Don't forget to check out the Online Learning Center, www.mhhe.com/forouzan for additional resources!

Instructors and students using *Data Communications and Networking,* Fourth Edition by Behrouz A. Forouzan will find a wide variety of resources available at the Online Learning Center, www.mhhe.comlforouzan

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Instructors can access the following resources by contacting their McGraw-Hill Repre sentative for a secure password.

a PowerPoint Slides. Contain figures, tables, highlighted points, and brief descriptions of each section.

O Complete Solutions Manual. Password-protected solutions to all end-of-chapter problems are provided.

a Pageout. A free tool that helps you create your own course website. D Instructor Message Board. Allows you to share ideas with other instructors using the text.

Student Resources

The student resources are available to those students using the book. Once you have accessed the Online Learning Center, click on "Studen"Student Resources," then select a chap ter from the drop down menu that appears. Each chapter has a wealth of materials to help you review communications and networking concepts. Included are:

a Chapter Summaries. Bulleted summary points provide an essential review of major ideas and concepts covered in each chapter.

a Student Solutions Manual. Contains answers for odd-numbered problems. O Glossary. Defines key terms presented in the book.

O Flashcards. Facilitate learning through practice and review.

a Animated Figures. Visual representations model key networking concept ging them to life.

D Automated Quizzes. Easy-to-use quizzes strengthen learning and emphas por tant ideas from the book.

a Web links. Connect students to additional resources available online.

DATA

COMMUNICATIONS AND NETWORKING

McGraw-Hill Forouzan Networking Series

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DATA COMMUNICATIONS AND NETWORKING

Fourth Edition

Behrouz A. Forouzan

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To Iny *wife, Faezeh, with love* Behrouz Forouzan

BRIEF CONTENTS

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Data communications and networking may be the fastest growing technologies in our culture today. One ofthe ramifications of that growth is a dramatic increase in the number of professions where an understanding of these technologies is essential for success and a proportionate increase in the number and types of students taking courses to learn about them.

Features of the Book

Several features of this text are designed to make it particularly easy for students to

understand data communications and networking.

Structure

We have used the five-layer Internet model as the framework for the text not only because a thorough understanding ofthe model is essential to understanding most current network ing theory but also because it is based on a structure of interdependencies: Each layer builds upon the layer beneath it and supports the layer above it. In the same way, each con cept introduced in our text builds upon the concepts examined in the previous sections. The Internet model was chosen because it is a protocol that is fully implemented.
This text is designed for students with little or no background in telecommunica tions or data communications. For this reason, we use a bottom-up approach. With this approach, students learn first about data communications (lower layers) before learning about networking (upper layers).

Visual Approach

The book presents highly technical subject matter without complex formulas by using a balance of text and figures. More than 700 figures accompanying the text provide a visual and intuitive opportunity for understanding the material. Figures are particularly important in explaining networking concepts, which are based on connections and transmission. Both of these ideas are easy to grasp visually.

Highlighted Points

We emphasize important concepts in highlighted boxes for quick reference and imme diate attention.

Examples and Applications

When appropriate, we have selected examples to reflect true-to-life situations. For exam ple, in Chapter 6 we have shown several cases of telecommunications in current telephone networks.

Recommended Reading

Each chapter includes a list of books and sites that can be used for further reading.

Key Terms

Each chapter includes a list of key terms for the student.

Summary

Each chapter ends with a summary of the material covered in that chapter. The sum mary provides a brief overview of all the important points in the chapter.

Practice Set

Each chapter includes a practice set designed to reinforce and apply salient concepts. It consists of three parts: review questions, exercises, and research activities (only for appropriate chapters). Review questions are intended to test the student's first-level under standing of the material presented in the chapter. Exercises require deeper understanding of the materiaL Research activities are designed to create motivation for further study.

Appendixes

The appendixes are intended to provide quick reference material or a review of materi als needed to understand the concepts discussed in the book.

Glossary andAcronyms

The book contains an extensive glossary and a list of acronyms.

Changes in the Fourth Edition

The Fourth Edition has major changes from the Third Edition, both in the organization and in the contents.

Organization

The following lists the changes in the organization of the book:

1. Chapter 6 now contains multiplexing as well as spreading.
2. Chapter 8 is now totally devoted to switching.
3. The contents of Chapter 12 are moved to Chapter 11.
4. Chapter 17 covers SONET technology.
5. Chapter 19 discusses IP addressing.
6. Chapter 20 is devoted to the Internet Protocol.
7. Chapter 21 discusses three protocols: ARP, ICMP, and IGMP.
8. Chapter 28 is new and devoted to network management in the Internet.
9. The previous Chapters 29 to 31 are now Chapters 30 to 32.

Contents

We have revised the contents of many chapters including the following: 1. The contents of Chapters 1 to 5 are revised and augmented. Examples are added to clarify the contents.

2. The contents of Chapter 10 are revised and augmented to include methods of error detection and correction.

3. Chapter 11 is revised to include a full discussion of several control link protocols. 4. Delivery, forwarding, and routing of datagrams are added to Chapter 22. 5. The new transport protocol, SCTP, is added to Chapter 23.

6. The contents of Chapters 30, 31, and 32 are revised and augmented to include additional discussion about security issues and the Internet.

7. New examples are added to clarify the understanding of concepts.

End Materials

1. A section is added to the end of each chapter listing additional sources for study. 2. The review questions are changed and updated.

3. The multiple-choice questions are moved to the book site to allow students to self-test their knowledge about the contents of the chapter and receive immediate feedback. 4. Exercises are revised and new ones are added to the appropriate chapters. 5. Some chapters contain research activities.

Instructional Materials

Instructional materials for both the student and the teacher are revised and augmented. The solutions to exercises contain both the explanation and answer including full col ored figures or tables when needed. The Powerpoint presentations are more compre hensive and

include text and figures.

Contents

The book is divided into seven parts. The first part is an overview; the last part concerns network security. The middle five parts are designed to represent the five layers of the Internet model. The following summarizes the contents of each part.

Part One: Overview

The first part gives a general overview of data communications and networking. Chap ter 1 covers introductory concepts needed for the rest of the book. Chapter 2 introduces the Internet model.

Part Two: Physical Layer

The second part is a discussion of the physical layer of the Internet model. Chapters 3 to 6 discuss telecommunication aspects of the physical layer. Chapter 7 introduces the transmission media, which, although not part of the physical layer, is controlled by it. Chapter 8 is devoted to switching, which can be used in several layers. Chapter 9 shows how two public networks, telephone and cable TV, can be used for data transfer.

Part Three: Data Link Layer

The third part is devoted to the discussion of the data link layer of the Internet model. Chapter 10 covers error detection and correction. Chapters 11, 12 discuss issues related to data link control. Chapters 13 through 16 deal with LANs. Chapters 17 and] 8 are about WANs. LANs and WANs are examples of networks operating in the first two lay ers of the Internet model.

Part Four: Network Layer

The fourth part is devoted to the discussion of the network layer of the Internet model. Chapter 19 covers **IP** addresses. Chapters 20 and 21 are devoted to the network layer protocols such as **IP,** ARP, ICMP, and IGMP. Chapter 22 discusses delivery, forwarding, and routing of packets in the Internet.

Part Five: Transport Layer

The fifth part is devoted to the discussion of the transport layer of the Internet model. Chapter 23 gives an overview of the transport layer and discusses the services and duties of this layer. It also introduces three transport-layer protocols: UDP, TCP, and SCTP. Chapter 24 discusses congestion control and quality of service, two issues related to the transport layer and the previous two layers.

Part Six: Application Layer

The sixth part is devoted to the discussion of the application layer of the Internet model. Chapter 25 is about DNS, the application program that is used by other application pro grams to map application layer addresses to network layer addresses. Chapter 26 to 29 discuss some common applications protocols in the Internet.

Part Seven: Security

The seventh part is a discussion of security. It serves as a prelude to further study in this subject. Chapter 30 briefly discusses cryptography. Chapter 31 introduces security

aspects. Chapter 32 shows how different security aspects can be applied to three layers of the Internet model.

Online Learning Center

The McGraw-Hill Online Learning Center contains much additional material. Avail able at www.mhhe.com/forouzan. As students read through *Data Communications and Networking,* they can go online to take self-grading quizzes. They can also access lec ture materials such as PowerPoint slides, and get additional review from animated fig ures from the book. Selected solutions are also available over the Web. The solutions to odd-numbered problems are provided to students, and instructors can use a password to access the complete set of solutions.

Additionally, McGraw-Hill makes it easy to create a website for your networking course with an exclusive McGraw-Hill product called PageOut. It requires no prior knowledge of HTML, no long hours, and no design skills on your part. Instead, Page:- Out offers a series of templates. Simply fill them with your course information and

click on one of 16 designs. The process takes under an hour and leaves you with a pro fessionally designed website.

Although PageOut offers "instant" development, the finished website provides pow erful features. An interactive course syllabus allows you to post content to coincide with your lectures, so when students visit your PageOut website, your syllabus will direct them to components of Forouzan's Online Learning Center, or specific material of your own.

How to Use the Book

This book is written for both an academic and a professional audience. The book can be used as a self-study guide for interested professionals. As a textbook, it can be used for a one-semester or one-quarter course. The following are some guidelines. O Parts one to three are strongly recommended.

O Parts four to six can be covered if there is no following course in TCP/IP protocol. O Part seven is recommended if there is no following course in network security.

Acknowledgments

It is obvious that the development of a book of this scope needs the support ofmany people.

Peer Review

The most important contribution to the development of a book such as this comes from peer reviews. We cannot express our gratitude in words to the many reviewers who spent numerous hours reading the manuscript and providing us with helpful comments and ideas. We would especially like to acknowledge the contributions of the following reviewers for the third and fourth editions of this book.

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Joseph Sherif, *California State University, Fullerton*
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Ronald 1. Srodawa, *Oakland University*
Daniel Tian, *California State University, Monterey Bay*
Richard Tibbs, *Radford University*
Christophe Veltsos, *Minnesota State University, Mankato*

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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 con cept 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 charac teristics 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 com ponents 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 dis cuss 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 communi cations 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

CHAPTERl

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 technolo gies. 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 dis cussed 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 com bination of hardware (physical equipment) and software (programs). The effectiveness of a data

communications system depends on four fundamental characteristics: deliv ery, accuracy, timeliness, and jitter.

l. 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.

7 Accuracy. The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.

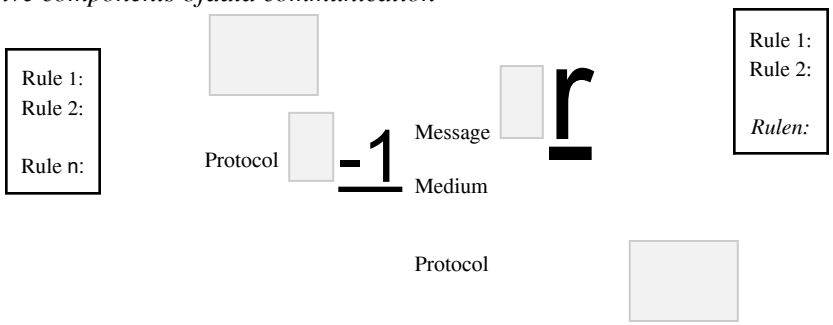
3. Timeliness. The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without signifi cant delay. This kind of delivery is called *real-time* transmission.

-\.. 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 3D ms. Ifsome of the packets arrive with 3D-ms delay and others with 4D-ms delay, an uneven quality in the video is the result.

COinponents

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

Figure 1.1 *Five components ofdata communication*



I. Message. The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video. 1 Sender. The sender is the device that sends the data message. It can be a com puter, workstation, telephone handset, video camera, and so on.

3. Receiver. The receiver is the device that receives the message. It can be a com puter, workstation, telephone handset, television, and so on.

-1.. 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 repre sents 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 (Os or Is).

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 Infor mation 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 I-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.

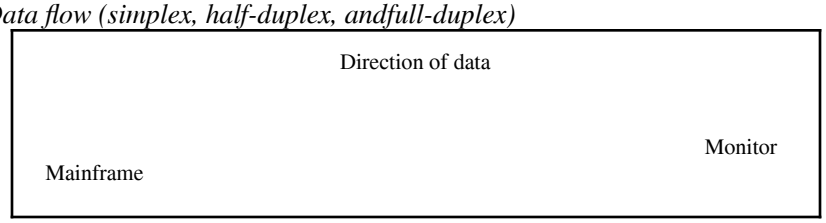
Video

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.

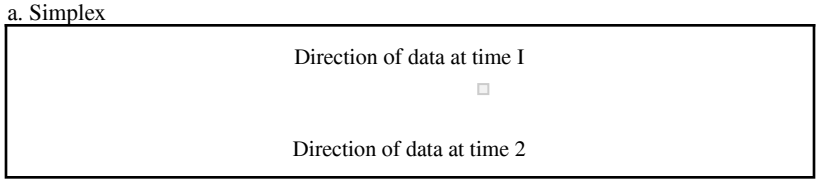
Data Flow

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

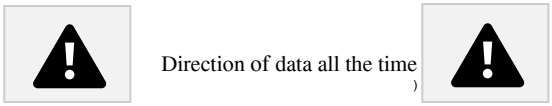
Figure 1.2 *Data flow (simplex, half-duplex, andfull-duplex)*



a. Simplex



b. Half-duplex



c. 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 key board 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 direc tions. 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 m.,lle (als@ called duplex), both stations can transmit and receive simul taneously (see Figure 1.2c).

The full-duplex mode is like a tW<D-way street with traffic flowing in both direc tions at the same time. In full-duplex mode, si~nals going in one direction share the capacity of the link: with signals going in the other din~c~on. This sharing can

occur in two ways: Either the link must contain two physically separate t:nmsmissiIDn paths, one for sending and the other for receiving; or the capacity of the ch:arillilel 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 per formance 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 ofConnection

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 con nect the two ends, but other options, such as microwave or satellite links, are also possi ble (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.

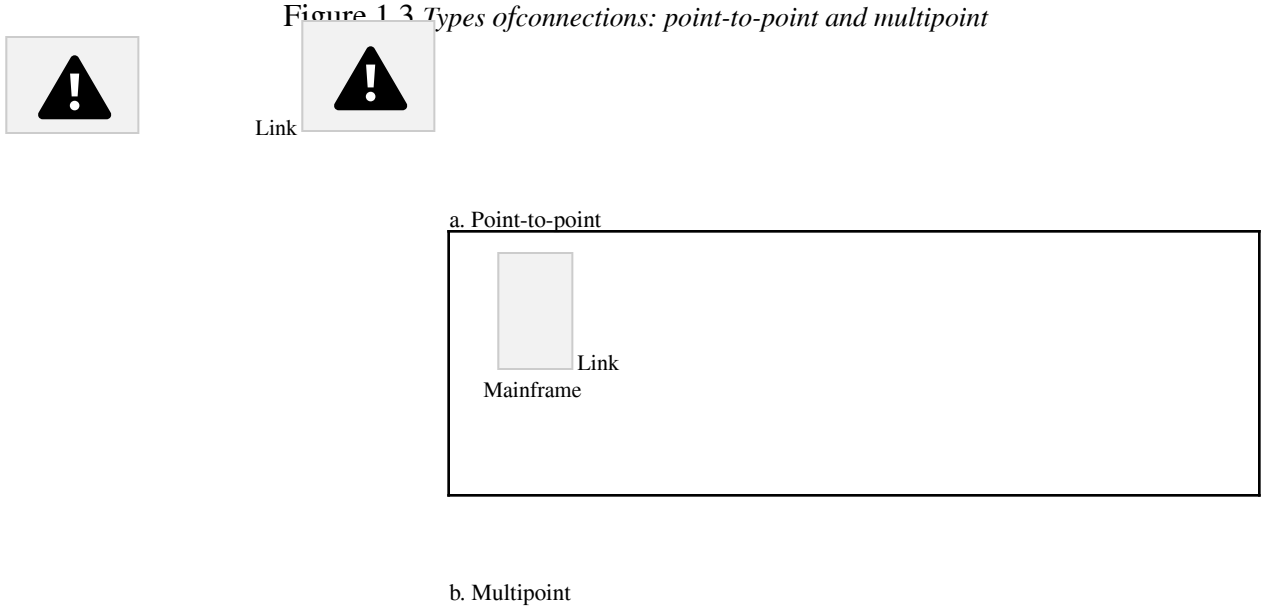
Multipoint A multipoint (also called multidrop) connection is one in which more than two specific devices share a single link (see Figure 1.3b).

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.: 1\vo or more devices connect to a link; two or more links form a topology. The topology

Figure 1.3 *Types ofconnections: 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 oftopology*

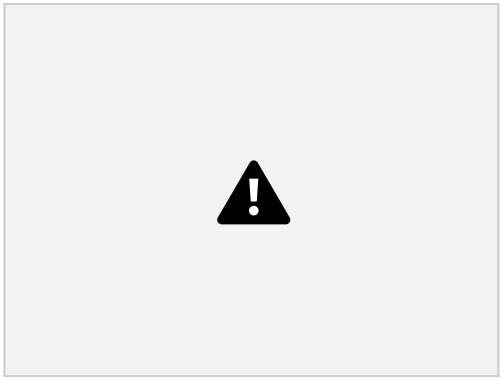
Mesh In a mesh topology, every device has a dedicated point-to-point link to every other device. The term *dedicated* means that the link carries traffic only between the two devices it connects. To find the number of physical links in a fully connected mesh network with *n* nodes, we first consider that each node must be connected to every other node. Node 1 must be connected to *n* - I 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 (VO) 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 elimi nating 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 incapaci tate 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 accom modate. 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.

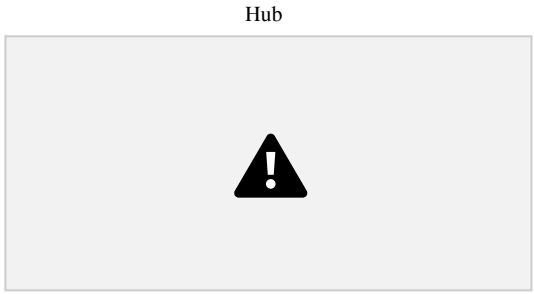
One practical example of a mesh topology is the connection of telephone regional offices in which each regional office needs to be connected to every other regional office.

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 con nected 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 addi tions, 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*



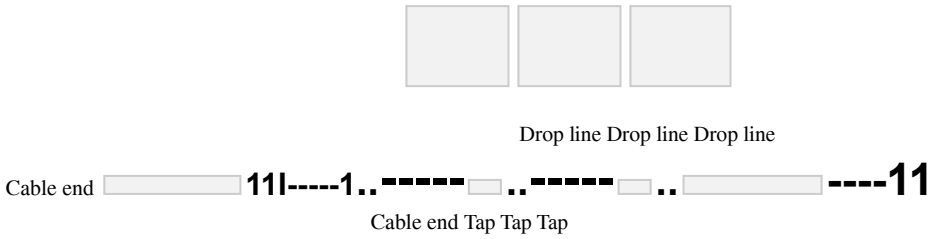
fault isolation. As long as the hub is working, it can be used to monitor link problems and bypass defective links.

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 con nection 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 ofits 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 near est point on the backbone.

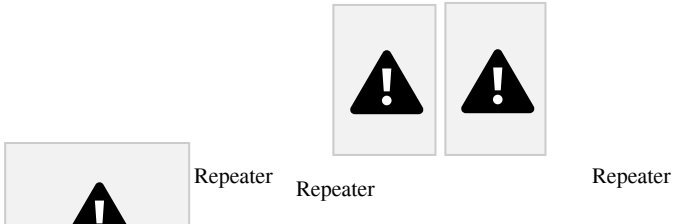
Disadvantages include difficult reconnection and fault isolation. A bus is usually designed to be optimally efficient at installation. It can therefore be difficult to add new devices. Signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting the number 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 con nection 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*



Repeater Repeater

Repeater

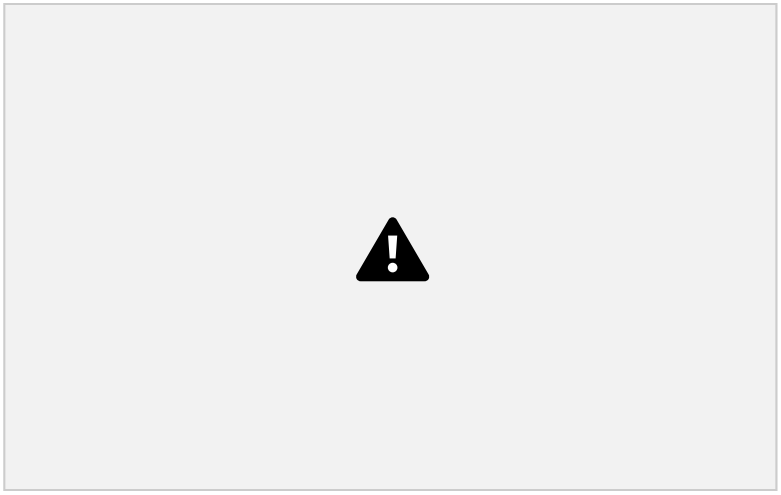
A ring is relatively easy to install and reconfigure. Each device is linked to only its immediate neighbors (either physically or logically). To add or delete a device requires changing only two connections. The only constraints are media and traffic consider ations (maximum ring length and number of devices). In addition, fault isolation is sim plified. 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 topol ogy 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* Hub



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 stan dards 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 net work; the Internet model defines a five-layer network. This book is based on the Internet model

with occasional references to the OSI model.

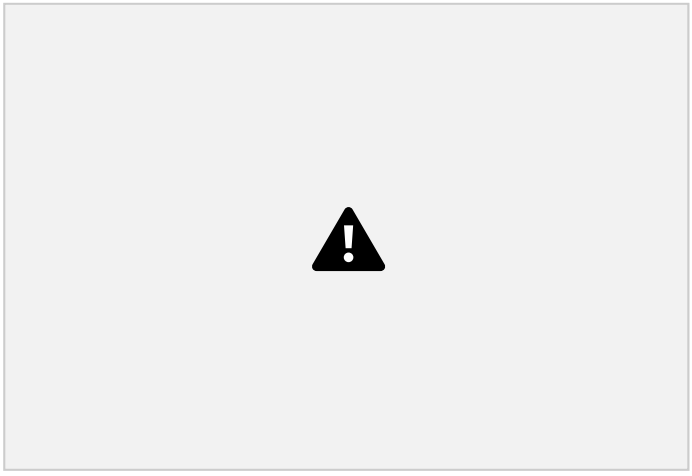
Categories of Networks

Today when we speak of networks, we are generally referring to two primary catego ries: 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 IAN connecting* 12 *computers to a hub in a closet*


Hub

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, engi neering 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 ofsoft ware, 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 conti nent, 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 (lSP). This type of WAN is often used to provide Internet access.

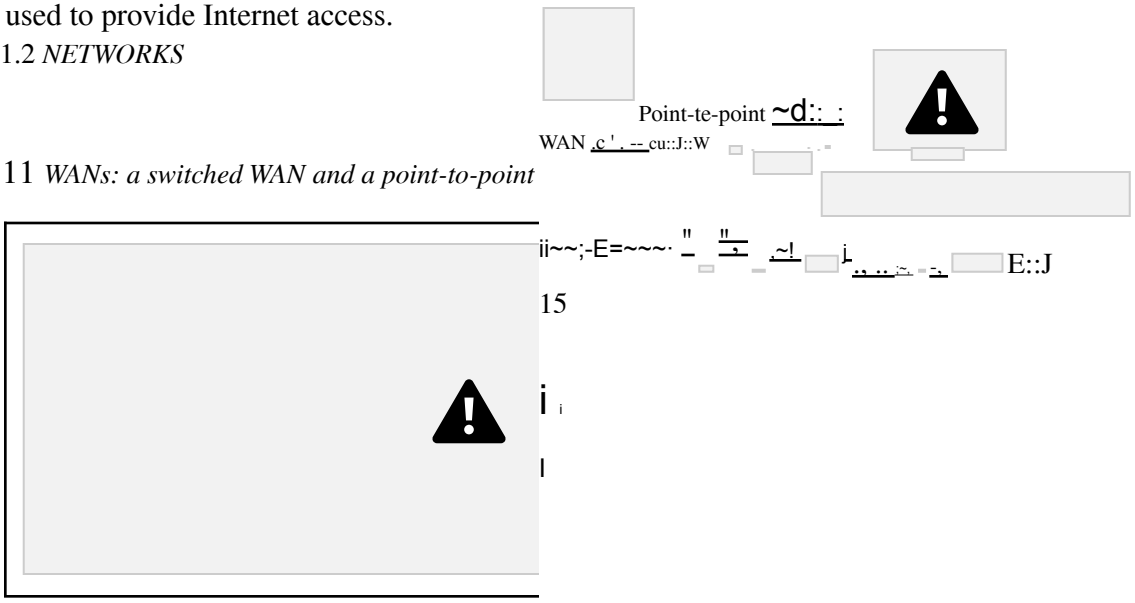


Figure 1.11 *WANs: a switched WAN and a point-to-point WAN*

An early example of a switched WAN is X.25, a network designed to provide con nectivity 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 net work with fixed-size data unit packets called cells. We will discuss ATM in Chapter 18. Another example ofWANs is the wireless WAN that is becoming more and more popu lar. 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.

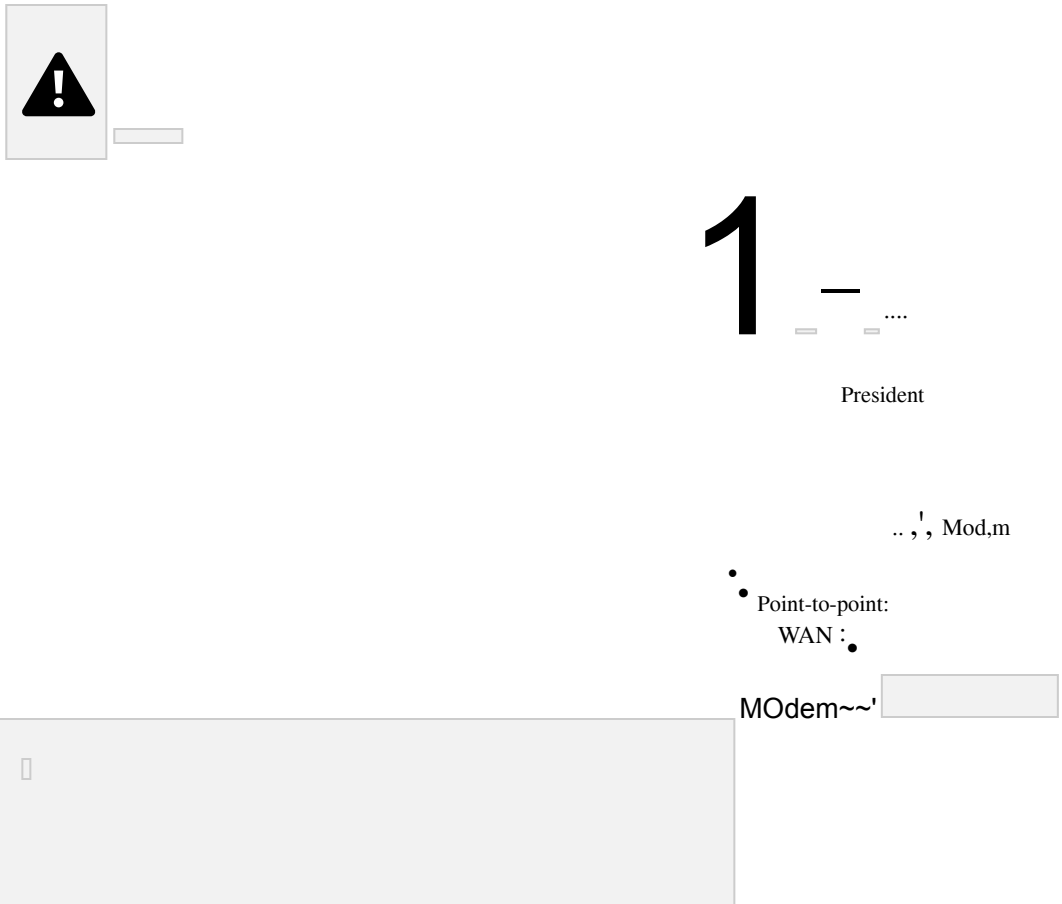
Interconnection of Networks: Internetwork

Today, it is very rare to see a LAN, a MAN, or a LAN in isolation; they are con nected 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 horne. 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 modern line offered by a cable TV provider as shown in Figure 1.12.

Figure 1.12 *A heterogeneous network made offour WANs and two LANs*



WAN

Point-to-point
WAN

LAN

LAN

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 descri 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 com municate with each other. The most notable internet is called the Internet (uppercase letter I), a collaboration of more than hundreds of thousands of interconnected net works. Private individuals as well as various organizations such as government agen cies, schools, research facilities, corporations, and libraries in more than 100 countries use the Internet. Millions of people are users. Yet this extraordinary communication sys tem 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 Depart ment 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 elim inating duplication of effort.

In 1967, at an Association for Computing Machinery (ACM) meeting, ARPA pre sented 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 *inteiface message processor* (IMP). The IMPs, in tum, would be connected to one another. Each IMP had to be able to commu nicate 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 com munication 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 Projec1.* Cerf and Kahn's land mark 1973 paper outlined the protocols to achieve end-to-end delivery of packets. This paper on Transmission Control Protocol (TCP) included concepts such as encapsula tion, 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 (lP). 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 TCPIIP.

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 represen tation 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 (lSPs). 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 ofthe Internet*

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 main tained 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 Mel. To provide connectivity between the end users, these back bone 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 can not 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. O 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.

O 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 com munications. 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 tele communications 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 compati bility. 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 affili ated 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 develop ment 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 connec tion interfaces and electronic signaling specifications for data communication.

Forums

Telecommunications technology development is moving faster than the ability of stan dards 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 devel oped **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 pur pose of these agencies is to protect the public interest by regulating radio, television, and wire/cable communications. The FCC has authority over interstate and interna tional 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 fol lowed. 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 docu ment (a work in progress) with no official status and a 6-month lifetime. Upon recom mendation 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.
22 CHAPTER 1 *INTRODUCTION*

Sites

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

- www.acm.org/sigcomm/sos.html This site gives the status of varililus networking standards.
- 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 chap ters we cite the RFCs pertinent to the chapter material.

- www.ietf.org/rfc.html

1.6 KEY TERMS

Advanced Research Projects Agency (ARPA)

American National Standards Institute (ANSI)

American Standard Code for Information Interchange (ASCII) ARPANET

audio

backbone

Basic Latin

bus topology

code

Consultative Committee for International Telegraphy and Telephony (CCITT)

data

data communications

de facto standards

de jure standards

delay

distributed processing

Electronic Industries Association (EIA) entity

Federal Communications Commission (FCC)

forum

full-duplex mode, or duplex half-duplex mode
hub
image
Institute of Electrical and Electronics Engineers (IEEE)
International Organization for Standardization (ISO)
International Telecommunication Union-Telecommunication Standards Sector (ITU-T)
Internet
Internet draft
Internet service provider (ISP) Internet standard
internetwork or internet
local area network (LAN)
local Internet service providers mesh topology
message
metropolitan area network (MAN) multipoint or multidrop connection national Internet service provider network

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

1.7 SUMMARY

SECTION 1.7 *SUMMARY 23*

- 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.

O A network is a set of communication devices connected by media links. O 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. O Topology refers to the physical or logical arrangement of a network. Devices may be arranged in a mesh, star, bus, or ring topology.

O A network can be categorized as a local area network or a wide area network. O A LAN is a data communication system within a building, plant, or campus, or between nearby buildings.

O A WAN is a data communication system spanning states, countries, or the whole world.

O An internet is a network of networks.

O The Internet is a collection of many separate networks.

O There are local, regional, national, and international Internet service providers. O A protocol is a set of rules that govern data communication; the key elements of a protocol are syntax, semantics, and timing.

O Standards are necessary to ensure that products from different manufacturers can work together as expected.

O The ISO, ITD-T, ANSI, IEEE, and EIA are some of the organizations involved in standards creation.

O Forums are special-interest groups that quickly evaluate and standardize new technologies.

O 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 ofthe 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 \\iww.cne.gmu.edu/modules/network/osi.html, discuss the OSI model.
27. Using the site www.ansi.org, discuss ANSI's activities.
28. Using the site www.ieee.org, discuss IEEE's activities.
29. Using the site 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 ofsolving 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 ofsoftware that are called by the higher levels.

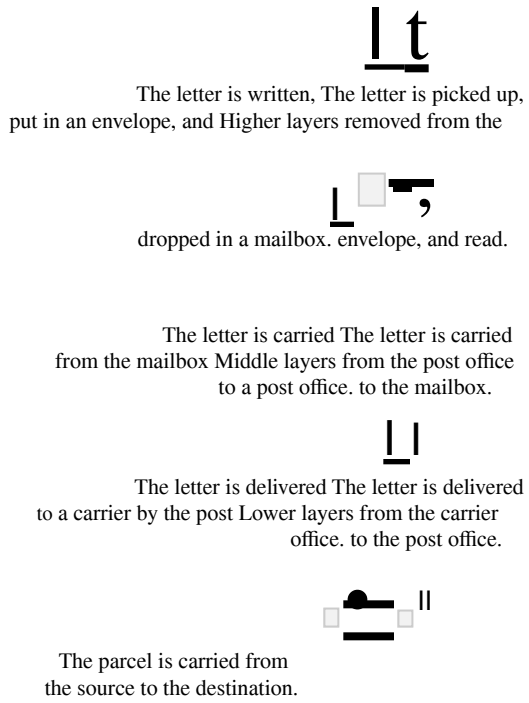
Compare this to a service provided by a computer network. For example, the task of sending an e-mail from one point in the world to another can be broken into several tasks, each performed by a separate software package. Each software package uses the services of another software package. At the lowest 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. Fig ure 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 Sellder Site

Let us first describe, in order, the activities that take place at the sender site. O 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. O Middle layer. The letter is picked up by a letter carrier and delivered to the post office.

O Lower layer. The letter is sorted at the post office; a carrier transports the letter.

011 *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 trans ported by truck, train, airplane, boat, or a combination of these.

At the Receiver Site

O Lower layer. The carrier transports the letter to the post office. O Middle layer.

The letter is sorted and delivered to the recipient's mailbox. O 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 TCPIIP protocol suite became the dominant commercial archi tecture 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 TCPIIP as a protocol suite.

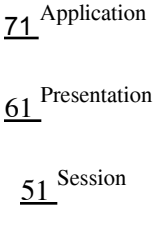
2.2 THE OSI MODEL

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 archi tecture. 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 hard ware 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 sep arate 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 ofthe OSI model*



41 Transport

31 Network

21 Data link

1 | Physical

Layered **Architecture**

The OSI model is composed ofseven 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.

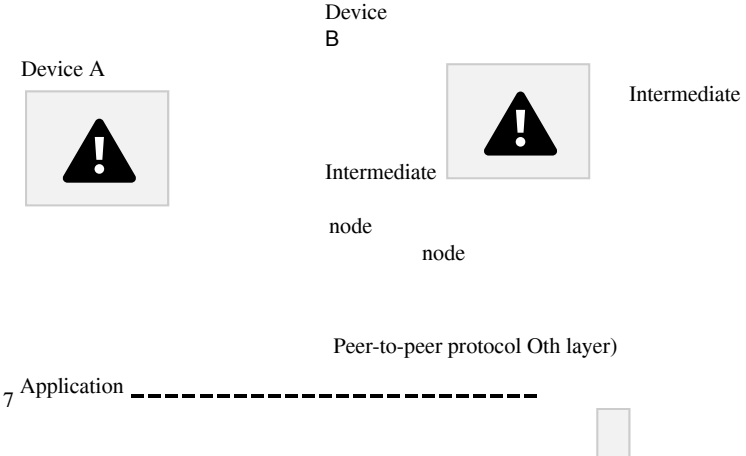
In *developing* the model, the designers distilled the process of transmitting data to its most fundamental elements. They identified which networking functions had related uses and collected those functions into discrete groups that became the layers. Each layer defines a family of functions distinct 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.

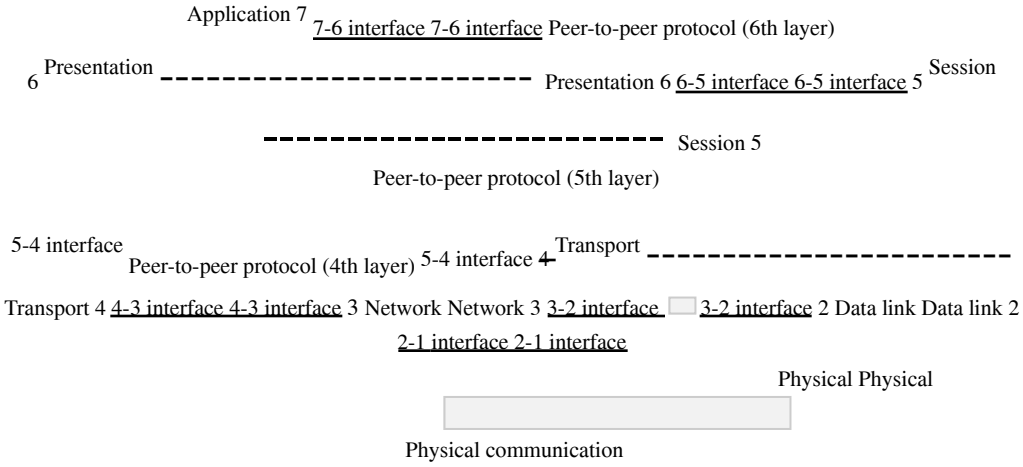
Within a single machine, each layer calls upon the services of the layer just below it. Layer 3, for example, uses the services provided by layer 2 and provides services for layer 4. Between machines, layer *x* on one machine communicates with layer *x* on another machine. This communication is governed 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, com munication 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 I 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 send ing 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 informa tion 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 ofthe Layers

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

the physical aspects of moving data from one device to another (such as electrical specifications, physical connections, physical addressing, and transport timing and reliability). Layers 5, 6, and 7-session, presentation, and application-can be thought of as the user support layers; they allow interoperability among unrelated software systems. Layer 4, the transport layer, links the two subgroups and ensures that what the lower layers have transmitted is in a form that the upper layers can use. The upper OSI layers are almost always implemented in software; lower layers are a combination of hardware and software, except for the physical layer, which is mostly hardware.

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 OS! 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: encapsula tion. 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.

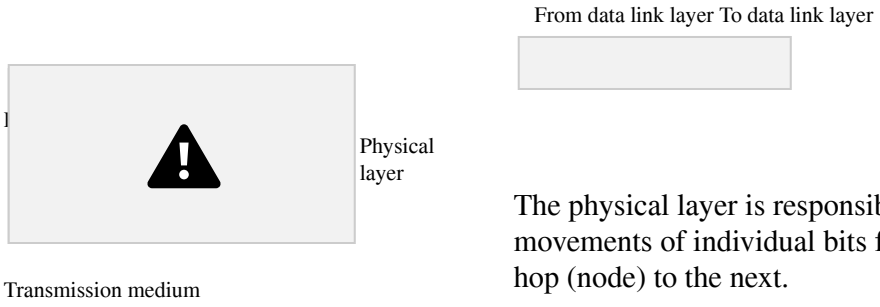
2.3 LAYERS IN THE OSI MODEL

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 physi cal 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 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 Os 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 Os and Is are changed to signals).

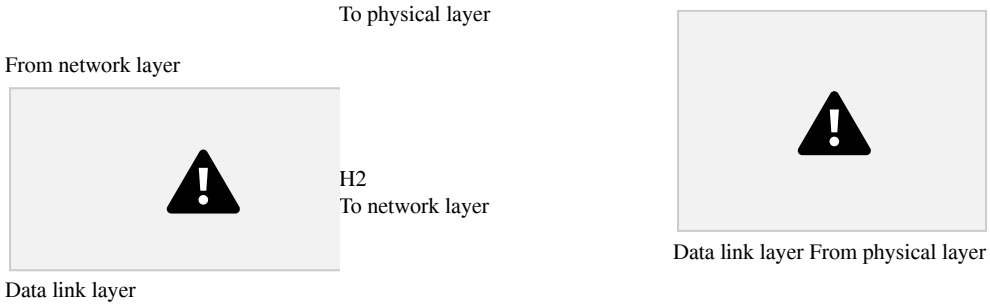
- Data rate. The transmission rate-the number of bits sent each second-is also defined by the physical layer. In other words, the physical layer defines the dura tion of a bit, which is how long it lasts.
- Synchronization of bits. The sender and receiver not only must use the same bit rate but also 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 reli able 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 phys icallayers.

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:

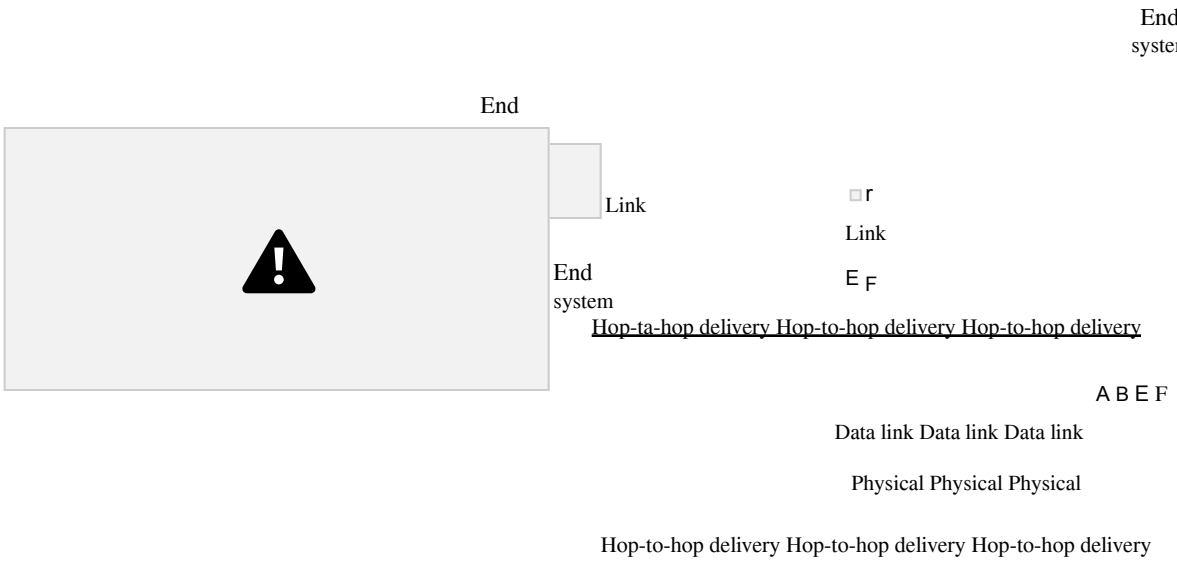
- [I Framing. The data link layer divides the stream of bits received from the network layer into manageable data units called frames.
- Physical addressing. If frames are to be distributed to different systems on the network, the data link layer adds a header to the frame to define the sender and/or 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.
- D 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 mecha nism to recognize duplicate frames. Error control is normally achieved through a trailer added to the end of the frame.

D 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-fa-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

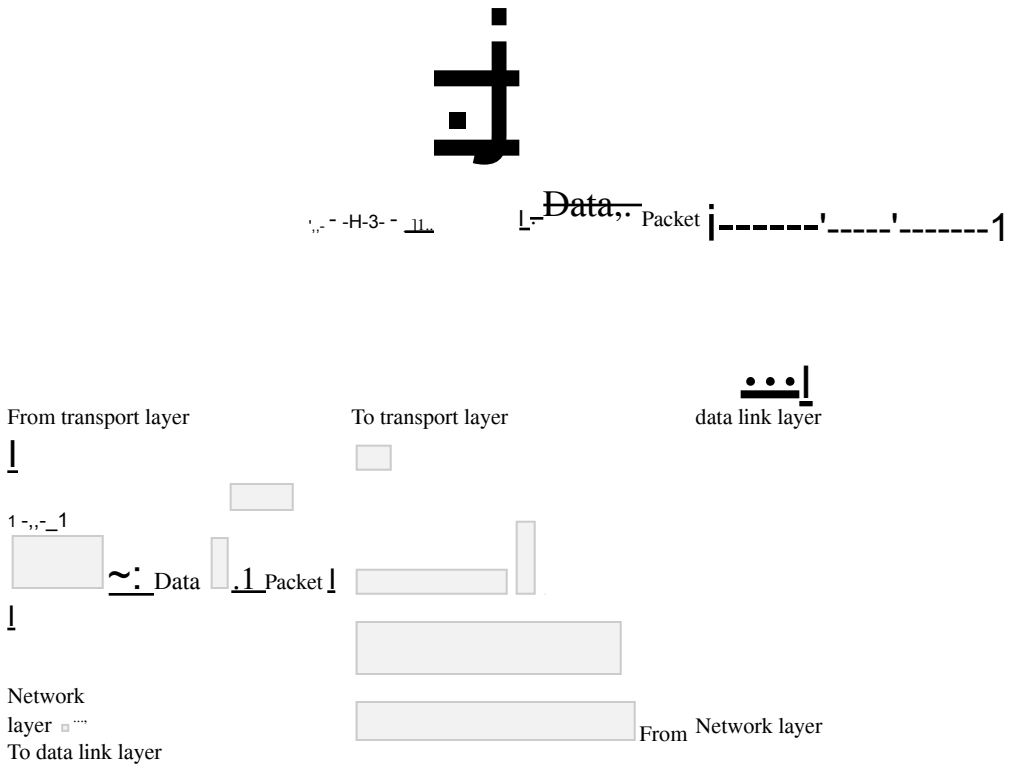
link layer at B sends a new frame to the data link layer at E. Finally, the data link layer at E sends a new frame to the data link layer at F. Note that the frames that are exchanged between the three nodes have different values in the headers. The frame from A to B has B as the destination address 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 net work 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.

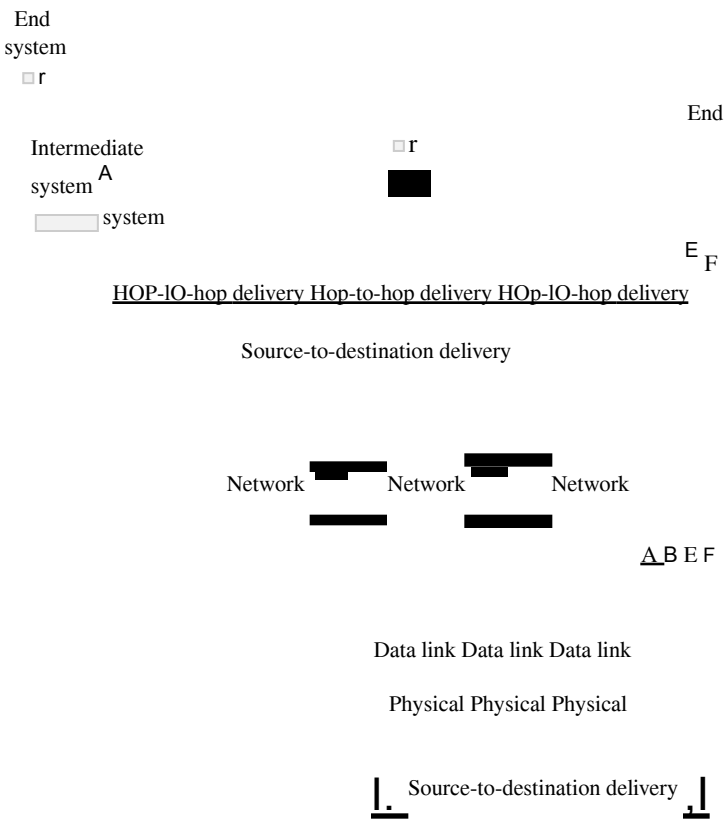
Other responsibilities of the network layer include the following:

- 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 *intemetworks* (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 func tions 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*

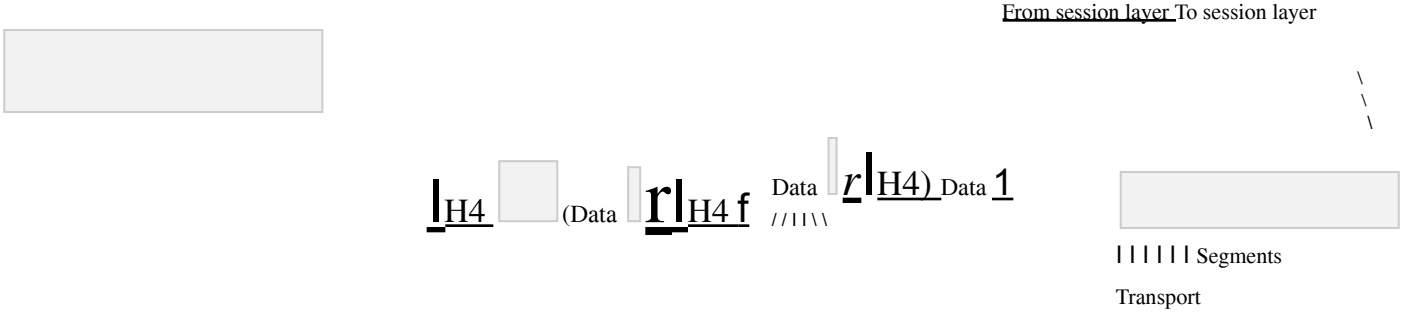


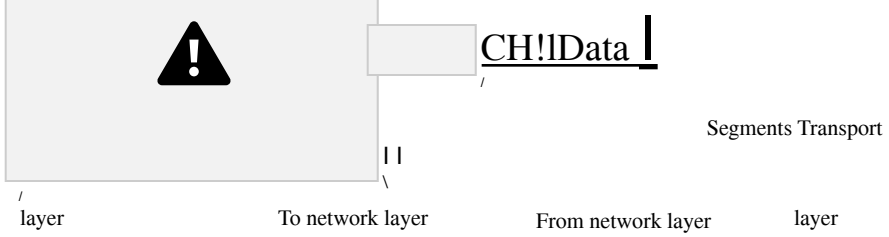
As the figure shows, now we need a source-to-destination delivery. The network layer at A sends the packet to the network layer at B. When the packet arrives at router B, the router makes a decision based on the final destination (F) of the packet. As we will see in later chapters, router B uses its 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 tum, sends the packet to the network layer at F.

Transport Layer

The transport layer is responsible for process-to-process delivery of the entire mes sage. 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*





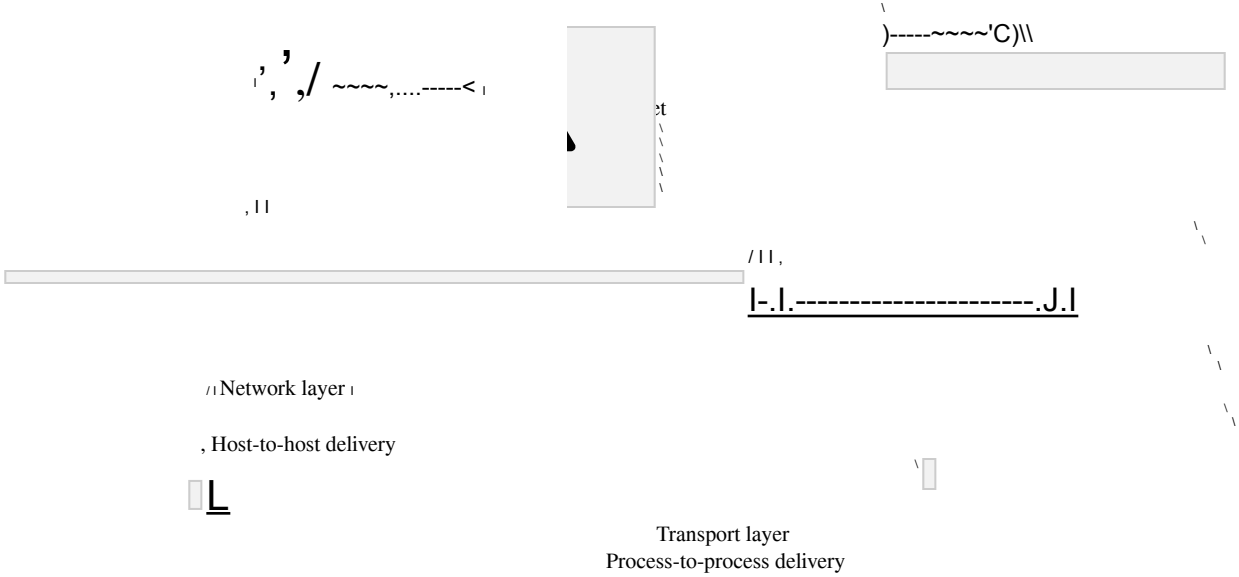
The transport layer is responsible for the delivery of a message from one process to another.

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 trans port 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 destina tion 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 ofa 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.

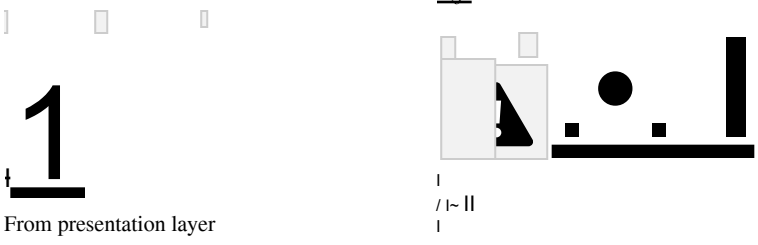
The session layer is responsible for dialog control and synchronization.

Specific responsibilities ofthe session layer include the following: O 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. O Synchronization. The session layer allows a process to add checkpoints, or syn Chronization 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 pre sentation layer and the application and session layers.

Figure 2.12 *Session layer*



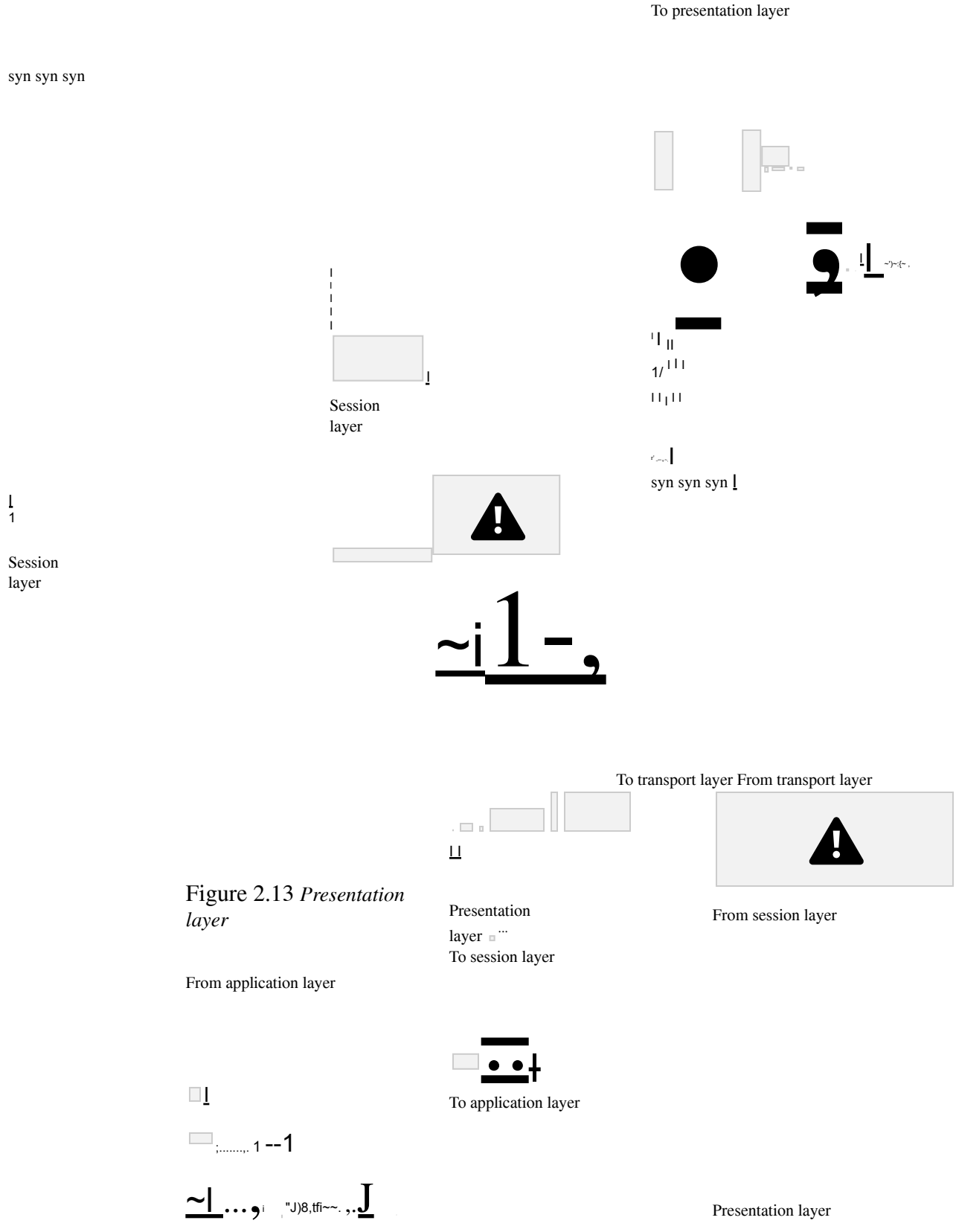


Figure 2.13 *Presentation layer*

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

Specific responsibilities of the presentation layer include the following: **O** Translation. The processes (running programs) in two systems are usually exchang ing information in the form of character strings, numbers, and so on. The infonna tion must be changed to bit streams before being transmitted. Because different computers use different

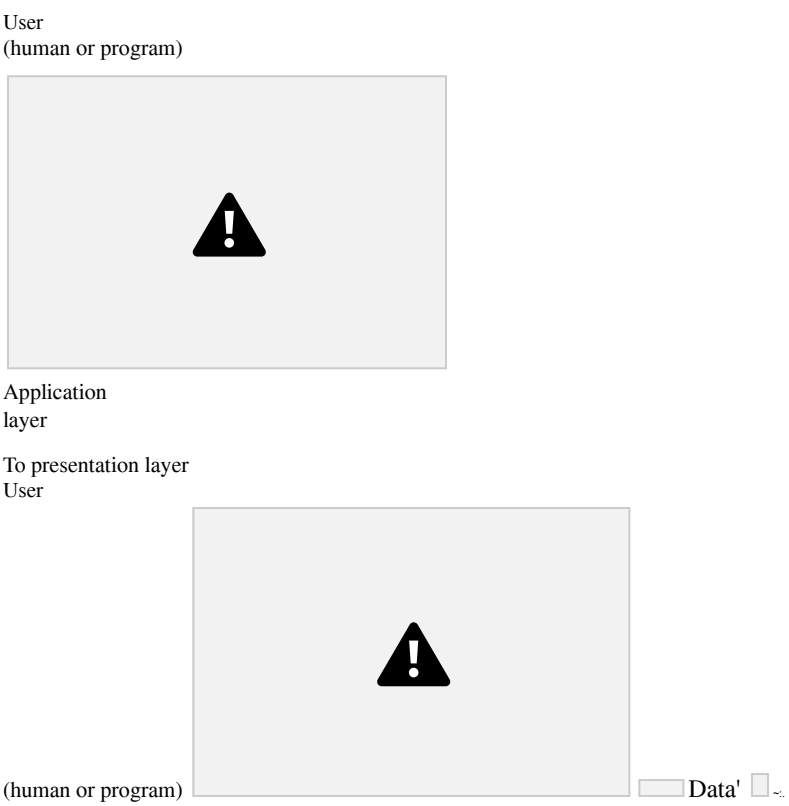
encoding systems, the presentation layer is responsible for interoperability between these different encoding methods. The presentation layer at the sender changes the information from its sender-dependent format into a common format. The presentation layer at the receiving machine changes the common 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 net work. It provides user interfaces and support for services such as electronic mail, remote file access and transfer, shared database management, and other types of distrib uted information services. Figure 2.14 shows the relationship of the application layer to the user and the pre sentation layer. Of the many application services available, the figure shows only three: XAOO (message-handling services), X.500 (directory services), and file transfer, access, and management (FTAM). The user in this example employs XAOO to send an e-mail message.

Figure 2.14 *Application layer*



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

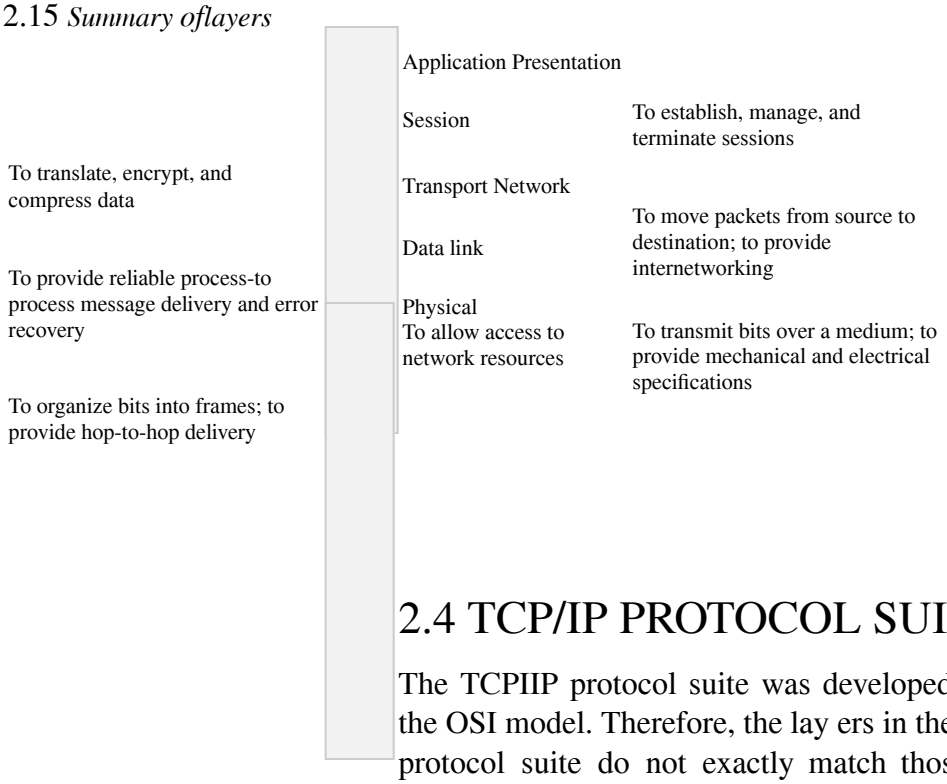
Specific services provided by the application layer include the following: O Network virtual terminal. A network virtual terminal is a software version of a physical terminal, and it allows a user to log on to a remote host. To do so, the application creates a software emulation of a terminal at the 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.

- O 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.
- O Mail services. This application provides the basis for e-mail forwarding and storage.
- O 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 oflayers*

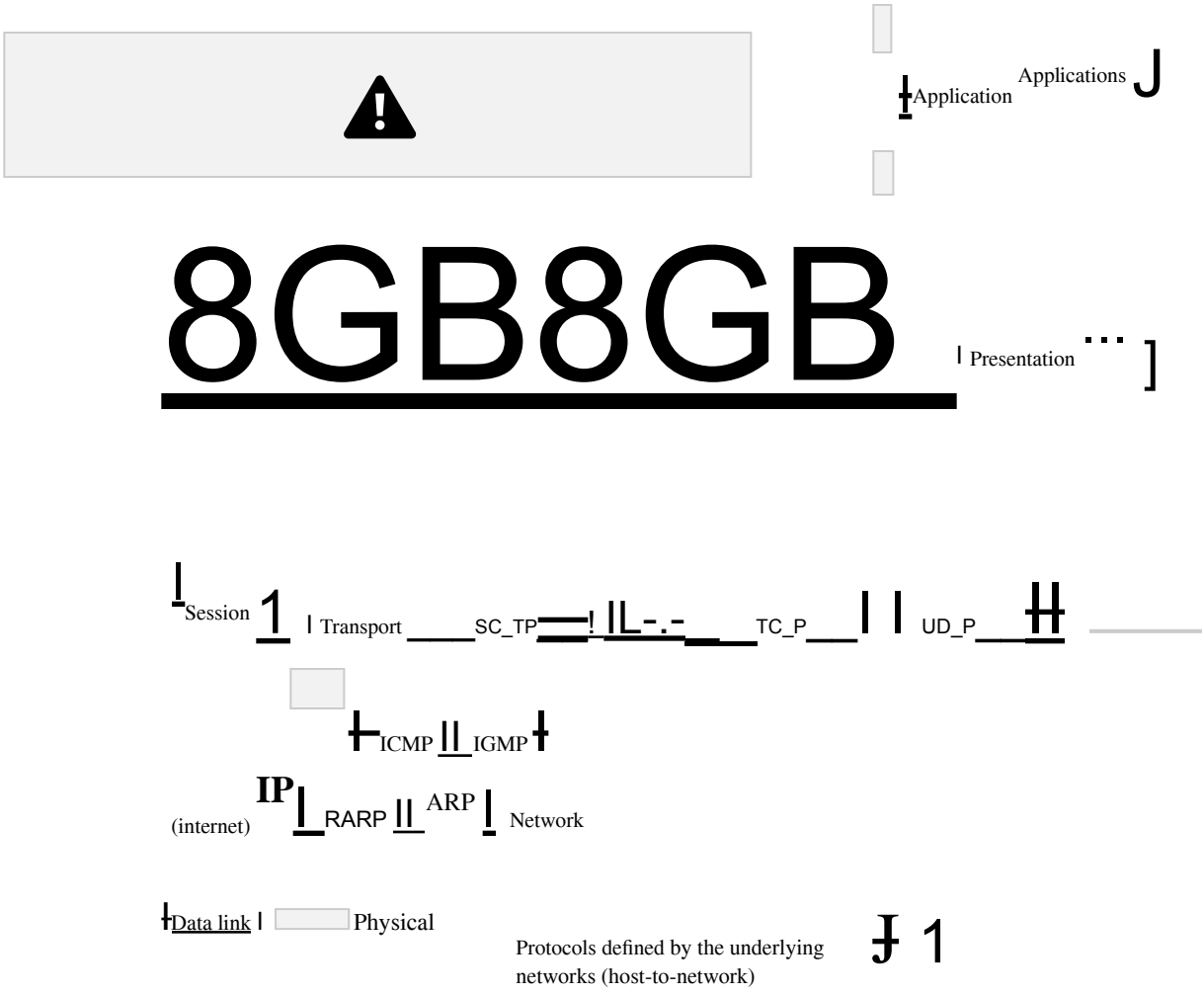


2.4 TCP/IP PROTOCOL SUITE

The TCPIIP protocol suite was developed prior to the OSI model. Therefore, the lay ers 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 applica tion layer is roughly doing the job of the session, presentation, and application layers with the transport layer in TCPIIP taking care of part of the duties of the session layer. So in this book, we assume that the TCPIIP protocol suite is made of five layers: physi cal, 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 TCPIIP by a single layer called the *application layer* (see Figure 2.16).

Figure 2.16 *TCPIIP 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 interdepen dent. 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 *hierarchi cal* 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, TCPIIP does not define any specific protocol. It supports all the standard and proprietary protocols. A network in a TCPIIP 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.