0x* in front of hex characters, so this could look like 0x01.) All of that tells the receiving host whom it should hand the payload to when the destination is reached—in this example, ICMP.
3. Once the packet is created, IP determines whether the destination IP address is on the local network or a remote one.
4. Since IP determines that this is a remote request, the packet needs to be sent to the default gateway so the packet can be routed to the remote network. The Registry in Windows is parsed to find the configured default gateway.
5. The default gateway of host 172.16.10.2 (Host_A) is configured to 172.16.10.1. For this packet to be sent to the default gateway, the hardware address of the router's interface

Ethernet 0 (configured with the IP address of 172.16.10.1) must be known. Why? So the packet can be handed down to the Data Link layer, framed, and sent to the router's interface that's connected to the 172.16.10.0 network. Because hosts only communicate via hardware addresses on the local LAN, it's important to recognize that for Host_A to communicate to Host_B, it has to send packets to the Media Access Control (MAC) address of the default gateway on the local network.

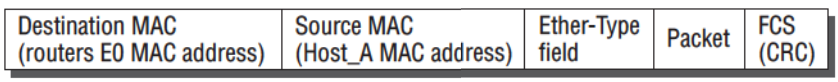
MAC addresses are always local on the LAN and never go through and past a router.

6. Next, the Address Resolution Protocol (ARP) cache of the host is checked to see if the IP address of the default gateway has already been resolved to a hardware address:
   - If it has, the packet is then free to be handed to the Data Link layer for framing. (The hardware destination address is also handed down with that packet.) To view the ARP cache on your host, use the following command:

     ```
     C:\>arp -a
     Interface: 172.16.10.2 --- 0x3
       Internet Address      Physical Address      Type
       172.16.10.1           00-15-05-06-31-b0     dynamic
     ```

   - If the hardware address isn't already in the ARP cache of the host, an ARP broadcast is sent out onto the local network to search for the hardware address of 172.16.10.1. The router responds to the request and provides the hardware address of Ethernet 0, and the host caches this address.
7. Once the packet and destination hardware address are handed to the Data Link layer, the LAN driver is used to provide media access via the type of LAN being used (in this example, Ethernet). A frame is then generated, encapsulating the packet with control information. Within that frame are the hardware destination and source addresses plus, in this case, an Ether-Type field that describes the Network layer protocol that handed the packet to the Data Link layer—in this instance, IP. At the end of the frame is something called a Frame Check Sequence (FCS) field that houses the result of the cyclic redundancy check (CRC). The frame would look something like what I've detailed in Figure 6.3. It contains Host_A's hardware (MAC) address and the destination hardware address of the default gateway. It does not include the remote host's MAC address—remember that!

FIGURE 6.3 Frame used from Host_A to the Lab_A router when Host_B is pinged



8. Once the frame is completed, it's handed down to the Physical layer to be put on the physical medium (in this example, twisted-pair wire) one bit at a time.
9. Every device in the collision domain receives these bits and builds the frame. They each run a CRC and check the answer in the FCS field. If the answers don't match, the frame is discarded.
   - If the CRC matches, then the hardware destination address is checked to see if it matches too (which, in this example, is the router's interface Ethernet 0).
   - If it's a match, then the Ether-Type field is checked to find the protocol used at the Network layer.
10. The packet is pulled from the frame, and what is left of the frame is discarded. The packet is handed to the protocol listed in the Ether-Type field—it's given to IP.
11. IP receives the packet and checks the IP destination address. Since the packet's destination address doesn't match any of the addresses configured on the receiving router itself, the router will look up the destination IP network address in its routing table.
12. The routing table must have an entry for the network 172.16.20.0 or the packet will be discarded immediately and an ICMP message will be sent back to the originating device with a destination network unreachable message.
13. If the router does find an entry for the destination network in its table, the packet is switched to the exit interface—in this example, interface Ethernet 1. The output below displays the Lab_A router's routing table. The **C** means "directly connected." No routing protocols are needed in this network since all networks (all two of them) are directly connected.

```
Lab_A>sh ip route
Codes:C - connected,S - static,I - IGRP,R - RIP,M - mobile,B -
   BGP, D - EIGRP,EX - EIGRP external,O - OSPF,IA - OSPF inter
   area, N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external
   type 2, E1 - OSPF external type 1, E2 - OSPF external type 2,
   E - EGP,i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia
   - IS-IS intearea * - candidate default, U - per-user static
   route, o - ODR P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Ethernet0
C       172.16.20.0 is directly connected, Ethernet1
```

14. The router packet-switches the packet to the Ethernet 1 buffer.

15. The Ethernet 1 buffer needs to know the hardware address of the destination host and first checks the ARP cache.
    - If the hardware address of Host_B has already been resolved and is in the router's ARP cache, then the packet and the hardware address are handed down to the Data Link layer to be framed. Let's take a look at the ARP cache on the Lab_A router by using the `show ip arp` command:

```
Lab_A#sh ip arp
Protocol  Address      Age(min) Hardware Addr  Type   Interface
Internet  172.16.20.1   -      00d0.58ad.05f4  ARPA   Ethernet0
Internet  172.16.20.2   3      0030.9492.a5dd  ARPA   Ethernet0
Internet  172.16.10.1   -      00d0.58ad.06aa  ARPA   Ethernet0
Internet  172.16.10.2   12     0030.9492.a4ac  ARPA   Ethernet0
```

      The dash (-) means that this is the physical interface on the router. From the output above, we can see that the router knows the 172.16.10.2 (Host_A) and 172.16.20.2 (Host_B) hardware addresses. Cisco routers will keep an entry in the ARP table for 4 hours.
    - If the hardware address has not already been resolved, the router sends an ARP request out E1 looking for the hardware address of 172.16.20.2. Host_B responds with its hardware address, and the packet and destination hardware address are both sent to the Data Link layer for framing.
16. The Data Link layer creates a frame with the destination and source hardware address, Ether-Type field, and FCS field at the end. The frame is handed to the Physical layer to be sent out on the physical medium one bit at a time.
17. Host_B receives the frame and immediately runs a CRC. If the result matches what's in the FCS field, the hardware destination address is then checked. If the host finds a match, the Ether-Type field is then checked to determine the protocol that the packet should be handed to at the Network layer—IP in this example.
18. At the Network layer, IP receives the packet and checks the IP destination address. Since there's finally a match made, the Protocol field is checked to find out whom the payload should be given to.
19. The payload is handed to ICMP, which understands that this is an echo request. ICMP responds to this by immediately discarding the packet and generating a new payload as an echo reply.
20. A packet is then created including the source and destination addresses, Protocol field, and payload. The destination device is now Host_A.
21. IP then checks to see whether the destination IP address is a device on the local LAN or on a remote network. Since the destination device is on a remote network, the packet needs to be sent to the default gateway.
22. The default gateway IP address is found in the Registry of the Windows device, and the ARP cache is checked to see if the hardware address has already been resolved from an IP address.
23. Once the hardware address of the default gateway is found, the packet and destination hardware addresses are handed down to the Data Link layer for framing.

24. The Data Link layer frames the packet of information and includes the following in the header:
    - The destination and source hardware addresses
    - The Ether-Type field with 0x0800 (IP) in it
    - The FCS field with the CRC result in tow
25. The frame is now handed down to the Physical layer to be sent out over the network medium one bit at a time.
26. The router's Ethernet 1 interface receives the bits and builds a frame. The CRC is run, and the FCS field is checked to make sure the answers match.
27. Once the CRC is found to be okay, the hardware destination address is checked. Since the router's interface is a match, the packet is pulled from the frame and the Ether-Type field is checked to see what protocol at the Network layer the packet should be delivered to.
28. The protocol is determined to be IP, so it gets the packet. IP runs a CRC check on the IP header first and then checks the destination IP address.

IP does not run a complete CRC as the Data Link layer does—it only checks the header for errors.

Since the IP destination address doesn't match any of the router's interfaces, the routing table is checked to see whether it has a route to 172.16.10.0. If it doesn't have a route over to the destination network, the packet will be discarded immediately. (This is the source point of confusion for a lot of administrators—when a ping fails, most people think the packet never reached the destination host. But as we see here, that's not *always* the case. All it takes is for just one of the remote routers to be lacking a route back to the originating host's network and—*poof!*—the packet is dropped on the *return trip*, not on its way to the host.)

Just a quick note to mention that when (if) the packet is lost on the way back to the originating host, you will typically see a "request timed out" message because it is an unknown error. If the error occurs because of a known issue, such as if a route is not in the routing table on the way to the destination device, you will see a destination unreachable message. This should help you determine if the problem occurred on the way to the destination or on the way back.

29. In this case, the router does know how to get to network 172.16.10.0—the exit interface is Ethernet 0—so the packet is switched to interface Ethernet 0.
30. The router checks the ARP cache to determine whether the hardware address for 172.16.10.2 has already been resolved.

31. Since the hardware address to 172.16.10.2 is already cached from the originating trip to Host_B, the hardware address and packet are handed to the Data Link layer.
32. The Data Link layer builds a frame with the destination hardware address and source hardware address and then puts IP in the Ether-Type field. A CRC is run on the frame and the result is placed in the FCS field.
33. The frame is then handed to the Physical layer to be sent out onto the local network one bit at a time.
34. The destination host receives the frame, runs a CRC, checks the destination hardware address, and looks in the Ether-Type field to find out whom to hand the packet to.
35. IP is the designated receiver, and after the packet is handed to IP at the Network layer, it checks the protocol field for further direction. IP finds instructions to give the payload to ICMP, and ICMP determines the packet to be an ICMP echo reply.
36. ICMP acknowledges that it has received the reply by sending an exclamation point (!) to the user interface. ICMP then attempts to send four more echo requests to the destination host.

You've just experienced Todd's 36 easy steps to understanding IP routing. The key point to understand here is that if you had a much larger network, the process would be the *same*. In a really big internetwork, the packet just goes through more hops before it finds the destination host.

It's super-important to remember that when Host_A sends a packet to Host_B, the destination hardware address used is the default gateway's Ethernet interface. Why? Because frames can't be placed on remote networks—only local networks. So packets destined for remote networks must go through the default gateway.

Let's take a look at Host_A's ARP cache now:

```
C:\ >arp -a
Interface: 172.16.10.2 --- 0x3
  Internet Address      Physical Address      Type
  172.16.10.1           00-15-05-06-31-b0     dynamic
  172.16.20.1           00-15-05-06-31-b0     dynamic
```

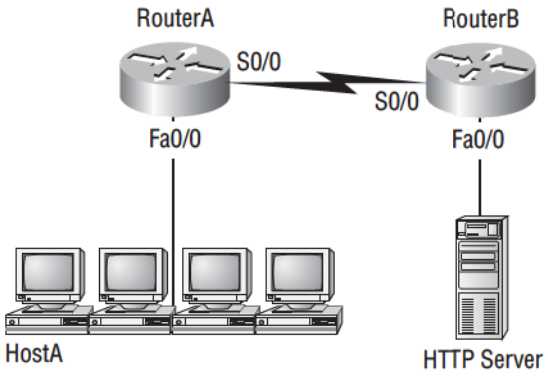
Did you notice that the hardware (MAC) address that Host_A uses to get to Host_B is the Lab_A E0 interface? Hardware addresses are *always* local, and they never pass a router's interface. Understanding this process is as important as air to you, so carve this into your memory!

Testing Your IP Routing Understanding

I really want to make sure you understand IP routing because it's super-important. So I'm going to use this section to test your understanding of the IP routing process by having you look at a couple of figures and answer some very basic IP routing questions.

Figure 6.4 shows a LAN connected to RouterA, which is, in turn, connected via a WAN link to RouterB. RouterB has a LAN connected with an HTTP server attached.

FIGURE 6.4 IP routing example 1



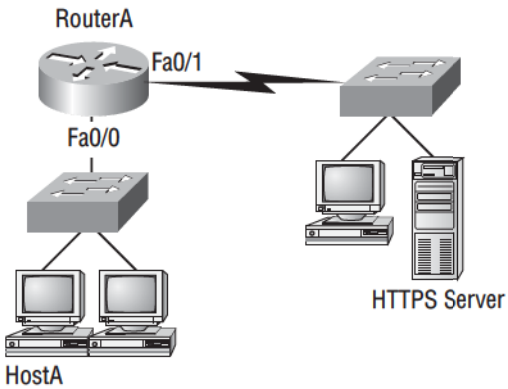
The critical information you need to glean from this figure is exactly how IP routing will occur in this example. Okay—we'll cheat a bit. I'll give you the answer, but then you should go back over the figure and see if you can answer example 2 without looking at my answers.

1. The destination address of a frame, from HostA, will be the MAC address of the F0/0 interface of the RouterA router.
2. The destination address of a packet will be the IP address of the network interface card (NIC) of the HTTP server.
3. The destination port number in the segment header will have a value of 80.

That example was a pretty simple one, and it was also very to the point. One thing to remember is that if multiple hosts are communicating to the server using HTTP, they must all use a different source port number. That is how the server keeps the data separated at the Transport layer.

Let's mix it up a little and add another internetworking device into the network and then see if you can find the answers. Figure 6.5 shows a network with only one router but two switches.

FIGURE 6.5 IP routing example 2



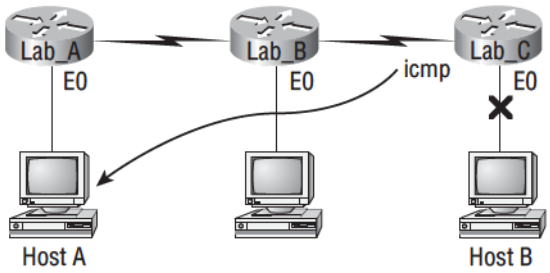
What you want to understand about the IP routing process here is what happens when HostA sends data to the HTTPS server:

1. The destination address of a frame, from HostA, will be the MAC address of the F0/0 interface of the RouterA router.
2. The destination address of a packet will be the IP address of the network interface card (NIC) of the HTTPS server.
3. The destination port number in the segment header will have a value of 443.

Notice that the switches weren't used as either a default gateway or another destination. That's because switches have nothing to do with routing. I wonder how many of you chose the switch as the default gateway (destination) MAC address for HostA? If you did, don't feel bad—just take another look with that fact in mind. It's very important to remember that the destination MAC address will always be the router's interface—if your packets are destined for outside the LAN, as they were in these last two examples.

Before we move into some of the more advanced aspects of IP routing, let's discuss ICMP in more detail, as well as how ICMP is used in an internetwork. Take a look at the network shown in Figure 6.6. Ask yourself what will happen if the LAN interface of Lab_C goes down.

FIGURE 6.6 ICMP error example



Lab_C will use ICMP to inform Host A that Host B can't be reached, and it will do this by sending an ICMP destination unreachable message. Lots of people think that the Lab_A router would be sending this message, but they would be wrong because the router that sends the message is the one with that interface that's down is located.

Let's look at another problem: Look at the output of a corporate router's routing table:

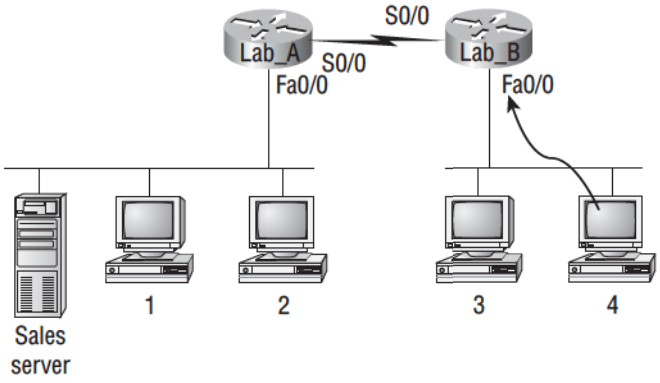
```
Corp#sh ip route
[output cut]
R    192.168.215.0 [120/2] via 192.168.20.2, 00:00:23, Serial0/0
R    192.168.115.0 [120/1] via 192.168.20.2, 00:00:23, Serial0/0
R    192.168.30.0 [120/1] via 192.168.20.2, 00:00:23, Serial0/0
C    192.168.20.0 is directly connected, Serial0/0
C    192.168.214.0 is directly connected, FastEthernet0/0
```

What do we see here? If I were to tell you that the corporate router received an IP packet with a source IP address of 192.168.214.20 and a destination address of 192.168.22.3, what do you think the Corp router will do with this packet?

If you said, "The packet came in on the FastEthernet 0/0 interface, but since the routing table doesn't show a route to network 192.168.22.0 (or a default route), the router will discard the packet and send an ICMP destination unreachable message back out interface FastEthernet 0/0," you're a genius! The reason it does this is because that's the source LAN where the packet originated from.

Now, let's check out another figure and talk about the frames and packets in detail. Really, we're not exactly chatting about anything new; I'm just making sure that you totally, completely, fully understand basic IP routing. That's because this book, and the exam objectives it's geared toward, are all about IP routing, which means you need to be all over this stuff! We'll use Figure 6.7 for the next few questions.

FIGURE 6.7 Basic IP routing using MAC and IP addresses



Referring to Figure 6.7, here's a list of all the questions you need the answers to emblazoned in your brain:

1. In order to begin communicating with the Sales server, Host 4 sends out an ARP request. How will the devices exhibited in the topology respond to this request?
2. Host 4 has received an ARP reply. Host 4 will now build a packet, then place this packet in the frame. What information will be placed in the header of the packet that leaves Host 4 if Host 4 is going to communicate to the Sales server?
3. At last, the Lab_A router has received the packet and will send it out Fa0/0 onto the LAN toward the server. What will the frame have in the header as the source and destination addresses?
4. Host 4 is displaying two web documents from the Sales server in two browser windows at the same time. How did the data find its way to the correct browser windows?

I probably should write the following in a teensy font and put them upside down in another part of the book so it would be really hard for you to cheat and peek, but since it's actually you who's going to lose out if you peek, here are your answers:

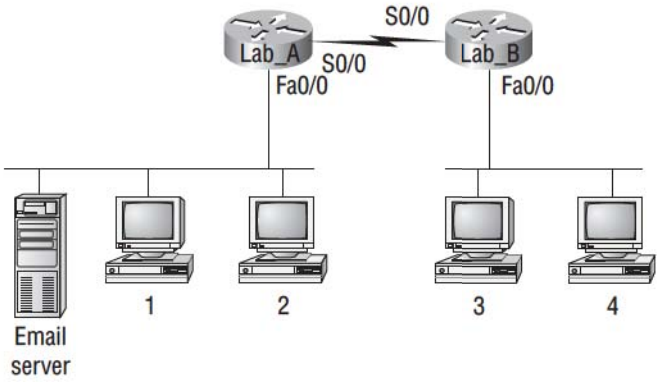
1. In order to begin communicating with the server, Host 4 sends out an ARP request. How will the devices exhibited in the topology respond to this request? Since MAC addresses must stay on the local network, the Lab_B router will respond with the MAC address of

the Fa0/0 interface and Host 4 will send all frames to the MAC address of the Lab_B Fa0/0 interface when sending packets to the Sales server.

2. Host 4 has received an ARP reply. Host 4 will now build a packet, then place this packet in the frame. What information will be placed in the header of the packet that leaves Host 4 if Host 4 is going to communicate to the Sales server? Since we're now talking about packets, not frames, the source address will be the IP address of Host 4 and the destination address will be the IP address of the Sales server.
3. Finally, the Lab_A router has received the packet and will send it out Fa0/0 onto the LAN toward the server. What will the frame have in the header as the source and destination addresses? The source MAC address will be the Lab_A router's Fa0/0 interface, and the destination MAC address will be the Sales server's MAC address. (All MAC addresses must be local on the LAN.)
4. Host 4 is displaying two web documents from the Sales server in two different browser windows at the same time. How did the data find its way to the correct browser windows? TCP port numbers are used to direct the data to the correct application window.

Great! But we're not quite done yet. I've got a few more questions for you before you actually get to configure routing in a real network. Ready? Figure 6.8 shows a basic network, and Host 4 needs to get email. Which address will be placed in the destination address field of the frame when it leaves Host 4?

FIGURE 6.8 Testing basic routing knowledge



The answer is that Host 4 will use the destination MAC address of the Fa0/0 interface of the Lab_B router—which I'm so sure you knew, right? Look at Figure 6.8 again: Host 4 needs to communicate to Host 1. Which OSI layer 3 source address will be placed in the packet header when it reaches Host 1?

Hopefully you know this: At layer 3, the source IP address will be Host 4 and the destination address in the packet will be the IP address of Host 1. Of course, the destination MAC address from Host 4 will always be the Fa0/0 address of the Lab_B router, right? And since we have more than one router, we'll need a routing protocol that communicates between both of them so that traffic can be forwarded in the right direction to reach the network in which Host 1 is attached.