5. Which of the following are true about a LAN-connected TCP/IP host and its IP routing (forwarding) choices?

   a. The host always sends packets to its default gateway.

   b. The host never sends packets to its default gateway.

   c. The host sends packets to its default gateway if the destination IP address is in a different subnet than the host.

   d. The host sends packets to its default gateway if the destination IP address is in the same subnet as the host.

6. Which of the following are functions of a routing protocol? (Choose two answers.)

   a. Advertising known routes to neighboring routers

   b. Learning routes for subnets directly connected to the router

   c. Learning routes and putting those routes into the routing table for routes advertised to the router by its neighboring routers

   d. Forwarding IP packets based on a packet's destination IP address

7. A company implements a TCP/IP network, with PC1 sitting on an Ethernet LAN. Which of the following protocols and features requires PC1 to learn information from some other server device?

   a. ARP

   b. ping

   c. DNS

   d. None of these answers is correct.

Foundation Topics

Wide-Area Networks

Imagine a typical day at the branch office at some enterprise. The user sits at some endpoint device: a PC, tablet, phone, and so on. It connects to a LAN, either via an Ethernet cable or using a wireless LAN. However, the user happens to be checking information on a website, and that web server sits at the home office of the company. To make that work, the data travels over one or more wide-area network (WAN) links.

WAN technologies define the physical (Layer 1) standards and data-link (Layer 2) protocols used to communicate long distances. This first section examines two such technologies: leased-line WANs and Ethernet WANs. Leased-line WANs have been an option for networks for half a century, are becoming much less common today, but you may still see some leased-line WAN links in the exam. Ethernet WAN links do use the same data-link protocols as Ethernet LANs, but they use additional features to make the links work over the much longer distances required for WANs. The next few pages examine leased-line WANs first, followed by Ethernet WANs.

đường dây thuê riêng

Leased-Line WANs

To connect LANs using a WAN, the internetwork uses a router connected to each LAN, with a WAN link between the routers. First, the enterprise's network engineer would order some kind of WAN link. A router at each site connects to both the WAN link and the LAN, as shown in Figure 3-1. Note that a crooked (đường gấp khúc) line between the routers is the common way to represent a leased line when the drawing does not need to show any of the physical details of the line.

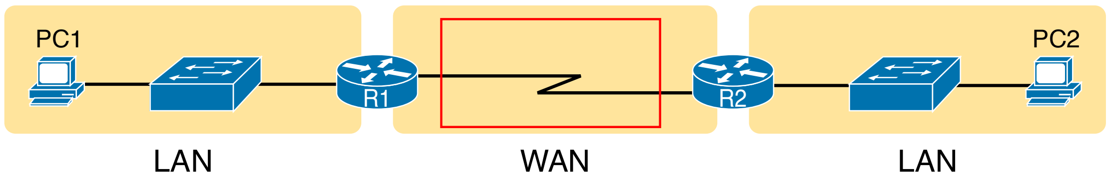

Figure 3-1 *Small Enterprise Network with One Leased Line*

This section begins by examining the physical details of leased lines, followed by a discussion of the default data-link protocol for leased lines (HDLC).

Physical Details of Leased Lines

The leased line service delivers bits in both directions, at a predetermined speed, using full-duplex logic. In fact, conceptually it acts as if you had a full-duplex crossover Ethernet link between two routers, as shown in Figure 3-2. The leased line uses two pairs of wires, one pair for each direction of sending data, which allows full-duplex operation.

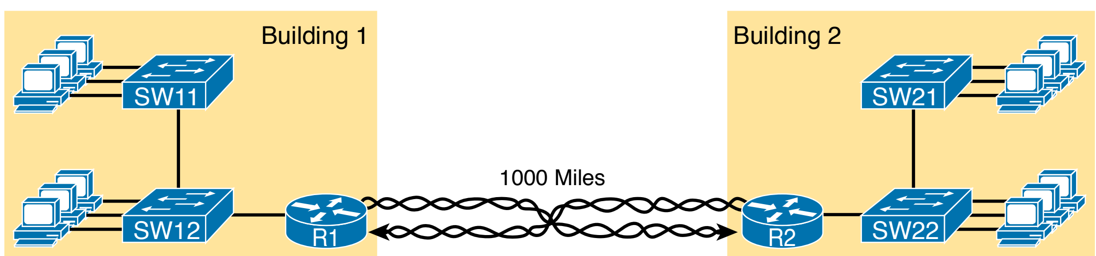

Figure 3-2 *Conceptual View of the Leased-Line Service*

Of course, leased lines have many differences compared to an Ethernet crossover cable. To create such possibly long links, or circuits, a leased line does not actually exist as a single long cable between the two sites. Instead, the telephone company (telco) that creates the leased line installs a large network of cables and specialized switching devices to create its own computer network. The telco network creates a service that acts like a crossover cable between two points, but the physical reality is hidden from the customer.

Leased lines come with their own set of terminology as well. First, the term *leased line* refers to the fact that the company using the leased line does not own the line but instead pays a monthly lease fee to use it. Table 3-2 lists some of the many names for leased lines, mainly so that in a networking job, you have a chance to translate from the terms each person uses with a basic description as to the meaning of the name.

Table 3-2 Different Names for a Leased Line

Name	Meaning or Reference
Leased circuit, Circuit	The words *line* and *circuit* are often used as synonyms in telco terminology; *circuit* makes reference to the electrical circuit between the two endpoints.
Serial link, Serial line	The words *link* and *line* are also often used as synonyms. *Serial* in this case refers to the fact that the bits flow serially and that routers use serial interfaces. tuần tự
Point-to-point link, Point-to-point line	These terms refer to the fact that the topology stretches between two points, and two points only. (Some older leased lines allowed more than two devices.)
T1	This specific type of leased line transmits data at 1.544 megabits per second (1.544 Mbps).
WAN link, Link	Both of these terms are very general, with no reference to any specific technology.
Private line	This term refers to the fact that the data sent over the line cannot be copied by other telco customers, so the data is private.

To create a leased line, some physical path must exist between the two routers on the ends of the link. The physical cabling must leave the customer buildings where each router sits. However, the telco does not simply install one cable between the two buildings. Instead, it uses what is typically a large and complex network that creates the appearance of a cable between the two routers.

công ty viễn thông không chỉ lắp đặt một cáp giữa hai tòa nhà. Thay vào đó, họ sử dụng thứ thường là mạng lớn và phức tạp tạo ra vẻ ngoài của một sợi cáp giữa hai bộ định tuyến.

Figure 3-3 gives a little insight into the cabling that could exist inside the telco for a short leased line. Telcos put their equipment in buildings called central offices (CO). The telco installs cables from the CO to most every other building in the city, expecting to sell services to the people in those buildings one day. The telco would then configure its switches to use some of the capacity on each cable to send data in both directions, creating the equivalent of a crossover cable between the two routers.

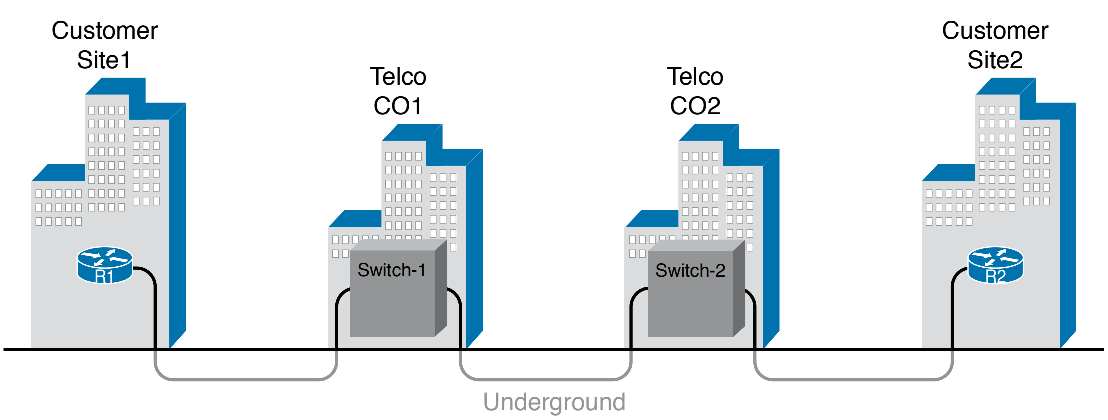

Figure 3-3 *Possible Cabling Inside a Telco for a Short Leased Line*

Các công ty viễn thông đặt thiết bị của họ trong các tòa nhà được gọi là văn phòng trung tâm (CO). Công ty viễn thông lắp đặt cáp từ CO đến hầu hết mọi tòa nhà khác trong thành phố, với kỳ vọng một ngày nào đó sẽ bán dịch vụ cho những người trong các tòa nhà đó. Sau đó, công ty viễn thông sẽ định cấu hình các thiết bị chuyển mạch của mình để sử dụng một số dung lượng trên mỗi cáp để gửi dữ liệu theo cả hai hướng, tạo ra tương đương với cáp chéo giữa hai bộ định tuyến.

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

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

Although the customer does not need to know all the details of how a telco creates a particular leased line, enterprise engineers do need to know about the parts of the link that exist inside the customer's building at the router. However, for the purposes of CCNA, you can think of any serial link as a point-to-point connection between two routers.

HDLC Data-Link Details of Leased Lines

A leased line provides a Layer 1 service. In other words, it promises to deliver bits between the devices connected to the leased line. However, the leased line itself does not define a data-link layer protocol to be used on the leased line.

Because leased lines define only the Layer 1 transmission service, many companies and standards organizations have created data-link protocols to control and use leased lines. Today, the two most popular data-link layer protocols used for leased lines between two routers are High-Level Data Link Control (HDLC) and Point-to-Point Protocol (PPP).

All data-link protocols perform a similar role: to control the correct delivery of data over a physical link of a particular type. For example, the Ethernet data-link protocol uses a destination address field to identify the correct device that should receive the data and an FCS field that allows the receiving device to determine whether the data arrived correctly. HDLC provides similar functions.

HDLC has less work to do than Ethernet because of the simple point-to-point topology of a leased line. When one router sends an HDLC frame, the frame can go only one place: to the other end of the link. So, while HDLC has an address field, the destination is implied, and the actual address is unimportant. The idea is sort of like when I have lunch with my friend Gary, and only Gary. I do not need to start every sentence with "Hey, Gary"—he knows I am talking to him.

HDLC has other fields and functions similar to Ethernet as well. Table 3-3 lists the HDLC fields, with the similar Ethernet header/trailer field, just for the sake of learning HDLC based on something you have already learned about (Ethernet).

Table 3-3 Comparing HDLC Header Fields to Ethernet

HDLC Field	Ethernet Equivalent	Description
Flag	Preamble, SFD	Lists a recognizable bit pattern so that the receiving nodes realize that a new frame is arriving.
Address	Destination Address	Identifies the destination device.
Control	N/A	Mostly used for purposes no longer in use today for links between routers.
Type	Type	Identifies the type of Layer 3 packet encapsulated inside the frame.
FCS	FCS	Identifies a field used by the error detection process. (It is the only trailer field in this table.)

HDLC exists today as a standard of the International Organization for Standardization (ISO), the same organization that brought us the OSI model. However, ISO standard HDLC does not have a Type field, and routers need to know the type of packet inside the frame. So, Cisco routers use a Cisco-proprietary variation of HDLC that adds a Type field, as shown in Figure 3-4.

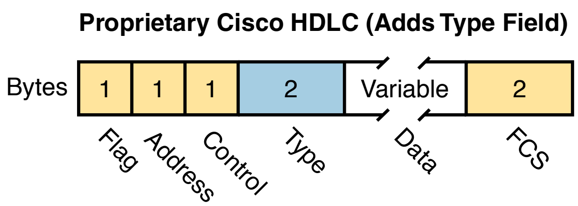

Figure 3-4 *HDLC Framing*

How Routers Use a WAN Data Link

Leased lines connect to routers, and routers focus on delivering packets to a destination host. However, routers physically connect to both LANs and WANs, with those LANs and WANs requiring that data be sent inside data-link frames. So, now that you know a little about HDLC, it helps to think about how routers use the HDLC protocol when sending data.

First, the TCP/IP network layer focuses on forwarding IP packets from the sending host to the destination host. The underlying LANs and WANs just act as a way to move the packets to the next router or end-user device. Figure 3-5 shows that network layer perspective.

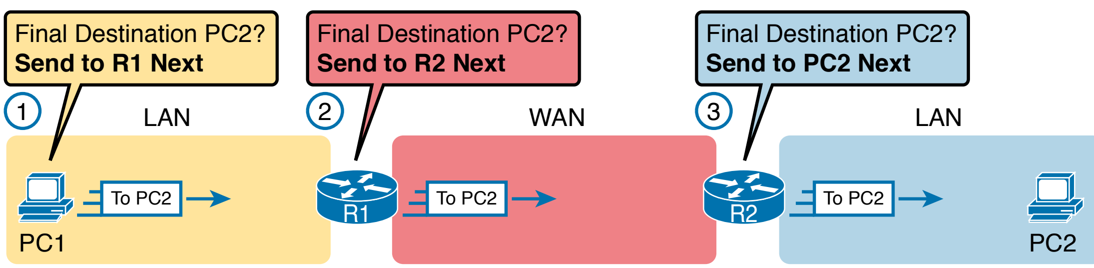

Figure 3-5 *IP Routing Logic over LANs and WANs*

Following the steps in the figure, for a packet sent by PC1 to PC2's IP address:

1. PC1's network layer (IP) logic tells it to send the packet to a nearby router (R1).
2. Router R1's network layer logic tells it to forward (route) the packet out the leased line to Router R2 next.
3. Router R2's network layer logic tells it to forward (route) the packet out the LAN link to PC2 next.

While Figure 3-5 shows the network layer logic, the PCs and routers must rely on the LANs and WANs in the figure to actually move the bits in the packet. Figure 3-6 shows the same figure, with the same packet, but this time showing some of the data-link layer logic used by the hosts and routers. Basically, three separate data-link layer steps encapsulate the packet, inside a data-link frame, over three hops through the internetwork: from PC1 to R1, from R1 to R2, and from R2 to PC2.

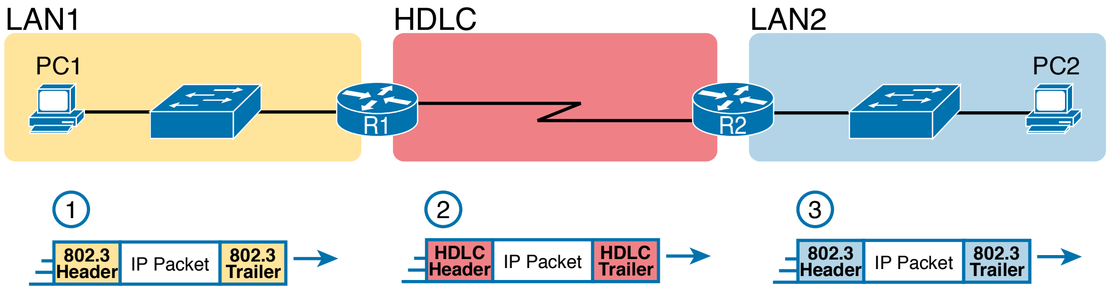

Figure 3-6 *General Concept of Routers De-encapsulating and Re-encapsulating IP Packets*

3

Following the steps in the figure, again for a packet sent by PC1 to PC2's IP address:

1. To send the IP packet to Router R1 next, PC1 encapsulates the IP packet in an Ethernet frame that has the destination MAC address of R1.
2. Router R1 de-encapsulates (removes) the IP packet from the Ethernet frame, encapsulates the packet into an HDLC frame using an HDLC header and trailer, and forwards the HDLC frame to Router R2 next.
3. Router R2 de-encapsulates (removes) the IP packet from the HDLC frame, encapsulates the packet into an Ethernet frame that has the destination MAC address of PC2, and forwards the Ethernet frame to PC2.

In summary, a leased line with HDLC creates a WAN link between two routers so that they can forward packets for the devices on the attached LANs. The leased line itself provides the physical means to transmit the bits, in both directions. The HDLC frames provide the means to encapsulate the network layer packet correctly so that it crosses the link between routers.

Leased lines have many benefits that have led to their relatively long life in the WAN marketplace. These lines are simple for the customer, are widely available, are of high quality, and are private. However, they do have some negatives as well compared to newer WAN technologies, including a higher cost and typically longer lead times to get the service installed. Additionally, by today's standards, leased-line LANs are slow, with faster speeds in the tens of megabits per second (Mbps). New faster WAN technology has been replacing leased lines for a long time, including the second WAN technology discussed in this book: Ethernet.

Ethernet as a WAN Technology

For the first several decades of the existence of Ethernet, Ethernet was only appropriate for LANs. The restrictions on cable lengths and devices might allow a LAN that stretched a kilometer or two, to support a campus LAN, but that was the limit.

As time passed, the IEEE improved Ethernet standards in ways that made Ethernet a reasonable WAN technology. For example, the 1000BASE-LX standard uses single-mode fiber cabling, with support for a 5-km cable length; the 1000BASE-ZX standard supports an even longer 70-km cable length. As time went by, and as the IEEE improved cabling distances for fiber Ethernet links, Ethernet became a reasonable WAN technology.

Today, many WAN service providers (SP) offer WAN services that take advantage of Ethernet. SPs offer a wide variety of these Ethernet WAN services, with many different names. But all of them use a similar model, with Ethernet used between the customer site and the SP's network, as shown in Figure 3-7.

Key Topic

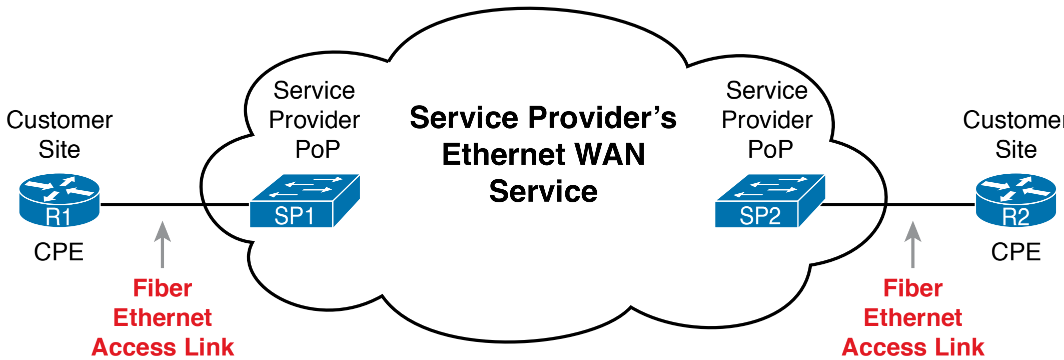

Figure 3-7 *Fiber Ethernet Link to Connect a CPE Router to a Service Provider's WAN*

The model shown in Figure 3-7 has many of the same ideas of how a telco creates a leased line, as shown earlier in Figure 3-3, but now with Ethernet links and devices. The customer connects to an Ethernet link using a router interface. The (fiber) Ethernet link leaves the customer building and connects to some nearby SP location called a point of presence (PoP). Instead of a telco switch as shown in Figure 3-3, the SP uses an Ethernet switch. Inside the SP's network, the SP uses any technology that it wants to create the specific Ethernet WAN services.

Ethernet WANs That Create a Layer 2 Service

Ethernet WAN services include a variety of specific services that vary in ways that change how routers use those services. However, for the purposes of CCNA, you just need to understand the most basic Ethernet WAN service, one that works much like an Ethernet crossover cable—just over a WAN. In other words:

- Logically, behaves like a point-to-point connection between two routers
- Physically, behaves as if a physical fiber Ethernet link existed between the two routers

NOTE For perspective about the broad world of the service provider network shown in Figure 3-7, look for more information about the Cisco CCNA, CCNP Service Provider, and CCIE Service Provider certifications. See www.cisco.com/go/certifications for more details.

This book refers to this particular Ethernet WAN service with a couple of the common names:

Ethernet WAN: A generic name to differentiate it from an Ethernet LAN.

Ethernet Line Service (E-Line): A term from the Metro Ethernet Forum (MEF) for the kind of point-to-point Ethernet WAN service shown throughout this book.

Ethernet emulation: A term emphasizing that the link is not a literal Ethernet link from end to end.

Ethernet over MPLS (EoMPLS): A term that refers to Multiprotocol Label Switching (MPLS), a technology that can be used to create the Ethernet service for the customer.

So, if you can imagine two routers, with a single Ethernet link between the two routers, you understand what this particular EoMPLS service does, as shown in Figure 3-8. In this case, the two routers, R1 and R2, connect with an EoMPLS service instead of a serial link. The routers use Ethernet interfaces, and they can send data in both directions at the same time. Physically, each router actually connects to some SP PoP, as shown earlier in Figure 3-7, but logically, the two routers can send Ethernet frames to each other over the link.

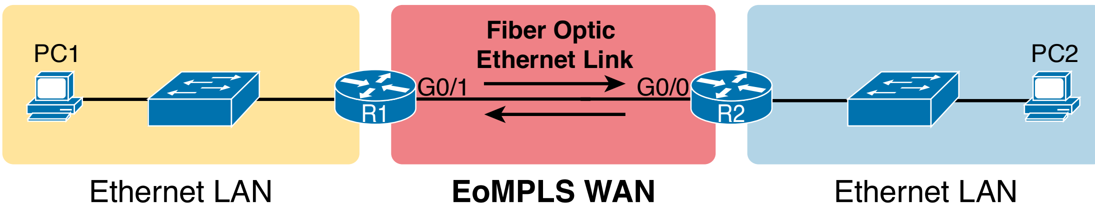

Figure 3-8 *EoMPLS Acting Like a Simple Ethernet Link Between Two Routers*

How Routers Route IP Packets Using Ethernet Emulation

WANs, by their very nature, give IP routers a way to forward IP packets from a LAN at one site, over the WAN, and to another LAN at another site. Routing over an EoMPLS WAN link still uses the WAN like a WAN, as a way to forward IP packets from one site to another. However, the WAN link happens to use the same Ethernet protocols as the Ethernet LAN links at each site.

The EoMPLS link uses Ethernet for both Layer 1 and Layer 2 functions. That means the link uses the same familiar Ethernet header and trailer, as shown in the middle of Figure 3-9. Note that the figure shows a small cloud over the Ethernet link as a way to tell us that the link is an Ethernet WAN link, rather than an Ethernet LAN link.

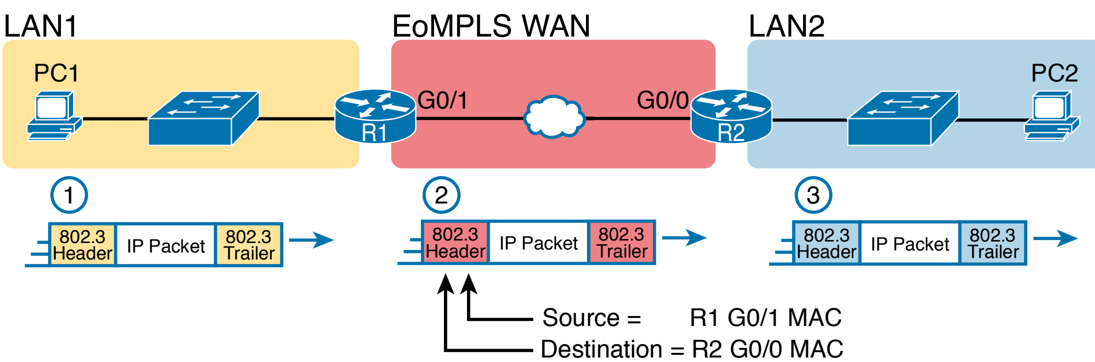

Figure 3-9 *Routing over an EoMPLS Link*

NOTE The 802.3 headers/trailers in the figure are different at each stage! Make sure to notice the reasons in the step-by-step explanations that follow.

The figure shows the same three routing steps as shown with the serial link in the earlier Figure 3-6. In this case, all three routing steps use the same Ethernet (802.3) protocol. However, note that each frame's data-link header and trailer are different. Each router discards the old data-link header/trailer and adds a new set, as described in these steps. Focus mainly on Step 2, because compared to the similar example shown in Figure 3-6, Steps 1 and 3 are unchanged:

1. To send the IP packet to Router R1 next, PC1 encapsulates the IP packet in an Ethernet frame that has the destination MAC address of R1.
2. Router R1 de-encapsulates (removes) the IP packet from the Ethernet frame and encapsulates the packet into a new Ethernet frame, with a new Ethernet header and trailer. The destination MAC address is R2's G0/0 MAC address, and the source MAC address is R1's G0/1 MAC address. R1 forwards this frame over the EoMPLS service to R2 next.
3. Router R2 de-encapsulates (removes) the IP packet from the Ethernet frame, encapsulates the packet into an Ethernet frame that has the destination MAC address of PC2, and forwards the Ethernet frame to PC2.

Throughout this book, the WAN links (serial and Ethernet) will connect routers as shown here, with the focus being on the LANs and IP routing. The rest of the chapter turns our attention to a closer look at IP routing.

IP Routing

Many protocol models have existed over the years, but today the TCP/IP model dominates. And at the network layer of TCP/IP, two options exist for the main protocol around which all other network layer functions revolve: IP version 4 (IPv4) and IP version 6 (IPv6). Both IPv4 and IPv6 define the same kinds of network layer functions, but with different details. This chapter introduces these network layer functions for IPv4.

NOTE All references to IP in this chapter refer to the older and more established IPv4.

Internet Protocol (IP) focuses on the job of routing data, in the form of IP packets, from the source host to the destination host. IP does not concern itself with the physical transmission of data, instead relying on the lower TCP/IP layers to do the physical transmission of the data. Instead, IP concerns itself with the logical details, rather than physical details, of delivering data. In particular, the network layer specifies how packets travel end to end over a TCP/IP network, even when the packet crosses many different types of LAN and WAN links.

This next major section of the chapter examines IP routing in more depth. First, IP defines what it means to route an IP packet from sending host to destination host, while using successive data-link protocols. This section then examines how IP addressing rules help to make IP routing much more efficient by grouping addresses into subnets. This section closes by looking at the role of IP routing protocols, which give routers a means by which to learn routes to all the IP subnets in an internetwork.

Network Layer Routing (Forwarding) Logic

Routers and end-user computers (called *hosts* in a TCP/IP network) work together to perform IP routing. The host operating system (OS) has TCP/IP software, including the software that implements the network layer. Hosts use that software to choose where to send IP packets,