

## Overview

### Objectives

Part 1 provides a general idea of what we will see in the rest of the book. Four major concepts are discussed: data communications, networking, protocols and standards, and networking models.

Networks exist so that data may be sent from one place to another—the basic concept of *data communications*. To fully grasp this subject, we must understand the data communication components, how different types of data can be represented, and how to create a data flow.

Data communications between remote parties can be achieved through a process called *networking*, involving the connection of computers, media, and networking devices. Networks are divided into two main categories: local area networks (LANs) and wide area networks (WANs). These two types of networks have different characteristics and different functionalities. The Internet, the main focus of the book, is a collection of LANs and WANs held together by internetworking devices.

*Protocols and standards* are vital to the implementation of data communications and networking. Protocols refer to the rules; a standard is a protocol that has been adopted by vendors and manufacturers.

*Network models* serve to organize, unify, and control the hardware and software components of data communications and networking. Although the term “network model” suggests a relationship to networking, the model also encompasses data communications.

### Chapters

This part consists of two chapters: Chapter 1 and Chapter 2.

#### *Chapter 1*

In Chapter 1, we introduce the concepts of data communications and networking. We discuss data communications components, data representation, and data flow. We then move to the structure of networks that carry data. We discuss network topologies, categories of networks, and the general idea behind the Internet. The section on protocols and standards gives a quick overview of the organizations that set standards in data communications and networking.

## *Chapter 2*

The two dominant networking models are the Open Systems Interconnection (OSI) and the Internet model (TCP/IP). The first is a theoretical framework; the second is the actual model used in today's data communications. In Chapter 2, we first discuss the OSI model to give a general background. We then concentrate on the Internet model, which is the foundation for the rest of the book.

# CHAPTER 1

## *Introduction*

Data communications and networking are changing the way we do business and the way we live. Business decisions have to be made ever more quickly, and the decision makers require immediate access to accurate information. Why wait a week for that report from Germany to arrive by mail when it could appear almost instantaneously through computer networks? Businesses today rely on computer networks and internetworks. But before we ask how quickly we can get hooked up, we need to know how networks operate, what types of technologies are available, and which design best fills which set of needs.

The development of the personal computer brought about tremendous changes for business, industry, science, and education. A similar revolution is occurring in data communications and networking. Technological advances are making it possible for communications links to carry more and faster signals. As a result, services are evolving to allow use of this expanded capacity. For example, established telephone services such as conference calling, call waiting, voice mail, and caller ID have been extended.

Research in data communications and networking has resulted in new technologies. One goal is to be able to exchange data such as text, audio, and video from all points in the world. We want to access the Internet to download and upload information quickly and accurately and at any time.

This chapter addresses four issues: data communications, networks, the Internet, and protocols and standards. First we give a broad definition of data communications. Then we define networks as a highway on which data can travel. The Internet is discussed as a good example of an internetwork (i.e., a network of networks). Finally, we discuss different types of protocols, the difference between protocols and standards, and the organizations that set those standards.

---

### 1.1 DATA COMMUNICATIONS

When we communicate, we are sharing information. This sharing can be local or remote. Between individuals, local communication usually occurs face to face, while remote communication takes place over distance. The term *telecommunication*, which

includes telephony, telegraphy, and television, means communication at a distance (*tele* is Greek for “far”).

The word **data** refers to information presented in whatever form is agreed upon by the parties creating and using the data.

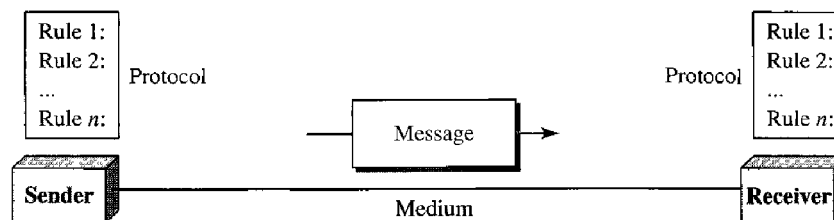
**Data communications** are the exchange of data between two devices via some form of transmission medium such as a wire cable. For data communications to occur, the communicating devices must be part of a communication system made up of a combination of hardware (physical equipment) and software (programs). The effectiveness of a data communications system depends on four fundamental characteristics: delivery, accuracy, timeliness, and jitter.

1. **Delivery.** The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.
2. **Accuracy.** The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.
3. **Timeliness.** The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called *real-time* transmission.
4. **Jitter.** Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets. For example, let us assume that video packets are sent every 30 ms. If some of the packets arrive with 30-ms delay and others with 40-ms delay, an uneven quality in the video is the result.

## Components

A data communications system has five components (see Figure 1.1).

**Figure 1.1** Five components of data communication



1. **Message.** The **message** is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.
2. **Sender.** The **sender** is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.
3. **Receiver.** The **receiver** is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.
4. **Transmission medium.** The **transmission medium** is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.

5. **Protocol.** A **protocol** is a set of rules that govern data communications. It represents an agreement between the communicating devices. Without a protocol, two devices may be connected but not communicating, just as a person speaking French cannot be understood by a person who speaks only Japanese.

## Data Representation

Information today comes in different forms such as text, numbers, images, audio, and video.

### *Text*

In data communications, text is represented as a bit pattern, a sequence of bits (0s or 1s). Different sets of bit patterns have been designed to represent text symbols. Each set is called a **code**, and the process of representing symbols is called coding. Today, the prevalent coding system is called **Unicode**, which uses 32 bits to represent a symbol or character used in any language in the world. The **American Standard Code for Information Interchange (ASCII)**, developed some decades ago in the United States, now constitutes the first 127 characters in Unicode and is also referred to as **Basic Latin**. Appendix A includes part of the Unicode.

### *Numbers*

Numbers are also represented by bit patterns. However, a code such as ASCII is not used to represent numbers; the number is directly converted to a binary number to simplify mathematical operations. Appendix B discusses several different numbering systems.

### *Images*

**Images** are also represented by bit patterns. In its simplest form, an image is composed of a matrix of pixels (picture elements), where each pixel is a small dot. The size of the pixel depends on the *resolution*. For example, an image can be divided into 1000 pixels or 10,000 pixels. In the second case, there is a better representation of the image (better resolution), but more memory is needed to store the image.

After an image is divided into pixels, each pixel is assigned a bit pattern. The size and the value of the pattern depend on the image. For an image made of only black-and-white dots (e.g., a chessboard), a 1-bit pattern is enough to represent a pixel.

If an image is not made of pure white and pure black pixels, you can increase the size of the bit pattern to include gray scale. For example, to show four levels of gray scale, you can use 2-bit patterns. A black pixel can be represented by 00, a dark gray pixel by 01, a light gray pixel by 10, and a white pixel by 11.

There are several methods to represent color images. One method is called **RGB**, so called because each color is made of a combination of three primary colors: *red*, *green*, and *blue*. The intensity of each color is measured, and a bit pattern is assigned to it. Another method is called **YCM**, in which a color is made of a combination of three other primary colors: *yellow*, *cyan*, and *magenta*.

### *Audio*

**Audio** refers to the recording or broadcasting of sound or music. Audio is by nature different from text, numbers, or images. It is continuous, not discrete. Even when we

use a microphone to change voice or music to an electric signal, we create a continuous signal. In Chapters 4 and 5, we learn how to change sound or music to a digital or an analog signal.

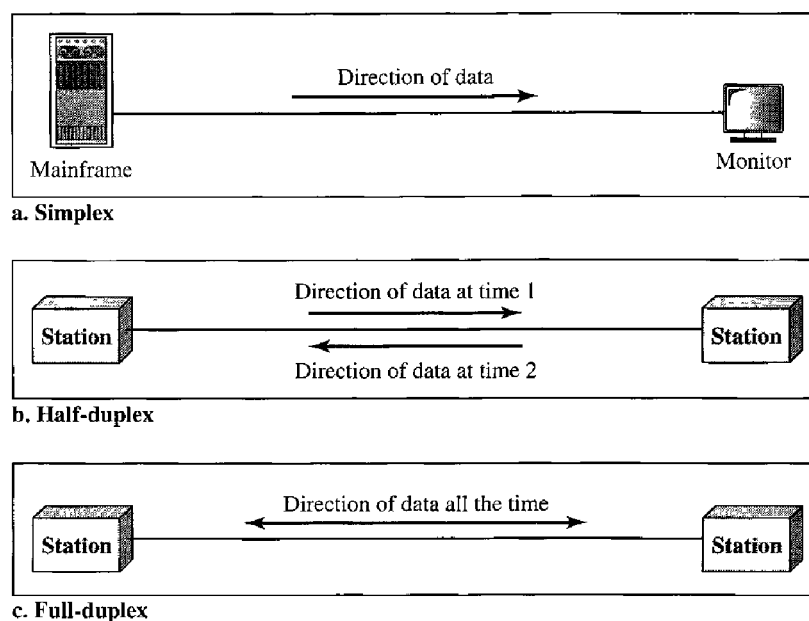
### Video

**Video** refers to the recording or broadcasting of a picture or movie. Video can either be produced as a continuous entity (e.g., by a TV camera), or it can be a combination of images, each a discrete entity, arranged to convey the idea of motion. Again we can change video to a digital or an analog signal, as we will see in Chapters 4 and 5.

### Data Flow

Communication between two devices can be simplex, half-duplex, or full-duplex as shown in Figure 1.2.

**Figure 1.2** Data flow (simplex, half-duplex, and full-duplex)



### Simplex

In **simplex mode**, the communication is unidirectional, as on a one-way street. Only one of the two devices on a link can transmit; the other can only receive (see Figure 1.2a).

Keyboards and traditional monitors are examples of simplex devices. The keyboard can only introduce input; the monitor can only accept output. The simplex mode can use the entire capacity of the channel to send data in one direction.

### Half-Duplex

In **half-duplex mode**, each station can both transmit and receive, but not at the same time. When one device is sending, the other can only receive, and vice versa (see Figure 1.2b).

The half-duplex mode is like a one-lane road with traffic allowed in both directions. When cars are traveling in one direction, cars going the other way must wait. In a half-duplex transmission, the entire capacity of a channel is taken over by whichever of the two devices is transmitting at the time. Walkie-talkies and CB (citizens band) radios are both half-duplex systems.

The half-duplex mode is used in cases where there is no need for communication in both directions at the same time; the entire capacity of the channel can be utilized for each direction.

### ***Full-Duplex***

In **full-duplex mode** (also called **duplex**), both stations can transmit and receive simultaneously (see Figure 1.2c).

The full-duplex mode is like a two-way street with traffic flowing in both directions at the same time. In full-duplex mode, signals going in one direction share the capacity of the link with signals going in the other direction. This sharing can occur in two ways: Either the link must contain two physically separate transmission paths, one for sending and the other for receiving; or the capacity of the channel is divided between signals traveling in both directions.

One common example of full-duplex communication is the telephone network. When two people are communicating by a telephone line, both can talk and listen at the same time.

The full-duplex mode is used when communication in both directions is required all the time. The capacity of the channel, however, must be divided between the two directions.

---

## 1.2 NETWORKS

A **network** is a set of devices (often referred to as *nodes*) connected by communication links. A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.

### **Distributed Processing**

Most networks use **distributed processing**, in which a task is divided among multiple computers. Instead of one single large machine being responsible for all aspects of a process, separate computers (usually a personal computer or workstation) handle a subset.

### **Network Criteria**

A network must be able to meet a certain number of criteria. The most important of these are performance, reliability, and security.

#### ***Performance***

**Performance** can be measured in many ways, including transit time and response time. Transit time is the amount of time required for a message to travel from one device to

another. Response time is the elapsed time between an inquiry and a response. The performance of a network depends on a number of factors, including the number of users, the type of transmission medium, the capabilities of the connected hardware, and the efficiency of the software.

Performance is often evaluated by two networking metrics: **throughput** and **delay**. We often need more throughput and less delay. However, these two criteria are often contradictory. If we try to send more data to the network, we may increase throughput but we increase the delay because of traffic congestion in the network.

### *Reliability*

In addition to accuracy of delivery, network **reliability** is measured by the frequency of failure, the time it takes a link to recover from a failure, and the network's robustness in a catastrophe.

### *Security*

Network **security** issues include protecting data from unauthorized access, protecting data from damage and development, and implementing policies and procedures for recovery from breaches and data losses.

## Physical Structures

Before discussing networks, we need to define some network attributes.

### *Type of Connection*

A network is two or more devices connected through links. A link is a communications pathway that transfers data from one device to another. For visualization purposes, it is simplest to imagine any link as a line drawn between two points. For communication to occur, two devices must be connected in some way to the same link at the same time. There are two possible types of connections: point-to-point and multipoint.

**Point-to-Point** A **point-to-point connection** provides a dedicated link between two devices. The entire capacity of the link is reserved for transmission between those two devices. Most point-to-point connections use an actual length of wire or cable to connect the two ends, but other options, such as microwave or satellite links, are also possible (see Figure 1.3a). When you change television channels by infrared remote control, you are establishing a point-to-point connection between the remote control and the television's control system.

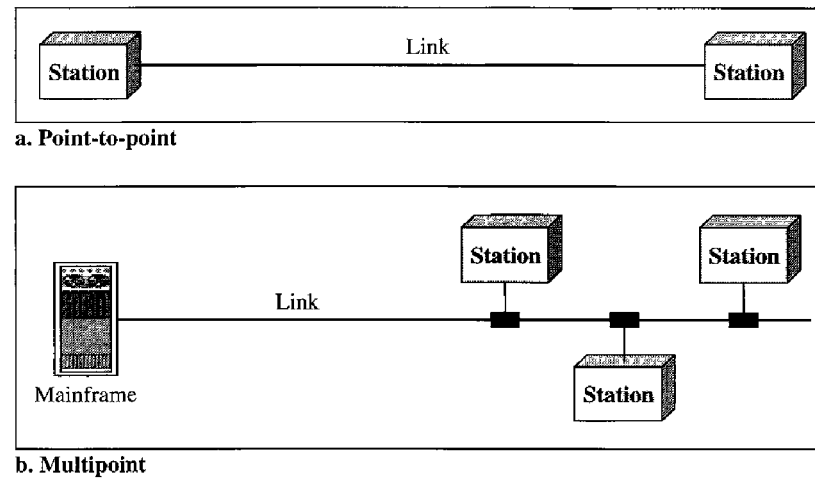
**Multipoint** A **multipoint** (also called **multidrop**) **connection** is one in which more than two specific devices share a single link (see Figure 1.3b).

In a multipoint environment, the capacity of the channel is shared, either spatially or temporally. If several devices can use the link simultaneously, it is a *spatially shared* connection. If users must take turns, it is a *timeshared* connection.

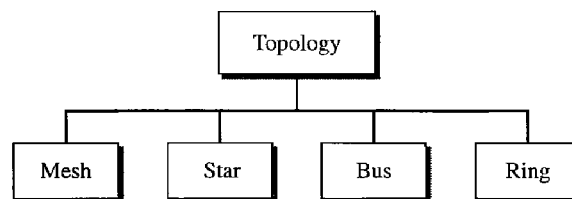
### *Physical Topology*

The term **physical topology** refers to the way in which a network is laid out physically. Two or more devices connect to a link; two or more links form a topology. The topology



**Figure 1.3** *Types of connections: point-to-point and multipoint*

of a network is the geometric representation of the relationship of all the links and linking devices (usually called **nodes**) to one another. There are four basic topologies possible: mesh, star, bus, and ring (see Figure 1.4).

**Figure 1.4** *Categories of topology*

**Mesh** In a **mesh topology**, every device has a dedicated point-to-point link to every other device. The term *dedicated* means that the link carries traffic only between the two devices it connects. To find the number of physical links in a fully connected mesh network with  $n$  nodes, we first consider that each node must be connected to every other node. Node 1 must be connected to  $n - 1$  nodes, node 2 must be connected to  $n - 1$  nodes, and finally node  $n$  must be connected to  $n - 1$  nodes. We need  $n(n - 1)$  physical links. However, if each physical link allows communication in both directions (duplex mode), we can divide the number of links by 2. In other words, we can say that in a mesh topology, we need

$$n(n - 1) / 2$$

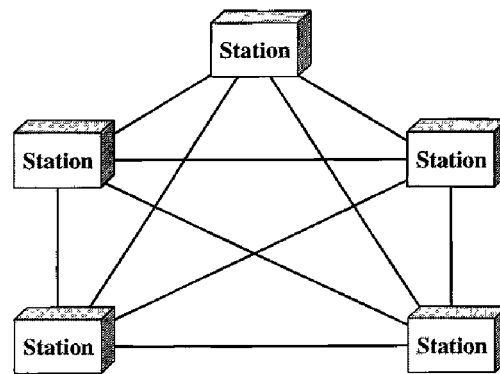
duplex-mode links.

To accommodate that many links, every device on the network must have  $n - 1$  input/output (I/O) ports (see Figure 1.5) to be connected to the other  $n - 1$  stations.

---

**Figure 1.5** *A fully connected mesh topology (five devices)*


---



A mesh offers several advantages over other network topologies. First, the use of dedicated links guarantees that each connection can carry its own data load, thus eliminating the traffic problems that can occur when links must be shared by multiple devices. Second, a mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system. Third, there is the advantage of privacy or security. When every message travels along a dedicated line, only the intended recipient sees it. Physical boundaries prevent other users from gaining access to messages. Finally, point-to-point links make fault identification and fault isolation easy. Traffic can be routed to avoid links with suspected problems. This facility enables the network manager to discover the precise location of the fault and aids in finding its cause and solution.

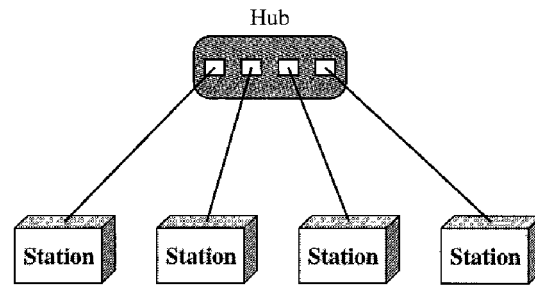
The main disadvantages of a mesh are related to the amount of cabling and the number of I/O ports required. First, because every device must be connected to every other device, installation and reconnection are difficult. Second, the sheer bulk of the wiring can be greater than the available space (in walls, ceilings, or floors) can accommodate. Finally, the hardware required to connect each link (I/O ports and cable) can be prohibitively expensive. For these reasons a mesh topology is usually implemented in a limited fashion, for example, as a backbone connecting the main computers of a hybrid network that can include several other topologies.

One practical example of a mesh topology is the connection of telephone regional offices in which each regional office needs to be connected to every other regional office.

**Star Topology** In a **star topology**, each device has a dedicated point-to-point link only to a central controller, usually called a **hub**. The devices are not directly linked to one another. Unlike a mesh topology, a star topology does not allow direct traffic between devices. The controller acts as an exchange: If one device wants to send data to another, it sends the data to the controller, which then relays the data to the other connected device (see Figure 1.6) .

A star topology is less expensive than a mesh topology. In a star, each device needs only one link and one I/O port to connect it to any number of others. This factor also makes it easy to install and reconfigure. Far less cabling needs to be housed, and additions, moves, and deletions involve only one connection: between that device and the hub.

Other advantages include robustness. If one link fails, only that link is affected. All other links remain active. This factor also lends itself to easy fault identification and

**Figure 1.6** *A star topology connecting four stations*

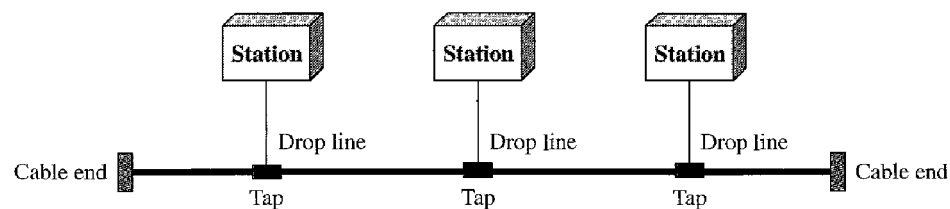
fault isolation. As long as the hub is working, it can be used to monitor link problems and bypass defective links.

One big disadvantage of a star topology is the dependency of the whole topology on one single point, the hub. If the hub goes down, the whole system is dead.

Although a star requires far less cable than a mesh, each node must be linked to a central hub. For this reason, often more cabling is required in a star than in some other topologies (such as ring or bus).

The star topology is used in local-area networks (LANs), as we will see in Chapter 13. High-speed LANs often use a star topology with a central hub.

**Bus Topology** The preceding examples all describe point-to-point connections. A **bus topology**, on the other hand, is multipoint. One long cable acts as a **backbone** to link all the devices in a network (see Figure 1.7).

**Figure 1.7** *A bus topology connecting three stations*

Nodes are connected to the bus cable by drop lines and taps. A drop line is a connection running between the device and the main cable. A tap is a connector that either splices into the main cable or punctures the sheathing of a cable to create a contact with the metallic core. As a signal travels along the backbone, some of its energy is transformed into heat. Therefore, it becomes weaker and weaker as it travels farther and farther. For this reason there is a limit on the number of taps a bus can support and on the distance between those taps.

Advantages of a bus topology include ease of installation. Backbone cable can be laid along the most efficient path, then connected to the nodes by drop lines of various lengths. In this way, a bus uses less cabling than mesh or star topologies. In a star, for example, four network devices in the same room require four lengths of cable reaching

all the way to the hub. In a bus, this redundancy is eliminated. Only the backbone cable stretches through the entire facility. Each drop line has to reach only as far as the nearest point on the backbone.

Disadvantages include difficult reconnection and fault isolation. A bus is usually designed to be optimally efficient at installation. It can therefore be difficult to add new devices. Signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting the number and spacing of devices connected to a given length of cable. Adding new devices may therefore require modification or replacement of the backbone.

In addition, a fault or break in the bus cable stops all transmission, even between devices on the same side of the problem. The damaged area reflects signals back in the direction of origin, creating noise in both directions.

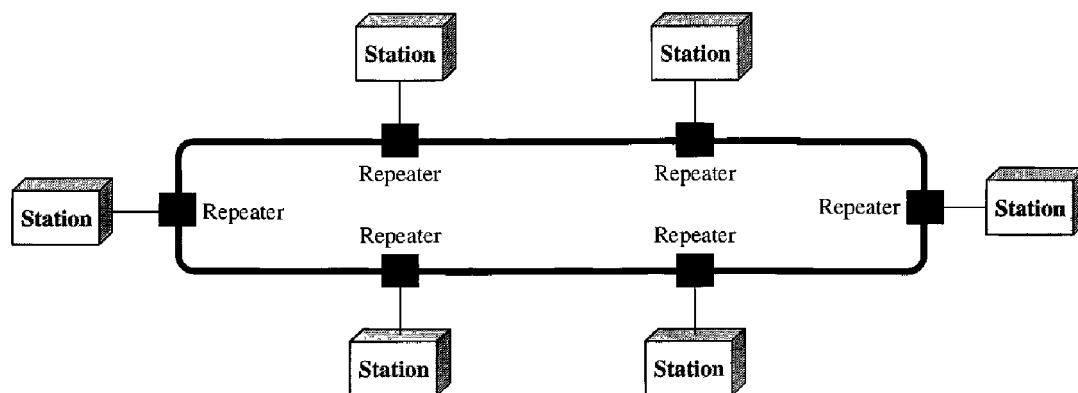
Bus topology was the one of the first topologies used in the design of early local-area networks. Ethernet LANs can use a bus topology, but they are less popular now for reasons we will discuss in Chapter 13.

**Ring Topology** In a **ring topology**, each device has a dedicated point-to-point connection with only the two devices on either side of it. A signal is passed along the ring in one direction, from device to device, until it reaches its destination. Each device in the ring incorporates a repeater. When a device receives a signal intended for another device, its repeater regenerates the bits and passes them along (see Figure 1.8).

---

**Figure 1.8** *A ring topology connecting six stations*

---



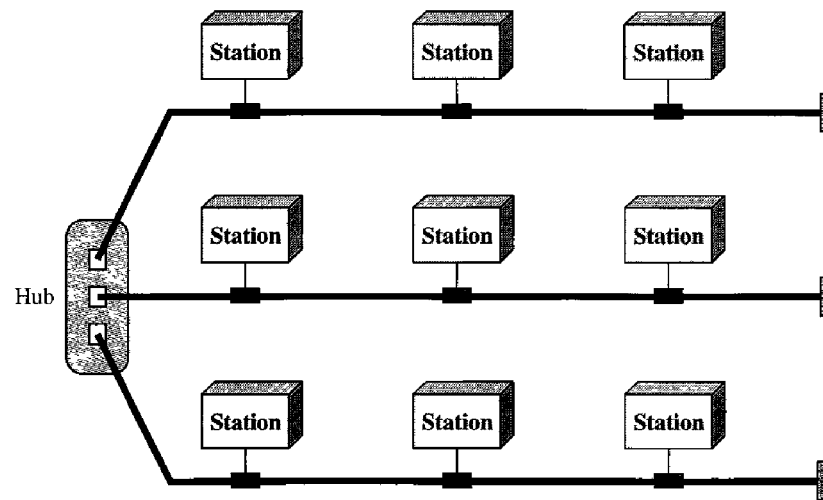
A ring is relatively easy to install and reconfigure. Each device is linked to only its immediate neighbors (either physically or logically). To add or delete a device requires changing only two connections. The only constraints are media and traffic considerations (maximum ring length and number of devices). In addition, fault isolation is simplified. Generally in a ring, a signal is circulating at all times. If one device does not receive a signal within a specified period, it can issue an alarm. The alarm alerts the network operator to the problem and its location.

However, unidirectional traffic can be a disadvantage. In a simple ring, a break in the ring (such as a disabled station) can disable the entire network. This weakness can be solved by using a dual ring or a switch capable of closing off the break.

Ring topology was prevalent when IBM introduced its local-area network Token Ring. Today, the need for higher-speed LANs has made this topology less popular.

**Hybrid Topology** A network can be hybrid. For example, we can have a main star topology with each branch connecting several stations in a bus topology as shown in Figure 1.9.

**Figure 1.9** A hybrid topology: a star backbone with three bus networks



## Network Models

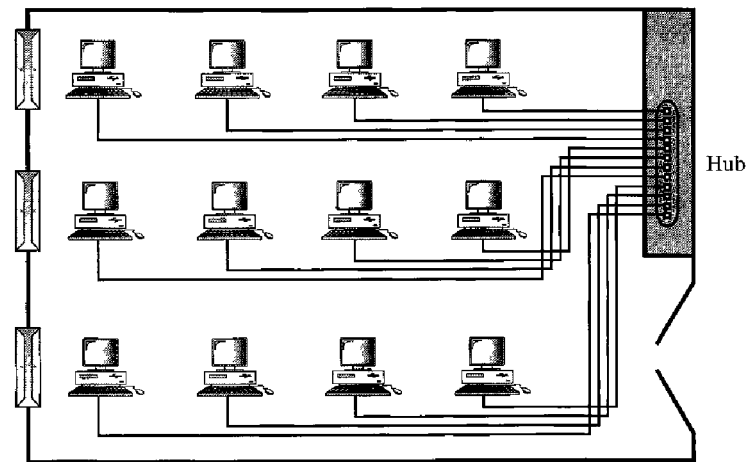
Computer networks are created by different entities. Standards are needed so that these heterogeneous networks can communicate with one another. The two best-known standards are the OSI model and the Internet model. In Chapter 2 we discuss these two models. The OSI (Open Systems Interconnection) model defines a seven-layer network; the Internet model defines a five-layer network. This book is based on the Internet model with occasional references to the OSI model.

## Categories of Networks

Today when we speak of networks, we are generally referring to two primary categories: local-area networks and wide-area networks. The category into which a network falls is determined by its size. A LAN normally covers an area less than 2 mi; a WAN can be worldwide. Networks of a size in between are normally referred to as metropolitan-area networks and span tens of miles.

### *Local Area Network*

A **local area network (LAN)** is usually privately owned and links the devices in a single office, building, or campus (see Figure 1.10). Depending on the needs of an organization and the type of technology used, a LAN can be as simple as two PCs and a printer in someone's home office; or it can extend throughout a company and include audio and video peripherals. Currently, LAN size is limited to a few kilometers.

**Figure 1.10** *An isolated LAN connecting 12 computers to a hub in a closet*

LANs are designed to allow resources to be shared between personal computers or workstations. The resources to be shared can include hardware (e.g., a printer), software (e.g., an application program), or data. A common example of a LAN, found in many business environments, links a workgroup of task-related computers, for example, engineering workstations or accounting PCs. One of the computers may be given a large-capacity disk drive and may become a server to clients. Software can be stored on this central server and used as needed by the whole group. In this example, the size of the LAN may be determined by licensing restrictions on the number of users per copy of software, or by restrictions on the number of users licensed to access the operating system.

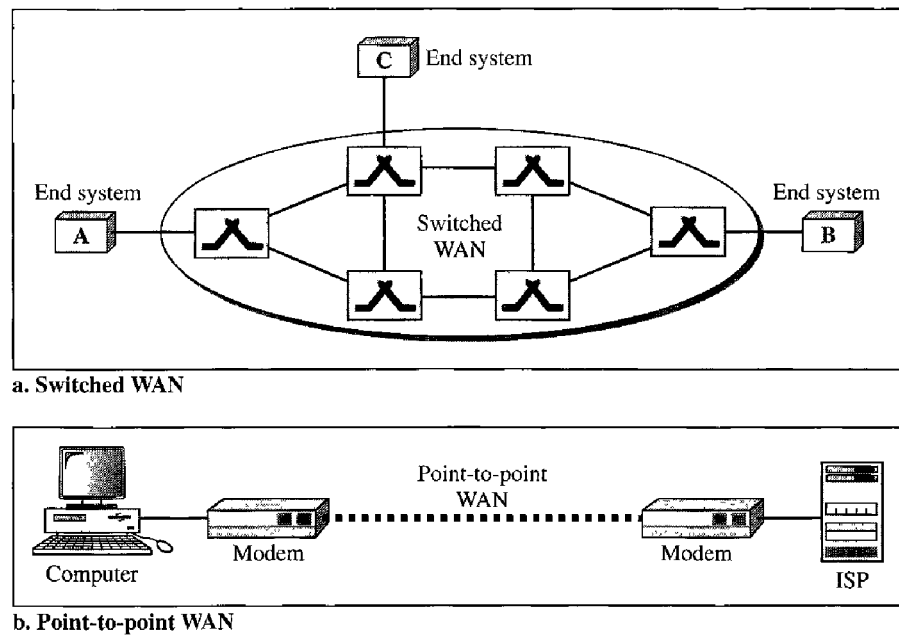
In addition to size, LANs are distinguished from other types of networks by their transmission media and topology. In general, a given LAN will use only one type of transmission medium. The most common LAN topologies are bus, ring, and star.

Early LANs had data rates in the 4 to 16 megabits per second (Mbps) range. Today, however, speeds are normally 100 or 1000 Mbps. LANs are discussed at length in Chapters 13, 14, and 15.

Wireless LANs are the newest evolution in LAN technology. We discuss wireless LANs in detail in Chapter 14.

### **Wide Area Network**

A **wide area network (WAN)** provides long-distance transmission of data, image, audio, and video information over large geographic areas that may comprise a country, a continent, or even the whole world. In Chapters 17 and 18 we discuss wide-area networks in greater detail. A WAN can be as complex as the backbones that connect the Internet or as simple as a dial-up line that connects a home computer to the Internet. We normally refer to the first as a switched WAN and to the second as a point-to-point WAN (Figure 1.11). The switched WAN connects the end systems, which usually comprise a router (internet-working connecting device) that connects to another LAN or WAN. The point-to-point WAN is normally a line leased from a telephone or cable TV provider that connects a home computer or a small LAN to an Internet service provider (ISP). This type of WAN is often used to provide Internet access.

**Figure 1.11** WANs: a switched WAN and a point-to-point WAN

An early example of a switched WAN is X.25, a network designed to provide connectivity between end users. As we will see in Chapter 18, X.25 is being gradually replaced by a high-speed, more efficient network called Frame Relay. A good example of a switched WAN is the asynchronous transfer mode (ATM) network, which is a network with fixed-size data unit packets called cells. We will discuss ATM in Chapter 18. Another example of WANs is the wireless WAN that is becoming more and more popular. We discuss wireless WANs and their evolution in Chapter 16.

### *Metropolitan Area Networks*

A **metropolitan area network (MAN)** is a network with a size between a LAN and a WAN. It normally covers the area inside a town or a city. It is designed for customers who need a high-speed connectivity, normally to the Internet, and have endpoints spread over a city or part of city. A good example of a MAN is the part of the telephone company network that can provide a high-speed DSL line to the customer. Another example is the cable TV network that originally was designed for cable TV, but today can also be used for high-speed data connection to the Internet. We discuss DSL lines and cable TV networks in Chapter 9.

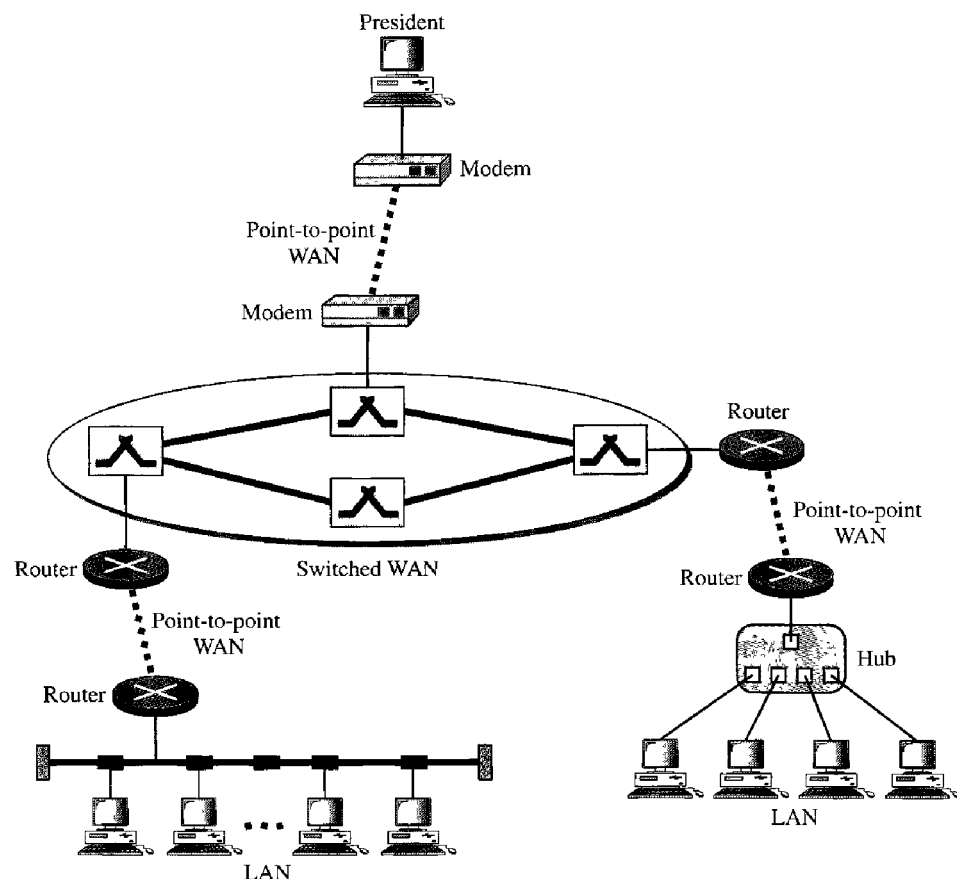
### **Interconnection of Networks: Internetwork**

Today, it is very rare to see a LAN, a MAN, or a LAN in isolation; they are connected to one another. When two or more networks are connected, they become an **internetwork**, or **internet**.

As an example, assume that an organization has two offices, one on the east coast and the other on the west coast. The established office on the west coast has a bus topology LAN; the newly opened office on the east coast has a star topology LAN. The president of the company lives somewhere in the middle and needs to have control over the company

from her home. To create a backbone WAN for connecting these three entities (two LANs and the president's computer), a switched WAN (operated by a service provider such as a telecom company) has been leased. To connect the LANs to this switched WAN, however, three point-to-point WANs are required. These point-to-point WANs can be a high-speed DSL line offered by a telephone company or a cable modem line offered by a cable TV provider as shown in Figure 1.12.

**Figure 1.12** *A heterogeneous network made of four WANs and two LANs*



### 1.3 THE INTERNET

The Internet has revolutionized many aspects of our daily lives. It has affected the way we do business as well as the way we spend our leisure time. Count the ways you've used the Internet recently. Perhaps you've sent electronic mail (e-mail) to a business associate, paid a utility bill, read a newspaper from a distant city, or looked up a local movie schedule—all by using the Internet. Or maybe you researched a medical topic, booked a hotel reservation, chatted with a fellow Trekkie, or comparison-shopped for a car. The Internet is a communication system that has brought a wealth of information to our fingertips and organized it for our use.

The Internet is a structured, organized system. We begin with a brief history of the Internet. We follow with a description of the Internet today.



## A Brief History

A network is a group of connected communicating devices such as computers and printers. An internet (note the lowercase letter i) is two or more networks that can communicate with each other. The most notable internet is called the **Internet** (uppercase letter I), a collaboration of more than hundreds of thousands of interconnected networks. Private individuals as well as various organizations such as government agencies, schools, research facilities, corporations, and libraries in more than 100 countries use the Internet. Millions of people are users. Yet this extraordinary communication system only came into being in 1969.

In the mid-1960s, mainframe computers in research organizations were stand-alone devices. Computers from different manufacturers were unable to communicate with one another. The **Advanced Research Projects Agency (ARPA)** in the Department of Defense (DoD) was interested in finding a way to connect computers so that the researchers they funded could share their findings, thereby reducing costs and eliminating duplication of effort.

In 1967, at an Association for Computing Machinery (ACM) meeting, ARPA presented its ideas for **ARPANET**, a small network of connected computers. The idea was that each host computer (not necessarily from the same manufacturer) would be attached to a specialized computer, called an *interface message processor* (IMP). The IMPs, in turn, would be connected to one another. Each IMP had to be able to communicate with other IMPs as well as with its own attached host.

By 1969, ARPANET was a reality. Four nodes, at the University of California at Los Angeles (UCLA), the University of California at Santa Barbara (UCSB), Stanford Research Institute (SRI), and the University of Utah, were connected via the IMPs to form a network. Software called the *Network Control Protocol* (NCP) provided communication between the hosts.

In 1972, Vint Cerf and Bob Kahn, both of whom were part of the core ARPANET group, collaborated on what they called the *Internetting Project*. Cerf and Kahn's landmark 1973 paper outlined the protocols to achieve end-to-end delivery of packets. This paper on Transmission Control Protocol (TCP) included concepts such as encapsulation, the datagram, and the functions of a gateway.

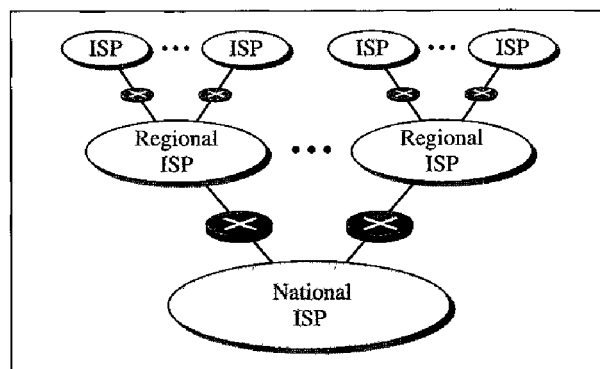
Shortly thereafter, authorities made a decision to split TCP into two protocols: **Transmission Control Protocol (TCP)** and **Internetworking Protocol (IP)**. IP would handle datagram routing while TCP would be responsible for higher-level functions such as segmentation, reassembly, and error detection. The internetworking protocol became known as TCP/IP.

## The Internet Today

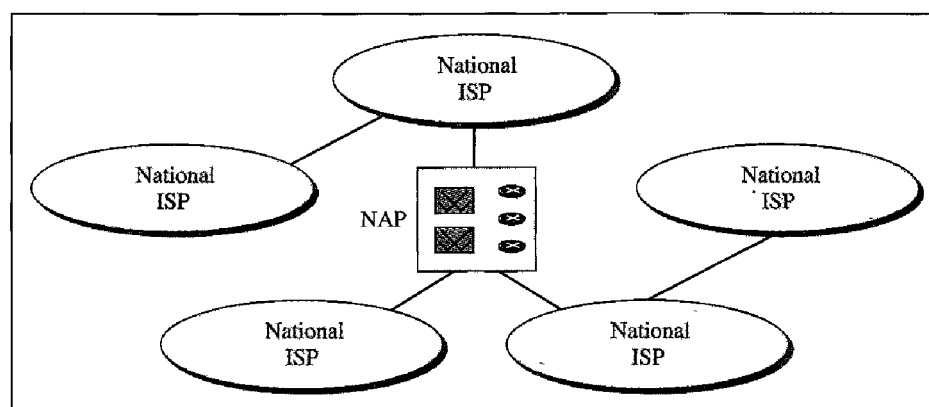
The Internet has come a long way since the 1960s. The Internet today is not a simple hierarchical structure. It is made up of many wide- and local-area networks joined by connecting devices and switching stations. It is difficult to give an accurate representation of the Internet because it is continually changing—new networks are being added, existing networks are adding addresses, and networks of defunct companies are being removed. Today most end users who want Internet connection use the services of **Internet service providers (ISPs)**. There are international service providers, national

service providers, regional service providers, and local service providers. The Internet today is run by private companies, not the government. Figure 1.13 shows a conceptual (not geographic) view of the Internet.

**Figure 1.13** *Hierarchical organization of the Internet*



**a. Structure of a national ISP**



**b. Interconnection of national ISPs**

### *International Internet Service Providers*

At the top of the hierarchy are the international service providers that connect nations together.

### *National Internet Service Providers*

The **national Internet service providers** are backbone networks created and maintained by specialized companies. There are many national ISPs operating in North America; some of the most well known are SprintLink, PSINet, UUNet Technology, AGIS, and internet MCI. To provide connectivity between the end users, these backbone networks are connected by complex switching stations (normally run by a third party) called **network access points (NAPs)**. Some national ISP networks are also connected to one another by private switching stations called *peering points*. These normally operate at a high data rate (up to 600 Mbps).

### ***Regional Internet Service Providers***

Regional internet service providers or **regional ISPs** are smaller ISPs that are connected to one or more national ISPs. They are at the third level of the hierarchy with a smaller data rate.

### ***Local Internet Service Providers***

**Local Internet service providers** provide direct service to the end users. The local ISPs can be connected to regional ISPs or directly to national ISPs. Most end users are connected to the local ISPs. Note that in this sense, a local ISP can be a company that just provides Internet services, a corporation with a network that supplies services to its own employees, or a nonprofit organization, such as a college or a university, that runs its own network. Each of these local ISPs can be connected to a regional or national service provider.

---

## **1.4 PROTOCOLS AND STANDARDS**

In this section, we define two widely used terms: protocols and standards. First, we define *protocol*, which is synonymous with *rule*. Then we discuss *standards*, which are agreed-upon rules.

### **Protocols**

In computer networks, communication occurs between entities in different systems. An **entity** is anything capable of sending or receiving information. However, two entities cannot simply send bit streams to each other and expect to be understood. For communication to occur, the entities must agree on a protocol. A protocol is a set of rules that govern data communications. A protocol defines what is communicated, how it is communicated, and when it is communicated. The key elements of a protocol are syntax, semantics, and timing.

- ❑ **Syntax.** The term *syntax* refers to the structure or format of the data, meaning the order in which they are presented. For example, a simple protocol might expect the first 8 bits of data to be the address of the sender, the second 8 bits to be the address of the receiver, and the rest of the stream to be the message itself.
- ❑ **Semantics.** The word *semantics* refers to the meaning of each section of bits. How is a particular pattern to be interpreted, and what action is to be taken based on that interpretation? For example, does an address identify the route to be taken or the final destination of the message?
- ❑ **Timing.** The term *timing* refers to two characteristics: when data should be sent and how fast they can be sent. For example, if a sender produces data at 100 Mbps but the receiver can process data at only 1 Mbps, the transmission will overload the receiver and some data will be lost.

### **Standards**

Standards are essential in creating and maintaining an open and competitive market for equipment manufacturers and in guaranteeing national and international interoperability of data and telecommunications technology and processes. Standards provide guidelines

to manufacturers, vendors, government agencies, and other service providers to ensure the kind of interconnectivity necessary in today's marketplace and in international communications. Data communication standards fall into two categories: *de facto* (meaning "by fact" or "by convention") and *de jure* (meaning "by law" or "by regulation").

- ❑ **De facto.** Standards that have not been approved by an organized body but have been adopted as standards through widespread use are **de facto standards**. De facto standards are often established originally by manufacturers who seek to define the functionality of a new product or technology.
- ❑ **De jure.** Those standards that have been legislated by an officially recognized body are **de jure standards**.

## Standards Organizations

Standards are developed through the cooperation of standards creation committees, forums, and government regulatory agencies.

### *Standards Creation Committees*

While many organizations are dedicated to the establishment of standards, data telecommunications in North America rely primarily on those published by the following:

- ❑ **International Organization for Standardization (ISO).** The ISO is a multinational body whose membership is drawn mainly from the standards creation committees of various governments throughout the world. The ISO is active in developing cooperation in the realms of scientific, technological, and economic activity.
- ❑ **International Telecommunication Union—Telecommunication Standards Sector (ITU-T).** By the early 1970s, a number of countries were defining national standards for telecommunications, but there was still little international compatibility. The United Nations responded by forming, as part of its International Telecommunication Union (ITU), a committee, the **Consultative Committee for International Telegraphy and Telephony (CCITT)**. This committee was devoted to the research and establishment of standards for telecommunications in general and for phone and data systems in particular. On March 1, 1993, the name of this committee was changed to the International Telecommunication Union—Telecommunication Standards Sector (ITU-T).
- ❑ **American National Standards Institute (ANSI).** Despite its name, the American National Standards Institute is a completely private, nonprofit corporation not affiliated with the U.S. federal government. However, all ANSI activities are undertaken with the welfare of the United States and its citizens occupying primary importance.
- ❑ **Institute of Electrical and Electronics Engineers (IEEE).** The Institute of Electrical and Electronics Engineers is the largest professional engineering society in the world. International in scope, it aims to advance theory, creativity, and product quality in the fields of electrical engineering, electronics, and radio as well as in all related branches of engineering. As one of its goals, the IEEE oversees the development and adoption of international standards for computing and communications.
- ❑ **Electronic Industries Association (EIA).** Aligned with ANSI, the Electronic Industries Association is a nonprofit organization devoted to the promotion of

electronics manufacturing concerns. Its activities include public awareness education and lobbying efforts in addition to standards development. In the field of information technology, the EIA has made significant contributions by defining physical connection interfaces and electronic signaling specifications for data communication.

### *Forums*

Telecommunications technology development is moving faster than the ability of standards committees to ratify standards. Standards committees are procedural bodies and by nature slow-moving. To accommodate the need for working models and agreements and to facilitate the standardization process, many special-interest groups have developed **forums** made up of representatives from interested corporations. The forums work with universities and users to test, evaluate, and standardize new technologies. By concentrating their efforts on a particular technology, the forums are able to speed acceptance and use of those technologies in the telecommunications community. The forums present their conclusions to the standards bodies.

### *Regulatory Agencies*

All communications technology is subject to regulation by government agencies such as the **Federal Communications Commission (FCC)** in the United States. The purpose of these agencies is to protect the public interest by regulating radio, television, and wire/cable communications. The FCC has authority over interstate and international commerce as it relates to communications.

### **Internet Standards**

An **Internet standard** is a thoroughly tested specification that is useful to and adhered to by those who work with the Internet. It is a formalized regulation that must be followed. There is a strict procedure by which a specification attains Internet standard status. A specification begins as an Internet draft. An **Internet draft** is a working document (a work in progress) with no official status and a 6-month lifetime. Upon recommendation from the Internet authorities, a draft may be published as a **Request for Comment (RFC)**. Each RFC is edited, assigned a number, and made available to all interested parties. RFCs go through maturity levels and are categorized according to their requirement level.

---

## **1.5 RECOMMENDED READING**

For more details about subjects discussed in this chapter, we recommend the following books and sites. The items enclosed in brackets [...] refer to the reference list at the end of the book.

### **Books**

The introductory materials covered in this chapter can be found in [Sta04] and [PD03]. [Tan03] discusses standardization in Section 1.6.

## Sites

The following sites are related to topics discussed in this chapter.

- ❑ [www.acm.org/sigcomm/sos.html](http://www.acm.org/sigcomm/sos.html) This site gives the status of various networking standards.
- ❑ [www.ietf.org/](http://www.ietf.org/) The Internet Engineering Task Force (IETF) home page.

## RFCs

The following site lists all RFCs, including those related to IP and TCP. In future chapters we cite the RFCs pertinent to the chapter material.

- ❑ [www.ietf.org/rfc.html](http://www.ietf.org/rfc.html)

---

## 1.6 KEY TERMS

Advanced Research Projects Agency (ARPA)	forum
American National Standards Institute (ANSI)	full-duplex mode, or duplex
American Standard Code for Information Interchange (ASCII)	half-duplex mode
ARPANET	hub
audio	image
backbone	Institute of Electrical and Electronics Engineers (IEEE)
Basic Latin	International Organization for Standardization (ISO)
bus topology	International Telecommunication Union—Telecommunication Standards Sector (ITU-T)
code	Internet
Consultative Committee for International Telegraphy and Telephony (CCITT)	Internet draft
data	Internet service provider (ISP)
data communications	Internet standard
de facto standards	internetwork or internet
de jure standards	local area network (LAN)
delay	local Internet service providers
distributed processing	mesh topology
Electronic Industries Association (EIA)	message
entity	metropolitan area network (MAN)
Federal Communications Commission (FCC)	multipoint or multidrop connection
	national Internet service provider
	network

network access points (NAPs)	sender
node	simplex mode
performance	star topology
physical topology	syntax
point-to-point connection	telecommunication
protocol	throughput
receiver	timing
regional ISP	Transmission Control Protocol/ Internetworking Protocol (TCP/IP)
reliability	transmission medium
Request for Comment (RFC)	Unicode
RGB	video
ring topology	wide area network (WAN)
security	YCM
semantics	

---

## 1.7 SUMMARY

- ☐ Data communications are the transfer of data from one device to another via some form of transmission medium.
- ☐ A data communications system must transmit data to the correct destination in an accurate and timely manner.
- ☐ The five components that make up a data communications system are the message, sender, receiver, medium, and protocol.
- ☐ Text, numbers, images, audio, and video are different forms of information.
- ☐ Data flow between two devices can occur in one of three ways: simplex, half-duplex, or full-duplex.
- ☐ A network is a set of communication devices connected by media links.
- ☐ In a point-to-point connection, two and only two devices are connected by a dedicated link. In a multipoint connection, three or more devices share a link.
- ☐ Topology refers to the physical or logical arrangement of a network. Devices may be arranged in a mesh, star, bus, or ring topology.
- ☐ A network can be categorized as a local area network or a wide area network.
- ☐ A LAN is a data communication system within a building, plant, or campus, or between nearby buildings.
- ☐ A WAN is a data communication system spanning states, countries, or the whole world.
- ☐ An internet is a network of networks.
- ☐ The Internet is a collection of many separate networks.
- ☐ There are local, regional, national, and international Internet service providers.
- ☐ A protocol is a set of rules that govern data communication; the key elements of a protocol are syntax, semantics, and timing.

- ☐ Standards are necessary to ensure that products from different manufacturers can work together as expected.
- ☐ The ISO, ITU-T, ANSI, IEEE, and EIA are some of the organizations involved in standards creation.
- ☐ Forums are special-interest groups that quickly evaluate and standardize new technologies.
- ☐ A Request for Comment is an idea or concept that is a precursor to an Internet standard.

---

## 1.8 PRACTICE SET

### Review Questions

1. Identify the five components of a data communications system.
2. What are the advantages of distributed processing?
3. What are the three criteria necessary for an effective and efficient network?
4. What are the advantages of a multipoint connection over a point-to-point connection?
5. What are the two types of line configuration?
6. Categorize the four basic topologies in terms of line configuration.
7. What is the difference between half-duplex and full-duplex transmission modes?
8. Name the four basic network topologies, and cite an advantage of each type.
9. For  $n$  devices in a network, what is the number of cable links required for a mesh, ring, bus, and star topology?
10. What are some of the factors that determine whether a communication system is a LAN or WAN?
11. What is an internet? What is the Internet?
12. Why are protocols needed?
13. Why are standards needed?

### Exercises

14. What is the maximum number of characters or symbols that can be represented by Unicode?
15. A color image uses 16 bits to represent a pixel. What is the maximum number of different colors that can be represented?
16. Assume six devices are arranged in a mesh topology. How many cables are needed? How many ports are needed for each device?
17. For each of the following four networks, discuss the consequences if a connection fails.
  - a. Five devices arranged in a mesh topology
  - b. Five devices arranged in a star topology (not counting the hub)
  - c. Five devices arranged in a bus topology
  - d. Five devices arranged in a ring topology



18. You have two computers connected by an Ethernet hub at home. Is this a LAN, a MAN, or a WAN? Explain your reason.
19. In the ring topology in Figure 1.8, what happens if one of the stations is unplugged?
20. In the bus topology in Figure 1.7, what happens if one of the stations is unplugged?
21. Draw a hybrid topology with a star backbone and three ring networks.
22. Draw a hybrid topology with a ring backbone and two bus networks.
23. Performance is inversely related to delay. When you use the Internet, which of the following applications are more sensitive to delay?
  - a. Sending an e-mail
  - b. Copying a file
  - c. Surfing the Internet
24. When a party makes a local telephone call to another party, is this a point-to-point or multipoint connection? Explain your answer.
25. Compare the telephone network and the Internet. What are the similarities? What are the differences?

### **Research Activities**

26. Using the site [www.cne.gmu.edu/modules/network/osi.html](http://www.cne.gmu.edu/modules/network/osi.html), discuss the OSI model.
27. Using the site [www.ansi.org](http://www.ansi.org), discuss ANSI's activities.
28. Using the site [www.ieee.org](http://www.ieee.org), discuss IEEE's activities.
29. Using the site [www.ietf.org/](http://www.ietf.org/), discuss the different types of RFCs.



## CHAPTER 2

# *Network Models*

A network is a combination of hardware and software that sends data from one location to another. The hardware consists of the physical equipment that carries signals from one point of the network to another. The software consists of instruction sets that make possible the services that we expect from a network.

We can compare the task of networking to the task of solving a mathematics problem with a computer. The fundamental job of solving the problem with a computer is done by computer hardware. However, this is a very tedious task if only hardware is involved. We would need switches for every memory location to store and manipulate data. The task is much easier if software is available. At the highest level, a program can direct the problem-solving process; the details of how this is done by the actual hardware can be left to the layers of software that are called by the higher levels.

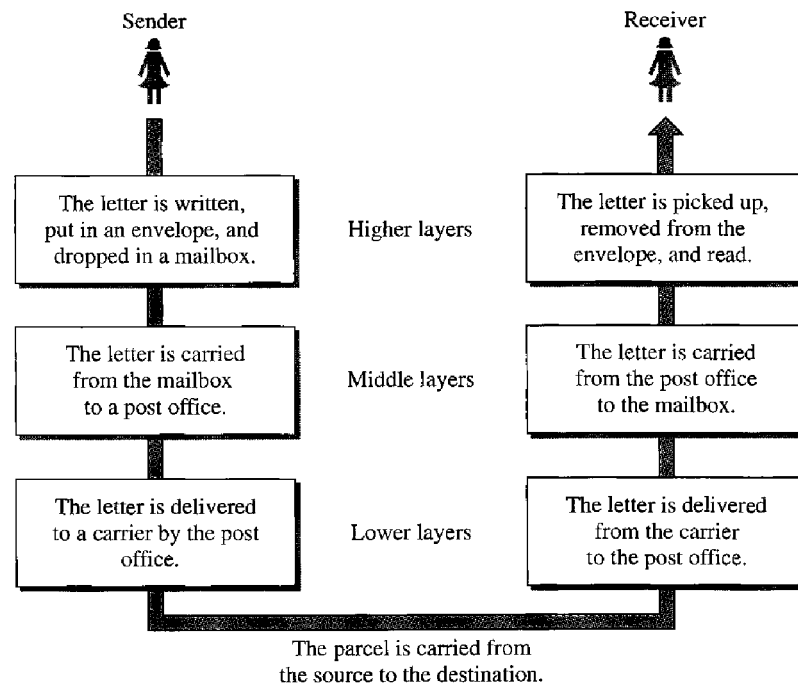
Compare this to a service provided by a computer network. For example, the task of sending an e-mail from one point in the world to another can be broken into several tasks, each performed by a separate software package. Each software package uses the services of another software package. At the lowest layer, a signal, or a set of signals, is sent from the source computer to the destination computer.

In this chapter, we give a general idea of the layers of a network and discuss the functions of each. Detailed descriptions of these layers follow in later chapters.

---

### 2.1 LAYERED TASKS

We use the concept of layers in our daily life. As an example, let us consider two friends who communicate through postal mail. The process of sending a letter to a friend would be complex if there were no services available from the post office. Figure 2.1 shows the steps in this task.

**Figure 2.1** *Tasks involved in sending a letter*

### Sender, Receiver, and Carrier

In Figure 2.1 we have a sender, a receiver, and a carrier that transports the letter. There is a hierarchy of tasks.

#### *At the Sender Site*

Let us first describe, in order, the activities that take place at the sender site.

- ☐ **Higher layer.** The sender writes the letter, inserts the letter in an envelope, writes the sender and receiver addresses, and drops the letter in a mailbox.
- ☐ **Middle layer.** The letter is picked up by a letter carrier and delivered to the post office.
- ☐ **Lower layer.** The letter is sorted at the post office; a carrier transports the letter.

#### *On the Way*

The letter is then on its way to the recipient. On the way to the recipient's local post office, the letter may actually go through a central office. In addition, it may be transported by truck, train, airplane, boat, or a combination of these.

#### *At the Receiver Site*

- ☐ **Lower layer.** The carrier transports the letter to the post office.
- ☐ **Middle layer.** The letter is sorted and delivered to the recipient's mailbox.
- ☐ **Higher layer.** The receiver picks up the letter, opens the envelope, and reads it.

## Hierarchy

According to our analysis, there are three different activities at the sender site and another three activities at the receiver site. The task of transporting the letter between the sender and the receiver is done by the carrier. Something that is not obvious immediately is that the tasks must be done in the order given in the hierarchy. At the sender site, the letter must be written and dropped in the mailbox before being picked up by the letter carrier and delivered to the post office. At the receiver site, the letter must be dropped in the recipient mailbox before being picked up and read by the recipient.

## Services

Each layer at the sending site uses the services of the layer immediately below it. The sender at the higher layer uses the services of the middle layer. The middle layer uses the services of the lower layer. The lower layer uses the services of the carrier.

The layered model that dominated data communications and networking literature before 1990 was the **Open Systems Interconnection (OSI) model**. Everyone believed that the OSI model would become the ultimate standard for data communications, but this did not happen. The TCP/IP protocol suite became the dominant commercial architecture because it was used and tested extensively in the Internet; the OSI model was never fully implemented.

In this chapter, first we briefly discuss the OSI model, and then we concentrate on TCP/IP as a protocol suite.

---

## 2.2 THE OSI MODEL

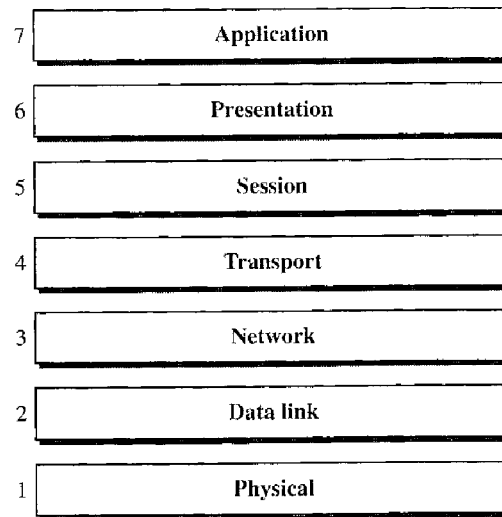
Established in 1947, the International Standards Organization (ISO) is a multinational body dedicated to worldwide agreement on international standards. An ISO standard that covers all aspects of network communications is the Open Systems Interconnection model. It was first introduced in the late 1970s. An **open system** is a set of protocols that allows any two different systems to communicate regardless of their underlying architecture. The purpose of the OSI model is to show how to facilitate communication between different systems without requiring changes to the logic of the underlying hardware and software. The OSI model is not a protocol; it is a model for understanding and designing a network architecture that is flexible, robust, and interoperable.

---

**ISO is the organization. OSI is the model.**

---

The OSI model is a layered framework for the design of network systems that allows communication between all types of computer systems. It consists of seven separate but related layers, each of which defines a part of the process of moving information across a network (see Figure 2.2). An understanding of the fundamentals of the OSI model provides a solid basis for exploring data communications.

**Figure 2.2** *Seven layers of the OSI model*

## Layered Architecture

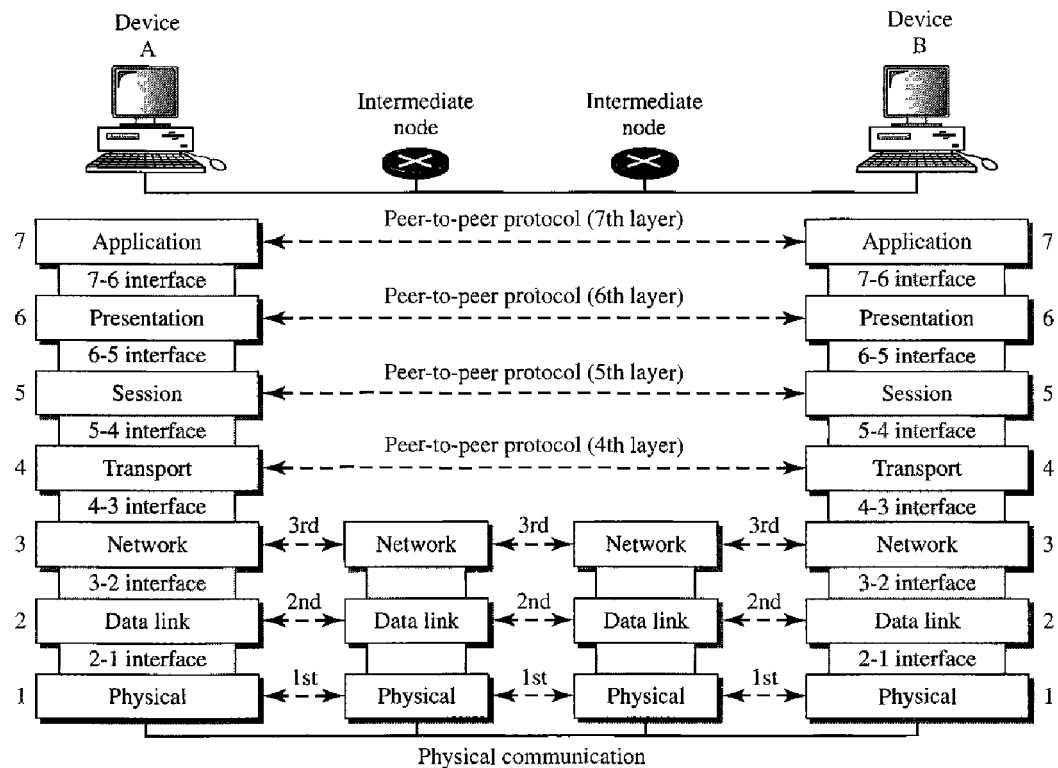
The OSI model is composed of seven ordered layers: physical (layer 1), data link (layer 2), network (layer 3), transport (layer 4), session (layer 5), presentation (layer 6), and application (layer 7). Figure 2.3 shows the layers involved when a message is sent from device A to device B. As the message travels from A to B, it may pass through many intermediate nodes. These intermediate nodes usually involve only the first three layers of the OSI model.

In developing the model, the designers distilled the process of transmitting data to its most fundamental elements. They identified which networking functions had related uses and collected those functions into discrete groups that became the layers. Each layer defines a family of functions distinct from those of the other layers. By defining and localizing functionality in this fashion, the designers created an architecture that is both comprehensive and flexible. Most importantly, the OSI model allows complete interoperability between otherwise incompatible systems.

Within a single machine, each layer calls upon the services of the layer just below it. Layer 3, for example, uses the services provided by layer 2 and provides services for layer 4. Between machines, layer  $x$  on one machine communicates with layer  $x$  on another machine. This communication is governed by an agreed-upon series of rules and conventions called protocols. The processes on each machine that communicate at a given layer are called **peer-to-peer processes**. Communication between machines is therefore a peer-to-peer process using the protocols appropriate to a given layer.

## Peer-to-Peer Processes

At the physical layer, communication is direct: In Figure 2.3, device A sends a stream of bits to device B (through intermediate nodes). At the higher layers, however, communication must move down through the layers on device A, over to device B, and then

**Figure 2.3** *The interaction between layers in the OSI model*

back up through the layers. Each layer in the sending device adds its own information to the message it receives from the layer just above it and passes the whole package to the layer just below it.

At layer 1 the entire package is converted to a form that can be transmitted to the receiving device. At the receiving machine, the message is unwrapped layer by layer, with each process receiving and removing the data meant for it. For example, layer 2 removes the data meant for it, then passes the rest to layer 3. Layer 3 then removes the data meant for it and passes the rest to layer 4, and so on.

### ***Interfaces Between Layers***

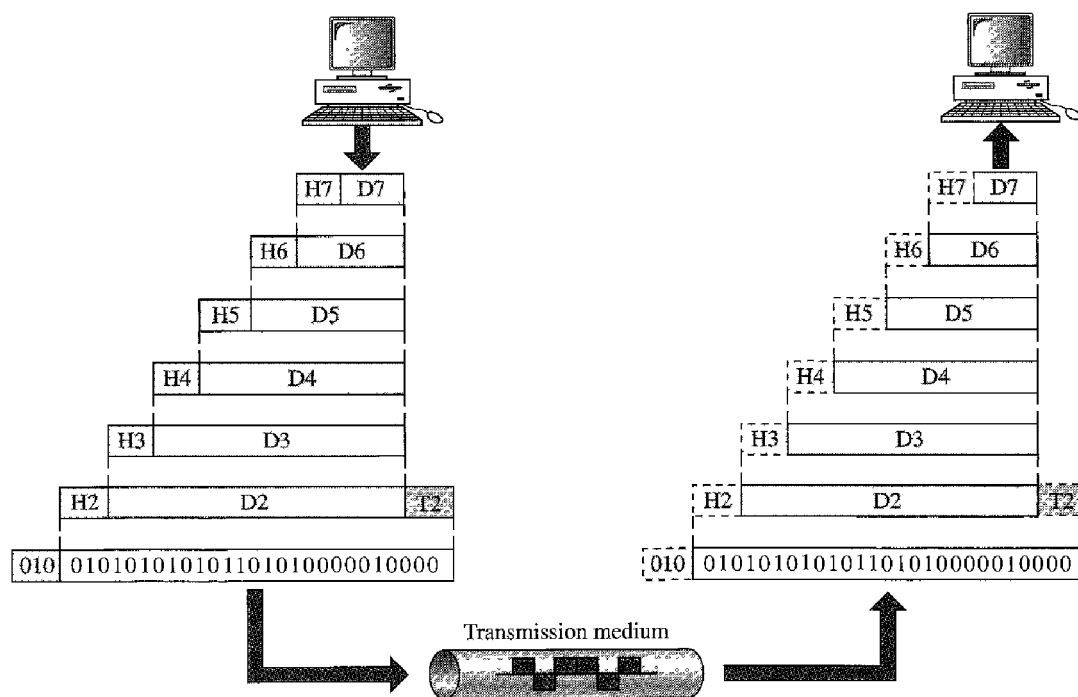
The passing of the data and network information down through the layers of the sending device and back up through the layers of the receiving device is made possible by an **interface** between each pair of adjacent layers. Each interface defines the information and services a layer must provide for the layer above it. Well-defined interfaces and layer functions provide modularity to a network. As long as a layer provides the expected services to the layer above it, the specific implementation of its functions can be modified or replaced without requiring changes to the surrounding layers.

### ***Organization of the Layers***

The seven layers can be thought of as belonging to three subgroups. Layers 1, 2, and 3—physical, data link, and network—are the network support layers; they deal with

In Figure 2.4, which gives an overall view of the OSI layers, D7 means the data unit at layer 7, D6 means the data unit at layer 6, and so on. The process starts at layer 7 (the application layer), then moves from layer to layer in descending, sequential order. At each layer, a **header**, or possibly a **trailer**, can be added to the data unit. Commonly, the trailer is added only at layer 2. When the formatted data unit passes through the physical layer (layer 1), it is changed into an electromagnetic signal and transported along a physical link.

**Figure 2.4** *An exchange using the OSI model*



Upon reaching its destination, the signal passes into layer 1 and is transformed back into digital form. The data units then move back up through the OSI layers. As each block of data reaches the next higher layer, the headers and trailers attached to it at the corresponding sending layer are removed, and actions appropriate to that layer are taken. By the time it reaches layer 7, the message is again in a form appropriate to the application and is made available to the recipient.



## Encapsulation

Figure 2.3 reveals another aspect of data communications in the OSI model: encapsulation. A packet (header and data) at level 7 is encapsulated in a packet at level 6. The whole packet at level 6 is encapsulated in a packet at level 5, and so on.

In other words, the data portion of a packet at level  $N - 1$  carries the whole packet (data and header and maybe trailer) from level  $N$ . The concept is called *encapsulation*; level  $N - 1$  is not aware of which part of the encapsulated packet is data and which part is the header or trailer. For level  $N - 1$ , the whole packet coming from level  $N$  is treated as one integral unit.

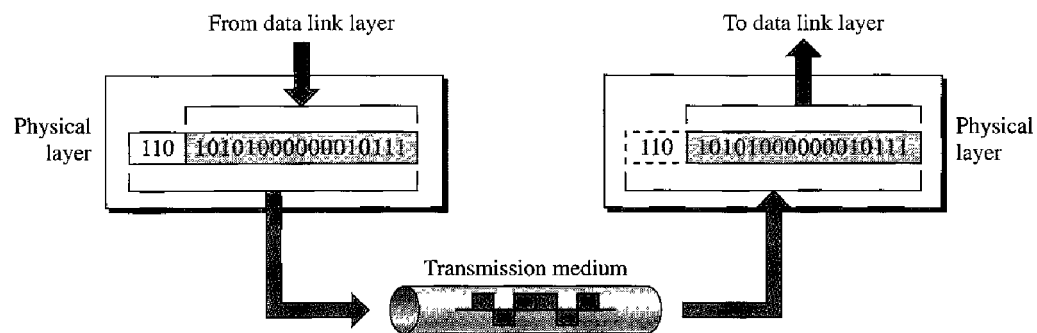
## 2.3 LAYERS IN THE OSI MODEL

In this section we briefly describe the functions of each layer in the OSI model.

### Physical Layer

The **physical layer** coordinates the functions required to carry a bit stream over a physical medium. It deals with the mechanical and electrical specifications of the interface and transmission medium. It also defines the procedures and functions that physical devices and interfaces have to perform for transmission to occur. Figure 2.5 shows the position of the physical layer with respect to the transmission medium and the data link layer.

**Figure 2.5** *Physical layer*



**The physical layer is responsible for movements of individual bits from one hop (node) to the next.**

The physical layer is also concerned with the following:

- ☐ **Physical characteristics of interfaces and medium.** The physical layer defines the characteristics of the interface between the devices and the transmission medium. It also defines the type of transmission medium.
- ☐ **Representation of bits.** The physical layer data consists of a stream of **bits** (sequence of 0s or 1s) with no interpretation. To be transmitted, bits must be

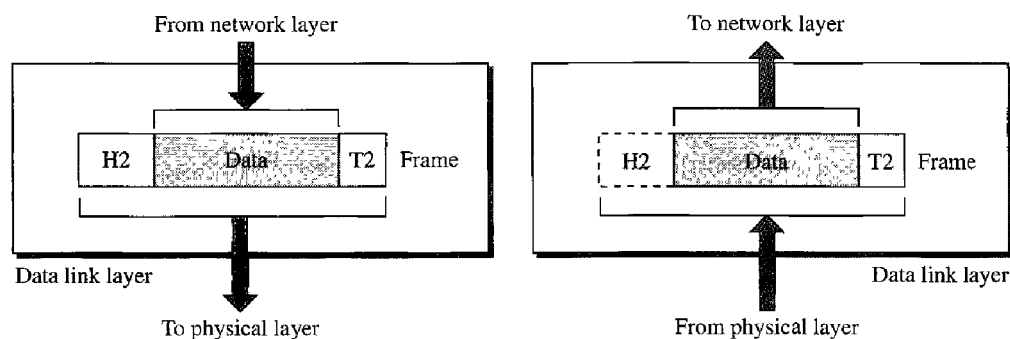
encoded into signals—electrical or optical. The physical layer defines the type of **encoding** (how 0s and 1s are changed to signals).

- ❑ **Data rate.** The **transmission rate**—the number of bits sent each second—is also defined by the physical layer. In other words, the physical layer defines the duration of a bit, which is how long it lasts.
- ❑ **Synchronization of bits.** The sender and receiver not only must use the same bit rate but also must be synchronized at the bit level. In other words, the sender and the receiver clocks must be synchronized.
- ❑ **Line configuration.** The physical layer is concerned with the connection of devices to the media. In a point-to-point configuration, two devices are connected through a dedicated link. In a multipoint configuration, a link is shared among several devices.
- ❑ **Physical topology.** The physical topology defines how devices are connected to make a network. Devices can be connected by using a mesh topology (every device is connected to every other device), a star topology (devices are connected through a central device), a ring topology (each device is connected to the next, forming a ring), a bus topology (every device is on a common link), or a hybrid topology (this is a combination of two or more topologies).
- ❑ **Transmission mode.** The physical layer also defines the direction of transmission between two devices: simplex, half-duplex, or full-duplex. In simplex mode, only one device can send; the other can only receive. The simplex mode is a one-way communication. In the half-duplex mode, two devices can send and receive, but not at the same time. In a full-duplex (or simply duplex) mode, two devices can send and receive at the same time.

## Data Link Layer

The **data link layer** transforms the physical layer, a raw transmission facility, to a reliable link. It makes the physical layer appear error-free to the upper layer (network layer). Figure 2.6 shows the relationship of the data link layer to the network and physical layers.

**Figure 2.6** *Data link layer*



---

**The data link layer is responsible for moving frames from one hop (node) to the next.**

---

Other responsibilities of the data link layer include the following:

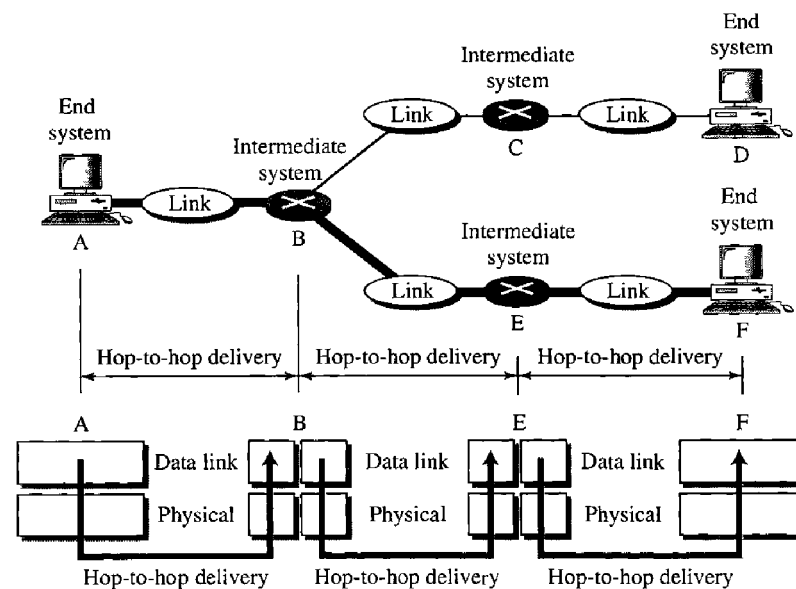
- ❑ **Framing.** The data link layer divides the stream of bits received from the network layer into manageable data units called **frames**.
- ❑ **Physical addressing.** If frames are to be distributed to different systems on the network, the data link layer adds a header to the frame to define the sender and/or receiver of the frame. If the frame is intended for a system outside the sender's network, the receiver address is the address of the device that connects the network to the next one.
- ❑ **Flow control.** If the rate at which the data are absorbed by the receiver is less than the rate at which data are produced in the sender, the data link layer imposes a flow control mechanism to avoid overwhelming the receiver.
- ❑ **Error control.** The data link layer adds reliability to the physical layer by adding mechanisms to detect and retransmit damaged or lost frames. It also uses a mechanism to recognize duplicate frames. Error control is normally achieved through a trailer added to the end of the frame.
- ❑ **Access control.** When two or more devices are connected to the same link, data link layer protocols are necessary to determine which device has control over the link at any given time.

Figure 2.7 illustrates **hop-to-hop (node-to-node) delivery** by the data link layer.

---

**Figure 2.7** *Hop-to-hop delivery*

---



As the figure shows, communication at the data link layer occurs between two adjacent nodes. To send data from A to F, three partial deliveries are made. First, the data link layer at A sends a frame to the data link layer at B (a router). Second, the data

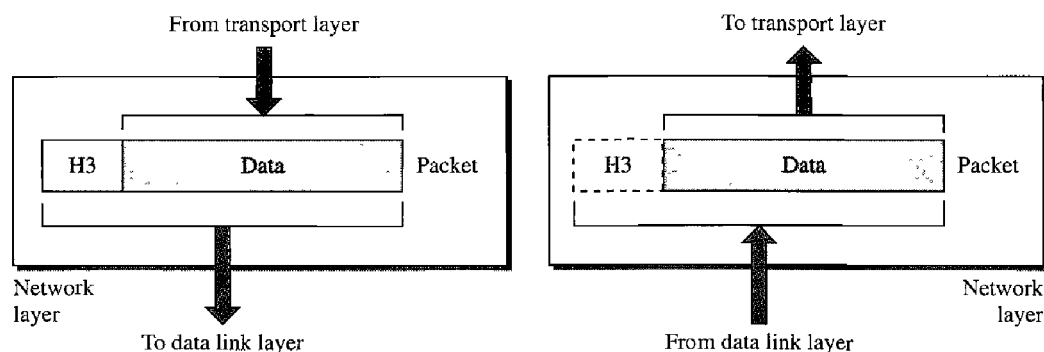
link layer at B sends a new frame to the data link layer at E. Finally, the data link layer at E sends a new frame to the data link layer at F. Note that the frames that are exchanged between the three nodes have different values in the headers. The frame from A to B has B as the destination address and A as the source address. The frame from B to E has E as the destination address and B as the source address. The frame from E to F has F as the destination address and E as the source address. The values of the trailers can also be different if error checking includes the header of the frame.

## Network Layer

The **network layer** is responsible for the source-to-destination delivery of a packet, possibly across multiple networks (links). Whereas the data link layer oversees the delivery of the packet between two systems on the same network (links), the network layer ensures that each packet gets from its point of origin to its final destination.

If two systems are connected to the same link, there is usually no need for a network layer. However, if the two systems are attached to different networks (links) with connecting devices between the networks (links), there is often a need for the network layer to accomplish source-to-destination delivery. Figure 2.8 shows the relationship of the network layer to the data link and transport layers.

**Figure 2.8** *Network layer*



**The network layer is responsible for the delivery of individual packets from the source host to the destination host.**

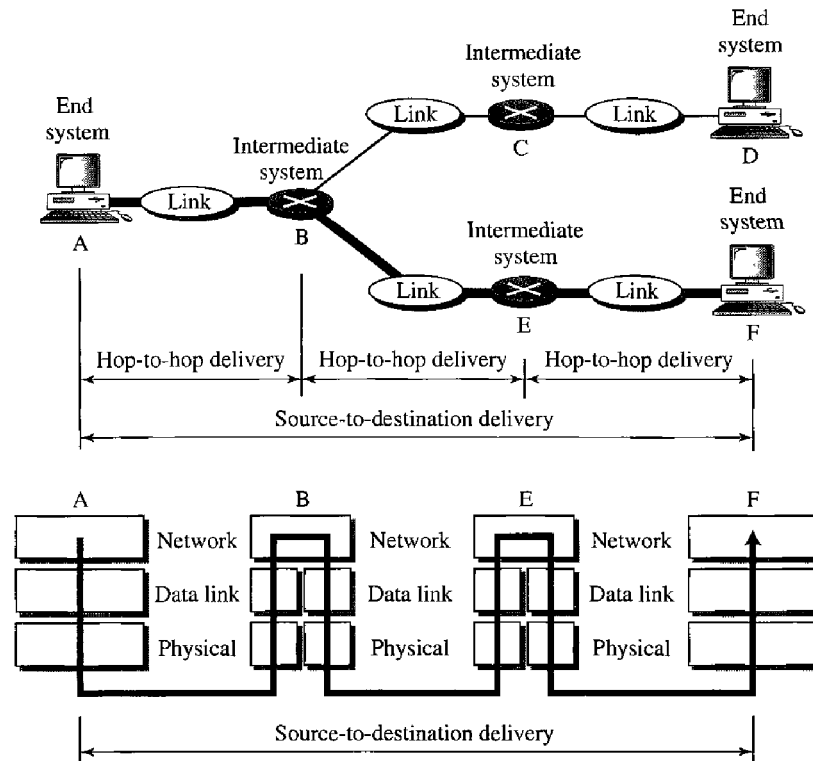
Other responsibilities of the network layer include the following:

- ❑ **Logical addressing.** The physical addressing implemented by the data link layer handles the addressing problem locally. If a packet passes the network boundary, we need another addressing system to help distinguish the source and destination systems. The network layer adds a header to the packet coming from the upper layer that, among other things, includes the logical addresses of the sender and receiver. We discuss logical addresses later in this chapter.
- ❑ **Routing.** When independent networks or links are connected to create *internetworks* (network of networks) or a large network, the connecting devices (called *routers*

or *switches*) route or switch the packets to their final destination. One of the functions of the network layer is to provide this mechanism.

Figure 2.9 illustrates end-to-end delivery by the network layer.

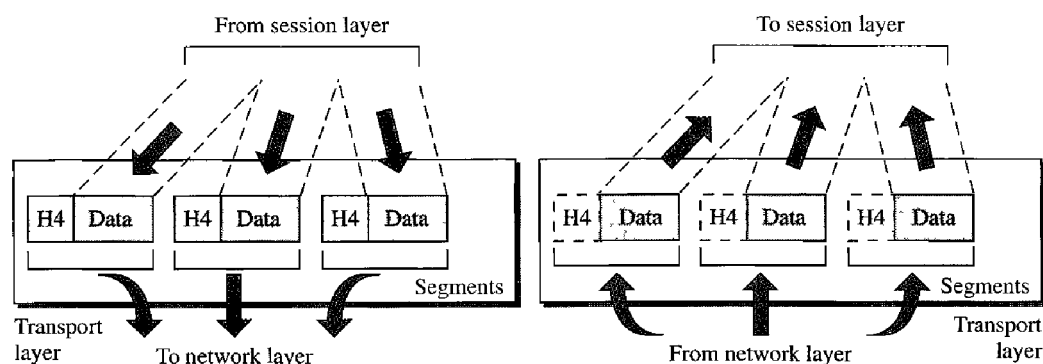
**Figure 2.9** *Source-to-destination delivery*



As the figure shows, now we need a source-to-destination delivery. The network layer at A sends the packet to the network layer at B. When the packet arrives at router B, the router makes a decision based on the final destination (F) of the packet. As we will see in later chapters, router B uses its routing table to find that the next hop is router E. The network layer at B, therefore, sends the packet to the network layer at E. The network layer at E, in turn, sends the packet to the network layer at F.

## Transport Layer

The **transport layer** is responsible for **process-to-process delivery** of the entire message. A process is an application program running on a host. Whereas the network layer oversees **source-to-destination delivery** of individual packets, it does not recognize any relationship between those packets. It treats each one independently, as though each piece belonged to a separate message, whether or not it does. The transport layer, on the other hand, ensures that the whole message arrives intact and in order, overseeing both error control and flow control at the source-to-destination level. Figure 2.10 shows the relationship of the transport layer to the network and session layers.

**Figure 2.10** *Transport layer*


---

**The transport layer is responsible for the delivery of a message from one process to another.**

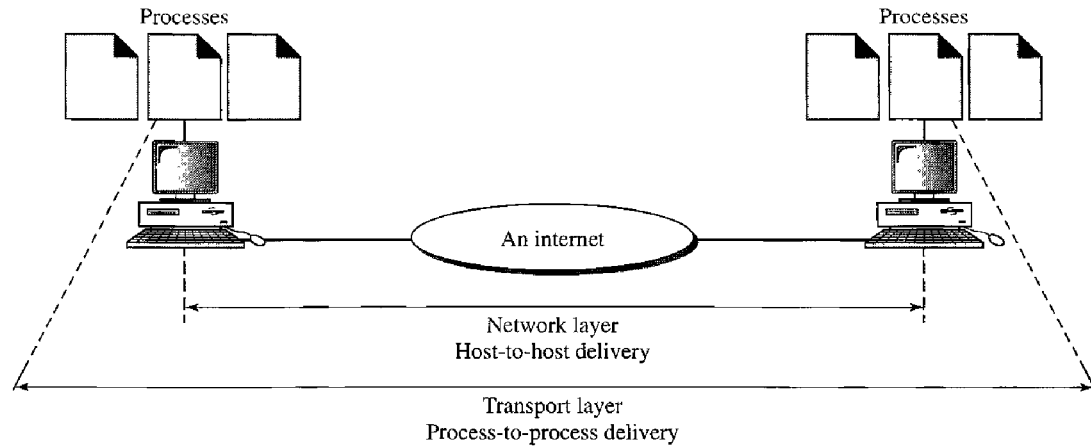
---

Other responsibilities of the transport layer include the following:

- ❑ **Service-point addressing.** Computers often run several programs at the same time. For this reason, source-to-destination delivery means delivery not only from one computer to the next but also from a specific process (running program) on one computer to a specific process (running program) on the other. The transport layer header must therefore include a type of address called a *service-point address* (or port address). The network layer gets each packet to the correct computer; the transport layer gets the entire message to the correct process on that computer.
- ❑ **Segmentation and reassembly.** A message is divided into transmittable segments, with each segment containing a sequence number. These numbers enable the transport layer to reassemble the message correctly upon arriving at the destination and to identify and replace packets that were lost in transmission.
- ❑ **Connection control.** The transport layer can be either connectionless or connection-oriented. A connectionless transport layer treats each segment as an independent packet and delivers it to the transport layer at the destination machine. A connection-oriented transport layer makes a connection with the transport layer at the destination machine first before delivering the packets. After all the data are transferred, the connection is terminated.
- ❑ **Flow control.** Like the data link layer, the transport layer is responsible for **flow control**. However, flow control at this layer is performed end to end rather than across a single link.
- ❑ **Error control.** Like the data link layer, the transport layer is responsible for **error control**. However, error control at this layer is performed process-to-process rather than across a single link. The sending transport layer makes sure that the entire message arrives at the receiving transport layer without **error** (damage, loss, or duplication). Error correction is usually achieved through retransmission.

Figure 2.11 illustrates process-to-process delivery by the transport layer.

**Figure 2.11** *Reliable process-to-process delivery of a message*



## Session Layer

The services provided by the first three layers (physical, data link, and network) are not sufficient for some processes. The **session layer** is the network *dialog controller*. It establishes, maintains, and synchronizes the interaction among communicating systems.

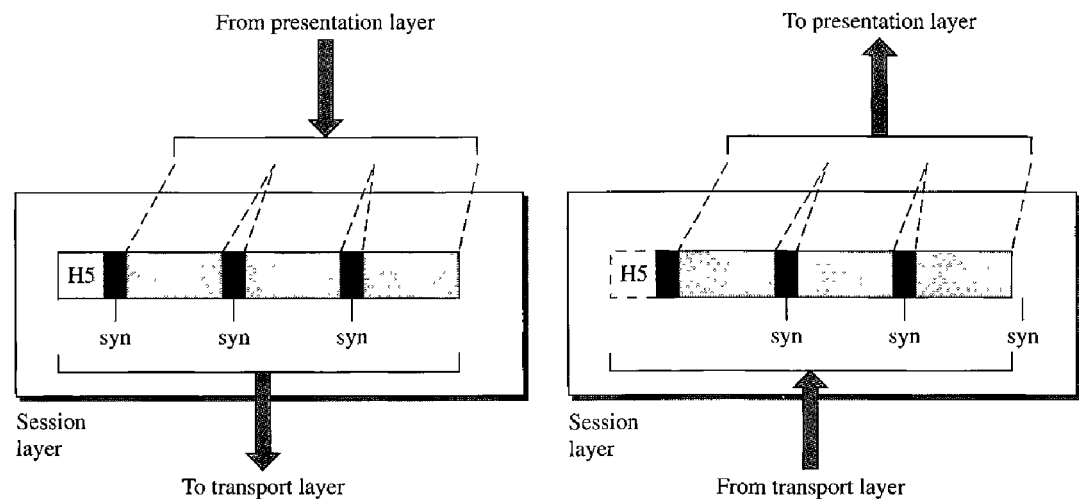
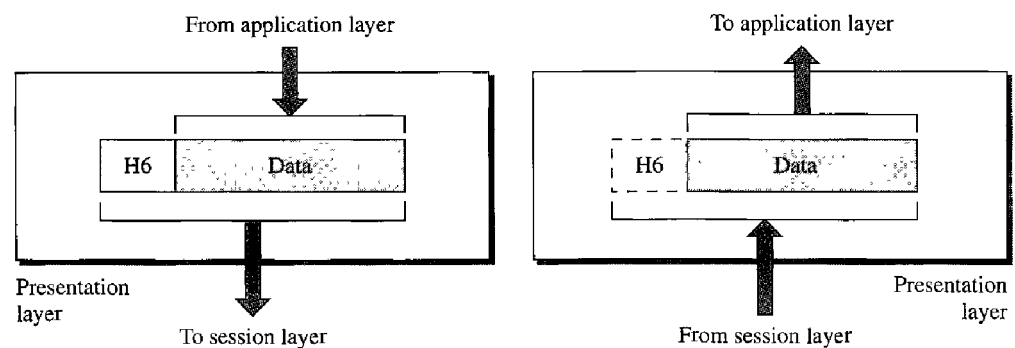
**The session layer is responsible for dialog control and synchronization.**

Specific responsibilities of the session layer include the following:

- ❑ **Dialog control.** The session layer allows two systems to enter into a dialog. It allows the communication between two processes to take place in either half-duplex (one way at a time) or full-duplex (two ways at a time) mode.
- ❑ **Synchronization.** The session layer allows a process to add checkpoints, or **synchronization points**, to a stream of data. For example, if a system is sending a file of 2000 pages, it is advisable to insert checkpoints after every 100 pages to ensure that each 100-page unit is received and acknowledged independently. In this case, if a crash happens during the transmission of page 523, the only pages that need to be resent after system recovery are pages 501 to 523. Pages previous to 501 need not be resent. Figure 2.12 illustrates the relationship of the session layer to the transport and presentation layers.

## Presentation Layer

The **presentation layer** is concerned with the syntax and semantics of the information exchanged between two systems. Figure 2.13 shows the relationship between the presentation layer and the application and session layers.

**Figure 2.12** *Session layer***Figure 2.13** *Presentation layer*

**The presentation layer is responsible for translation, compression, and encryption.**

Specific responsibilities of the presentation layer include the following:

- ❑ **Translation.** The processes (running programs) in two systems are usually exchanging information in the form of character strings, numbers, and so on. The information must be changed to bit streams before being transmitted. Because different computers use different encoding systems, the presentation layer is responsible for interoperability between these different encoding methods. The presentation layer at the sender changes the information from its sender-dependent format into a common format. The presentation layer at the receiving machine changes the common format into its receiver-dependent format.
- ❑ **Encryption.** To carry sensitive information, a system must be able to ensure privacy. Encryption means that the sender transforms the original information to



another form and sends the resulting message out over the network. Decryption reverses the original process to transform the message back to its original form.

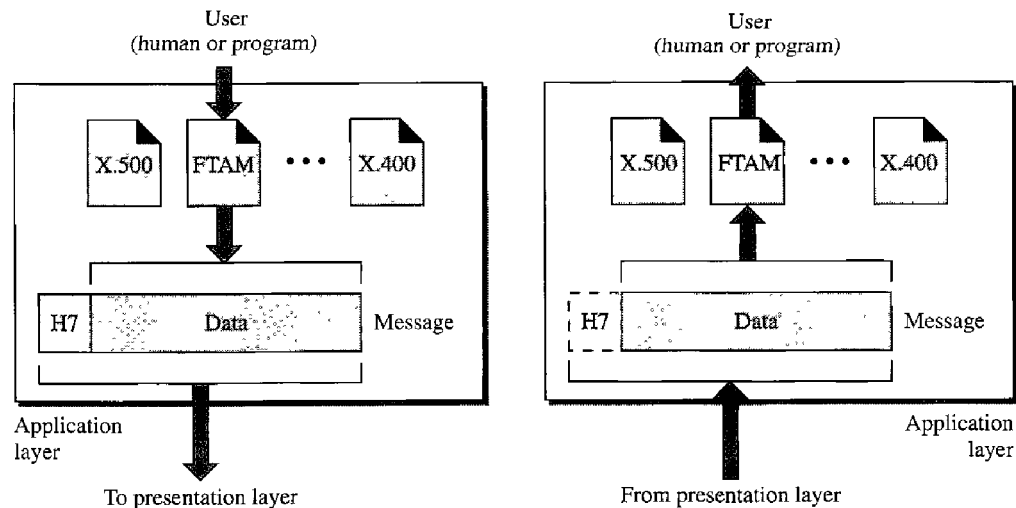
- ❑ **Compression.** Data compression reduces the number of bits contained in the information. Data compression becomes particularly important in the transmission of multimedia such as text, audio, and video.

## Application Layer

The **application layer** enables the user, whether human or software, to access the network. It provides user interfaces and support for services such as electronic mail, remote file access and transfer, shared database management, and other types of distributed information services.

Figure 2.14 shows the relationship of the application layer to the user and the presentation layer. Of the many application services available, the figure shows only three: X.400 (message-handling services), X.500 (directory services), and file transfer, access, and management (FTAM). The user in this example employs X.400 to send an e-mail message.

**Figure 2.14** *Application layer*




---

**The application layer is responsible for providing services to the user.**

---

Specific services provided by the application layer include the following:

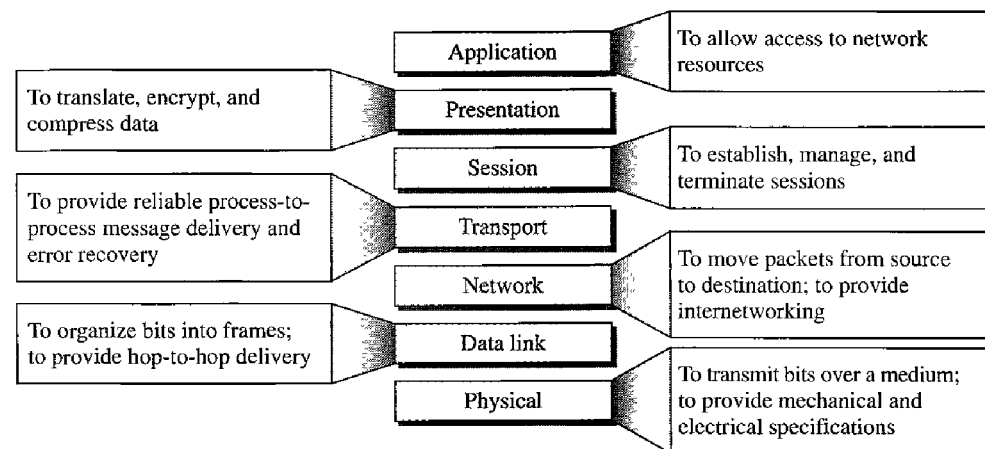
- ❑ **Network virtual terminal.** A network virtual terminal is a software version of a physical terminal, and it allows a user to log on to a remote host. To do so, the application creates a software emulation of a terminal at the remote host. The user's computer talks to the software terminal which, in turn, talks to the host, and vice versa. The remote host believes it is communicating with one of its own terminals and allows the user to log on.

- ❑ **File transfer, access, and management.** This application allows a user to access files in a remote host (to make changes or read data), to retrieve files from a remote computer for use in the local computer, and to manage or control files in a remote computer locally.
- ❑ **Mail services.** This application provides the basis for e-mail forwarding and storage.
- ❑ **Directory services.** This application provides distributed database sources and access for global information about various objects and services.

## Summary of Layers

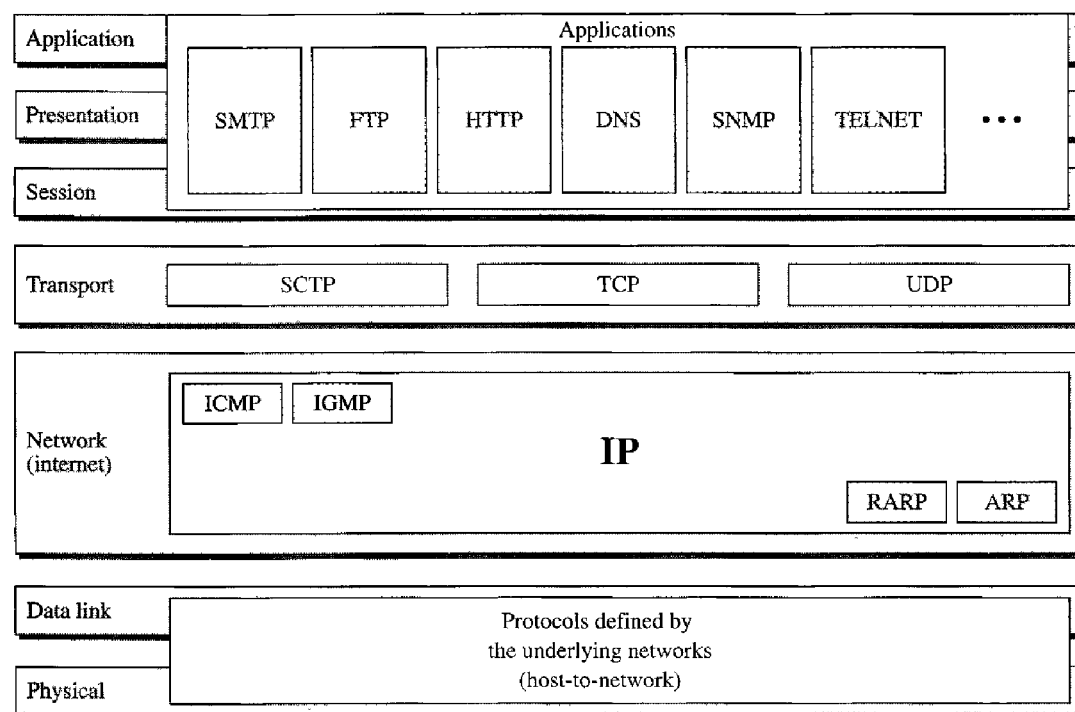
Figure 2.15 shows a summary of duties for each layer.

**Figure 2.15** *Summary of layers*



## 2.4 TCP/IP PROTOCOL SUITE

The **TCP/IP protocol suite** was developed prior to the OSI model. Therefore, the layers in the TCP/IP protocol suite do not exactly match those in the OSI model. The original TCP/IP protocol suite was defined as having four layers: host-to-network, internet, transport, and application. However, when TCP/IP is compared to OSI, we can say that the host-to-network layer is equivalent to the combination of the physical and data link layers. The internet layer is equivalent to the network layer, and the application layer is roughly doing the job of the session, presentation, and application layers with the transport layer in TCP/IP taking care of part of the duties of the session layer. So in this book, we assume that the TCP/IP protocol suite is made of five layers: physical, data link, network, transport, and application. The first four layers provide physical standards, network interfaces, internetworking, and transport functions that correspond to the first four layers of the OSI model. The three topmost layers in the OSI model, however, are represented in TCP/IP by a single layer called the *application layer* (see Figure 2.16).

**Figure 2.16** TCP/IP and OSI model

TCP/IP is a hierarchical protocol made up of interactive modules, each of which provides a specific functionality; however, the modules are not necessarily interdependent. Whereas the OSI model specifies which functions belong to each of its layers, the layers of the TCP/IP protocol suite contain relatively independent protocols that can be mixed and matched depending on the needs of the system. The term *hierarchical* means that each upper-level protocol is supported by one or more lower-level protocols.

At the transport layer, TCP/IP defines three protocols: Transmission Control Protocol (TCP), User Datagram Protocol (UDP), and Stream Control Transmission Protocol (SCTP). At the network layer, the main protocol defined by TCP/IP is the Internetworking Protocol (IP); there are also some other protocols that support data movement in this layer.

## Physical and Data Link Layers

At the physical and data link layers, TCP/IP does not define any specific protocol. It supports all the standard and proprietary protocols. A network in a TCP/IP internetwork can be a local-area network or a wide-area network.

## Network Layer

At the network layer (or, more accurately, the internetwork layer), TCP/IP supports the Internetworking Protocol. IP, in turn, uses four supporting protocols: ARP, RARP, ICMP, and IGMP. Each of these protocols is described in greater detail in later chapters.

### *Internetworking Protocol (IP)*

The Internetworking Protocol (IP) is the transmission mechanism used by the TCP/IP protocols. It is an unreliable and connectionless protocol—a **best-effort delivery** service. The term *best effort* means that IP provides no error checking or tracking. IP assumes the unreliability of the underlying layers and does its best to get a transmission through to its destination, but with no guarantees.

IP transports data in packets called *datagrams*, each of which is transported separately. Datagrams can travel along different routes and can arrive out of sequence or be duplicated. IP does not keep track of the routes and has no facility for reordering datagrams once they arrive at their destination.

The limited functionality of IP should not be considered a weakness, however. IP provides bare-bones transmission functions that free the user to add only those facilities necessary for a given application and thereby allows for maximum efficiency. IP is discussed in Chapter 20.

### *Address Resolution Protocol*

The **Address Resolution Protocol (ARP)** is used to associate a logical address with a physical address. On a typical physical network, such as a LAN, each device on a link is identified by a physical or station address, usually imprinted on the network interface card (NIC). ARP is used to find the physical address of the node when its Internet address is known. ARP is discussed in Chapter 21.

### *Reverse Address Resolution Protocol*

The **Reverse Address Resolution Protocol (RARP)** allows a host to discover its Internet address when it knows only its physical address. It is used when a computer is connected to a network for the first time or when a diskless computer is booted. We discuss RARP in Chapter 21.

### *Internet Control Message Protocol*

The **Internet Control Message Protocol (ICMP)** is a mechanism used by hosts and gateways to send notification of datagram problems back to the sender. ICMP sends query and error reporting messages. We discuss ICMP in Chapter 21.

### *Internet Group Message Protocol*

The **Internet Group Message Protocol (IGMP)** is used to facilitate the simultaneous transmission of a message to a group of recipients. We discuss IGMP in Chapter 22.

## **Transport Layer**

Traditionally the transport layer was represented in TCP/IP by two protocols: TCP and UDP. IP is a **host-to-host protocol**, meaning that it can deliver a packet from one physical device to another. UDP and TCP are **transport level protocols** responsible for delivery of a message from a process (running program) to another process. A new transport layer protocol, SCTP, has been devised to meet the needs of some newer applications.

### *User Datagram Protocol*

The **User Datagram Protocol (UDP)** is the simpler of the two standard TCP/IP transport protocols. It is a process-to-process protocol that adds only port addresses, checksum error control, and length information to the data from the upper layer. UDP is discussed in Chapter 23.

### *Transmission Control Protocol*

The **Transmission Control Protocol (TCP)** provides full transport-layer services to applications. TCP is a reliable stream transport protocol. The term *stream*, in this context, means connection-oriented: A connection must be established between both ends of a transmission before either can transmit data.

At the sending end of each transmission, TCP divides a stream of data into smaller units called *segments*. Each segment includes a sequence number for reordering after receipt, together with an acknowledgment number for the segments received. Segments are carried across the internet inside of IP datagrams. At the receiving end, TCP collects each datagram as it comes in and reorders the transmission based on sequence numbers. TCP is discussed in Chapter 23.

### *Stream Control Transmission Protocol*

The **Stream Control Transmission Protocol (SCTP)** provides support for newer applications such as voice over the Internet. It is a transport layer protocol that combines the best features of UDP and TCP. We discuss SCTP in Chapter 23.

## **Application Layer**

The *application layer* in TCP/IP is equivalent to the combined session, presentation, and application layers in the OSI model. Many protocols are defined at this layer. We cover many of the standard protocols in later chapters.

---

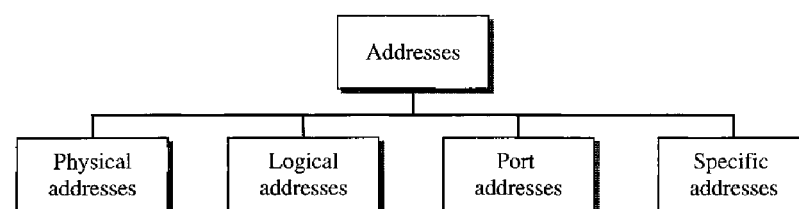
## **2.5 ADDRESSING**

Four levels of addresses are used in an internet employing the TCP/IP protocols: **physical** (link) **addresses**, **logical** (IP) **addresses**, **port** **addresses**, and **specific** addresses (see Figure 2.17).

---

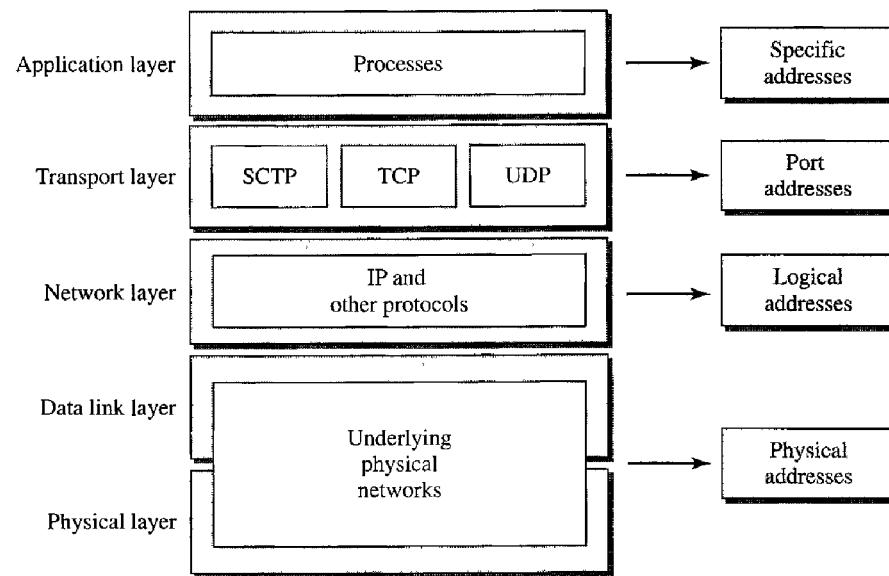
**Figure 2.17** *Addresses in TCP/IP*

---



Each address is related to a specific layer in the TCP/IP architecture, as shown in Figure 2.18.

**Figure 2.18** Relationship of layers and addresses in TCP/IP



## Physical Addresses

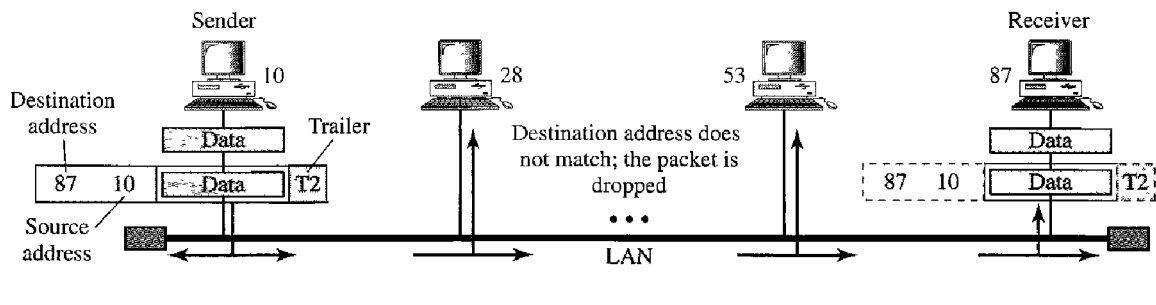
The physical address, also known as the link address, is the address of a node as defined by its LAN or WAN. It is included in the frame used by the data link layer. It is the lowest-level address.

The physical addresses have authority over the network (LAN or WAN). The size and format of these addresses vary depending on the network. For example, Ethernet uses a 6-byte (48-bit) physical address that is imprinted on the network interface card (NIC). LocalTalk (Apple), however, has a 1-byte dynamic address that changes each time the station comes up.

### Example 2.1

In Figure 2.19 a node with physical address 10 sends a frame to a node with physical address 87. The two nodes are connected by a link (bus topology LAN). At the data link layer, this frame contains physical (link) addresses in the header. These are the only addresses needed. The rest of the header contains other information needed at this level. The trailer usually contains extra bits needed for error detection. As the figure shows, the computer with physical address 10 is the sender, and the computer with physical address 87 is the receiver. The data link layer at the sender receives data from an upper layer. It encapsulates the data in a frame, adding a header and a trailer. The header, among other pieces of information, carries the receiver and the sender physical (link) addresses. Note that in most data link protocols, the destination address, 87 in this case, comes before the source address (10 in this case).

We have shown a bus topology for an isolated LAN. In a bus topology, the frame is propagated in both directions (left and right). The frame propagated to the left dies when it reaches the end of the cable if the cable end is terminated appropriately. The frame propagated to the right is

**Figure 2.19** *Physical addresses*

sent to every station on the network. Each station with a physical addresses other than 87 drops the frame because the destination address in the frame does not match its own physical address. The intended destination computer, however, finds a match between the destination address in the frame and its own physical address. The frame is checked, the header and trailer are dropped, and the data part is decapsulated and delivered to the upper layer.

### Example 2.2

As we will see in Chapter 13, most local-area networks use a 48-bit (6-byte) physical address written as 12 hexadecimal digits; every byte (2 hexadecimal digits) is separated by a colon, as shown below:

**07:01:02:01:2C:4B**

A 6-byte (12 hexadecimal digits) physical address

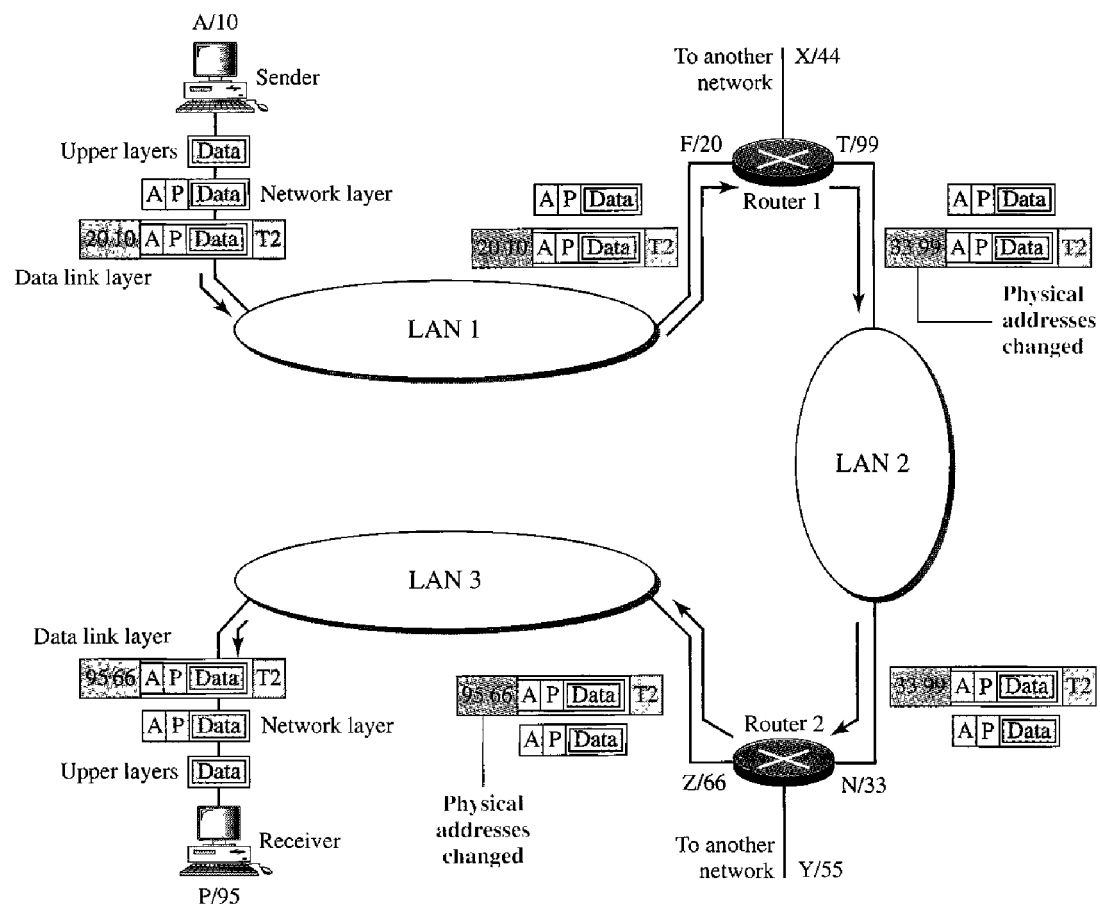
## Logical Addresses

Logical addresses are necessary for universal communications that are independent of underlying physical networks. Physical addresses are not adequate in an internetwork environment where different networks can have different address formats. A universal addressing system is needed in which each host can be identified uniquely, regardless of the underlying physical network.

The logical addresses are designed for this purpose. A logical address in the Internet is currently a 32-bit address that can uniquely define a host connected to the Internet. No two publicly addressed and visible hosts on the Internet can have the same IP address.

### Example 2.3

Figure 2.20 shows a part of an internet with two routers connecting three LANs. Each device (computer or router) has a pair of addresses (logical and physical) for each connection. In this case, each computer is connected to only one link and therefore has only one pair of addresses. Each router, however, is connected to three networks (only two are shown in the figure). So each router has three pairs of addresses, one for each connection. Although it may obvious that each router must have a separate physical address for each connection, it may not be obvious why it needs a logical address for each connection. We discuss these issues in Chapter 22 when we discuss routing.

**Figure 2.20** IP addresses

The computer with logical address A and physical address 10 needs to send a packet to the computer with logical address P and physical address 95. We use letters to show the logical addresses and numbers for physical addresses, but note that both are actually numbers, as we will see later in the chapter.

The sender encapsulates its data in a packet at the network layer and adds two logical addresses (A and P). Note that in most protocols, the logical source address comes before the logical destination address (contrary to the order of physical addresses). The network layer, however, needs to find the physical address of the next hop before the packet can be delivered. The network layer consults its routing table (see Chapter 22) and finds the logical address of the next hop (router 1) to be F. The ARP discussed previously finds the physical address of router 1 that corresponds to the logical address of 20. Now the network layer passes this address to the data link layer, which in turn, encapsulates the packet with physical destination address 20 and physical source address 10.

The frame is received by every device on LAN 1, but is discarded by all except router 1, which finds that the destination physical address in the frame matches with its own physical address. The router decapsulates the packet from the frame to read the logical destination address P. Since the logical destination address does not match the router's logical address, the router knows that the packet needs to be forwarded. The



router consults its routing table and ARP to find the physical destination address of the next hop (router 2), creates a new frame, encapsulates the packet, and sends it to router 2.

Note the physical addresses in the frame. The source physical address changes from 10 to 99. The destination physical address changes from 20 (router 1 physical address) to 33 (router 2 physical address). The logical source and destination addresses must remain the same; otherwise the packet will be lost.

At router 2 we have a similar scenario. The physical addresses are changed, and a new frame is sent to the destination computer. When the frame reaches the destination, the packet is decapsulated. The destination logical address P matches the logical address of the computer. The data are decapsulated from the packet and delivered to the upper layer. Note that although physical addresses will change from hop to hop, logical addresses remain the same from the source to destination. There are some exceptions to this rule that we discover later in the book.

---

**The physical addresses will change from hop to hop,  
but the logical addresses usually remain the same.**

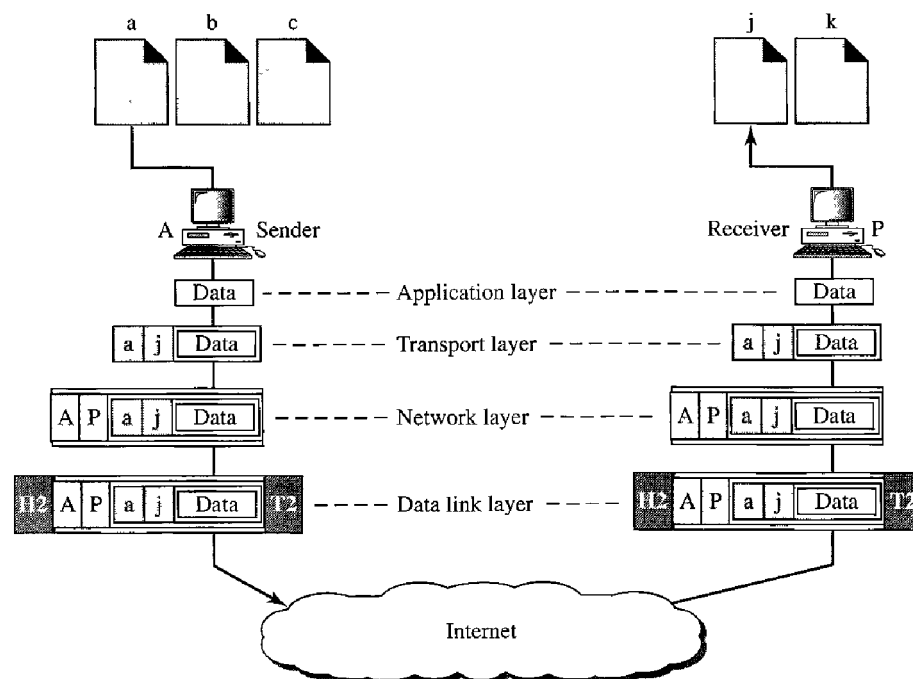
---

## Port Addresses

The IP address and the physical address are necessary for a quantity of data to travel from a source to the destination host. However, arrival at the destination host is not the final objective of data communications on the Internet. A system that sends nothing but data from one computer to another is not complete. Today, computers are devices that can run multiple processes at the same time. The end objective of Internet communication is a process communicating with another process. For example, computer A can communicate with computer C by using TELNET. At the same time, computer A communicates with computer B by using the File Transfer Protocol (FTP). For these processes to receive data simultaneously, we need a method to label the different processes. In other words, they need addresses. In the TCP/IP architecture, the label assigned to a process is called a port address. A port address in TCP/IP is 16 bits in length.

### *Example 2.4*

Figure 2.21 shows two computers communicating via the Internet. The sending computer is running three processes at this time with port addresses a, b, and c. The receiving computer is running two processes at this time with port addresses j and k. Process a in the sending computer needs to communicate with process j in the receiving computer. Note that although both computers are using the same application, FTP, for example, the port addresses are different because one is a client program and the other is a server program, as we will see in Chapter 23. To show that data from process a need to be delivered to process j, and not k, the transport layer encapsulates data from the application layer in a packet and adds two port addresses (a and j), source and destination. The packet from the transport layer is then encapsulated in another packet at the network layer with logical source and destination addresses (A and P). Finally, this packet is encapsulated in a frame with the physical source and destination addresses of the next hop. We have not shown the physical addresses because they change from hop to hop inside the cloud designated as the Internet. Note that although physical addresses change from hop to hop, logical and port addresses remain the same from the source to destination. There are some exceptions to this rule that we discuss later in the book.

**Figure 2.21** *Port addresses*

**The physical addresses change from hop to hop,  
but the logical and port addresses usually remain the same.**

**Example 2.5**

As we will see in Chapter 23, a port address is a 16-bit address represented by one decimal number as shown.

**753**

A 16-bit port address represented as one single number

**Specific Addresses**

Some applications have user-friendly addresses that are designed for that specific address. Examples include the e-mail address (for example, `forouzan@fhda.edu`) and the Universal Resource Locator (URL) (for example, `www.mhhe.com`). The first defines the recipient of an e-mail (see Chapter 26); the second is used to find a document on the World Wide Web (see Chapter 27). These addresses, however, get changed to the corresponding port and logical addresses by the sending computer, as we will see in Chapter 25.

**2.6 RECOMMENDED READING**

For more details about subjects discussed in this chapter, we recommend the following books and sites. The items enclosed in brackets, [. . .] refer to the reference list at the end of the text.

## Books

Network models are discussed in Section 1.3 of [Tan03], Chapter 2 of [For06], Chapter 2 of [Sta04], Sections 2.2 and 2.3 of [GW04], Section 1.3 of [PD03], and Section 1.7 of [KR05]. A good discussion about addresses can be found in Section 1.7 of [Ste94].

## Sites

The following site is related to topics discussed in this chapter.

❑ [www.osi.org/](http://www.osi.org/) Information about OSI.

## RFCs

The following site lists all RFCs, including those related to IP and port addresses.

❑ [www.ietf.org/rfc.html](http://www.ietf.org/rfc.html)

---

## 2.7 KEY TERMS

access control	Open Systems Interconnection (OSI) model
Address Resolution Protocol (ARP)	peer-to-peer process
application layer	physical addressing
best-effort delivery	physical layer
bits	port address
connection control	presentation layer
data link layer	process-to-process delivery
encoding	Reverse Address Resolution Protocol (RARP)
error	routing
error control	segmentation
flow control	session layer
frame	source-to-destination delivery
header	Stream Control Transmission Protocol (SCTP)
hop-to-hop delivery	synchronization point
host-to-host protocol	TCP/IP protocol suite
interface	trailer
Internet Control Message Protocol (ICMP)	Transmission Control Protocol (TCP)
Internet Group Message Protocol (IGMP)	transmission rate
logical addressing	transport layer
mail service	transport level protocols
network layer	User Datagram Protocol (UDP)
node-to-node delivery	
open system	

## 2.8 SUMMARY

- ☐ The International Standards Organization created a model called the Open Systems Interconnection, which allows diverse systems to communicate.
  - ☐ The seven-layer OSI model provides guidelines for the development of universally compatible networking protocols.
  - ☐ The physical, data link, and network layers are the network support layers.
  - ☐ The session, presentation, and application layers are the user support layers.
  - ☐ The transport layer links the network support layers and the user support layers.
  - ☐ The physical layer coordinates the functions required to transmit a bit stream over a physical medium.
  - ☐ The data link layer is responsible for delivering data units from one station to the next without errors.
  - ☐ The network layer is responsible for the source-to-destination delivery of a packet across multiple network links.
  - ☐ The transport layer is responsible for the process-to-process delivery of the entire message.
  - ☐ The session layer establishes, maintains, and synchronizes the interactions between communicating devices.
  - ☐ The presentation layer ensures interoperability between communicating devices through transformation of data into a mutually agreed upon format.
  - ☐ The application layer enables the users to access the network.
  - ☐ TCP/IP is a five-layer hierarchical protocol suite developed before the OSI model.
  - ☐ The TCP/IP application layer is equivalent to the combined session, presentation, and application layers of the OSI model.
  - ☐ Four levels of addresses are used in an internet following the TCP/IP protocols: physical (link) addresses, logical (IP) addresses, port addresses, and specific addresses.
  - ☐ The physical address, also known as the link address, is the address of a node as defined by its LAN or WAN.
  - ☐ The IP address uniquely defines a host on the Internet.
  - ☐ The port address identifies a process on a host.
  - ☐ A specific address is a user-friendly address.
- 

## 2.9 PRACTICE SET

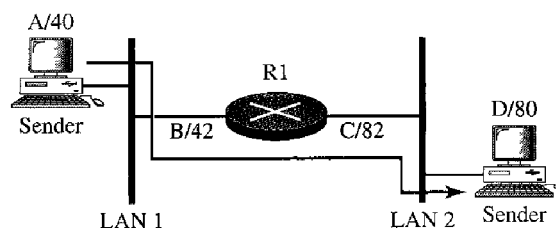
### Review Questions

1. List the layers of the Internet model.
2. Which layers in the Internet model are the network support layers?
3. Which layer in the Internet model is the user support layer?
4. What is the difference between network layer delivery and transport layer delivery?

5. What is a peer-to-peer process?
6. How does information get passed from one layer to the next in the Internet model?
7. What are headers and trailers, and how do they get added and removed?
8. What are the concerns of the physical layer in the Internet model?
9. What are the responsibilities of the data link layer in the Internet model?
10. What are the responsibilities of the network layer in the Internet model?
11. What are the responsibilities of the transport layer in the Internet model?
12. What is the difference between a port address, a logical address, and a physical address?
13. Name some services provided by the application layer in the Internet model.
14. How do the layers of the Internet model correlate to the layers of the OSI model?

## Exercises

15. How are OSI and ISO related to each other?
16. Match the following to one or more layers of the OSI model:
  - a. Route determination
  - b. Flow control
  - c. Interface to transmission media
  - d. Provides access for the end user
17. Match the following to one or more layers of the OSI model:
  - a. Reliable process-to-process message delivery
  - b. Route selection
  - c. Defines frames
  - d. Provides user services such as e-mail and file transfer
  - e. Transmission of bit stream across physical medium
18. Match the following to one or more layers of the OSI model:
  - a. Communicates directly with user's application program
  - b. Error correction and retransmission
  - c. Mechanical, electrical, and functional interface
  - d. Responsibility for carrying frames between adjacent nodes
19. Match the following to one or more layers of the OSI model:
  - a. Format and code conversion services
  - b. Establishes, manages, and terminates sessions
  - c. Ensures reliable transmission of data
  - d. Log-in and log-out procedures
  - e. Provides independence from differences in data representation
20. In Figure 2.22, computer A sends a message to computer D via LAN1, router R1, and LAN2. Show the contents of the packets and frames at the network and data link layer for each hop interface.

**Figure 2.22** Exercise 20

21. In Figure 2.22, assume that the communication is between a process running at computer A with port address  $i$  and a process running at computer D with port address  $j$ . Show the contents of packets and frames at the network, data link, and transport layer for each hop.
22. Suppose a computer sends a frame to another computer on a bus topology LAN. The physical destination address of the frame is corrupted during the transmission. What happens to the frame? How can the sender be informed about the situation?
23. Suppose a computer sends a packet at the network layer to another computer somewhere in the Internet. The logical destination address of the packet is corrupted. What happens to the packet? How can the source computer be informed of the situation?
24. Suppose a computer sends a packet at the transport layer to another computer somewhere in the Internet. There is no process with the destination port address running at the destination computer. What will happen?
25. If the data link layer can detect errors between hops, why do you think we need another checking mechanism at the transport layer?

### Research Activities

26. Give some advantages and disadvantages of combining the session, presentation, and application layer in the OSI model into one single application layer in the Internet model.
27. Dialog control and synchronization are two responsibilities of the session layer in the OSI model. Which layer do you think is responsible for these duties in the Internet model? Explain your answer.
28. Translation, encryption, and compression are some of the duties of the presentation layer in the OSI model. Which layer do you think is responsible for these duties in the Internet model? Explain your answer.
29. There are several transport layer models proposed in the OSI model. Find all of them. Explain the differences between them.
30. There are several network layer models proposed in the OSI model. Find all of them. Explain the differences between them.