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Data Communication and Computer Network

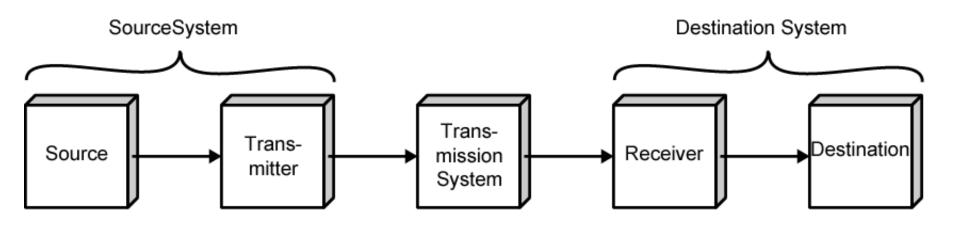# CSE 339

Chapter 1

Introduction

1-1 DATA COMMUNICATIONS

*The term **telecommunication** means communication at a distance. 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 (wired/wireless).*
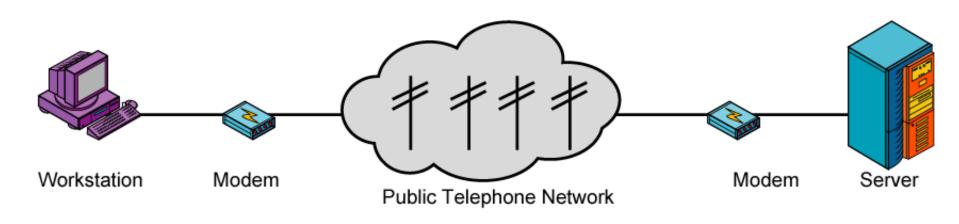
Topics discussed in this section:

§ **Components of a data communications system**
§ **Data Flow**

1.3

A Communications Model

Source System

Destination System

Source → Trans-mitter → Trans-mission System → Receiver → Destination

(a) General block diagram

Workstation — Modem — Public Telephone Network — Modem — Server

(b) Example

Figure 1.1 *Components of a data communication system*
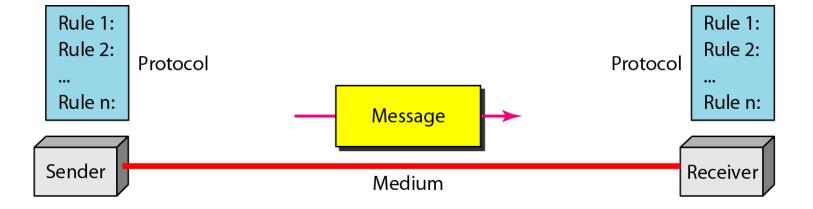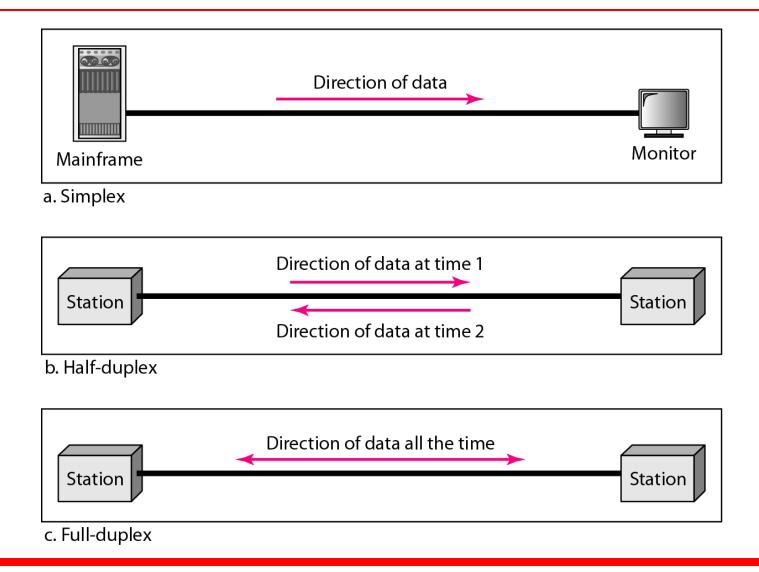
Figure 1.2 *Data flow (simplex, half-duplex, and full-duplex)*

Direction of data

Mainframe

Monitor

a. Simplex

Direction of data at time 1

Direction of data at time 2

Station

Station

b. Half-duplex

Direction of data all the time

Station

Station

c. Full-duplex

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. A link can be a cable, air, optical fiber, or any medium which can transport a signal carrying information.

Topics discussed in this section:

§ **Network Criteria**
§ **Physical Structures**
§ **Categories of Networks**

Network Criteria

- **Performance**
  - **Depends on Network Elements**
  - **Measured in terms of Delay and Throughput**
- **Reliability**
  - **Failure rate of network components**
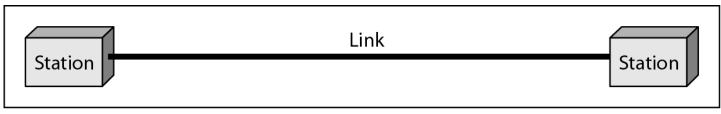 - **Measured in terms of availability/robustness**
- **Security**
  - **Data protection against corruption/loss of data due to:**
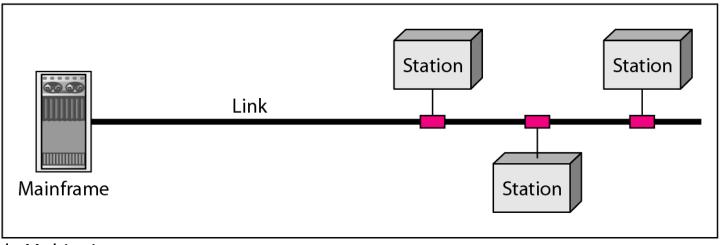   - **Errors**
    - **Malicious users**

Physical Structures

- **Type of Connection**
    - **Point to Point - single transmitter and receiver**
    - **Multipoint - multiple recipients of single transmission**
- **Physical Topology**
    - **Connection of devices**
    - **Type of transmission - unicast, mulitcast, broadcast**

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

a. Point-to-point

b. Multipoint

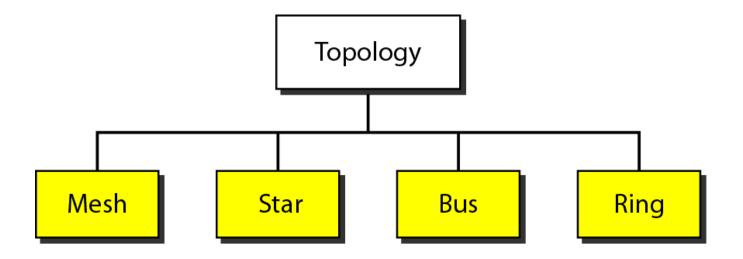# Figure 1.4 *Categories of topology*

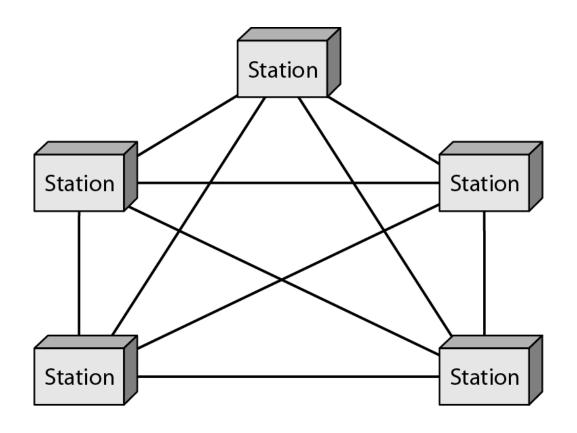# Figure 1.5 *A fully connected mesh topology (five devices)*

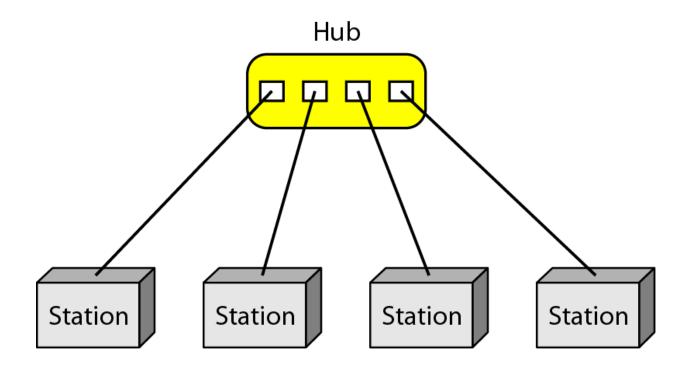# Figure 1.6 *A star topology connecting four stations*

Figure 1.7 *A bus topology connecting three stations*
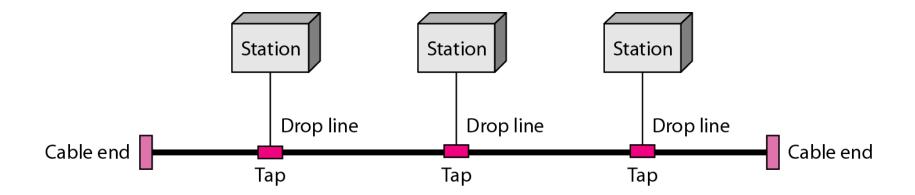
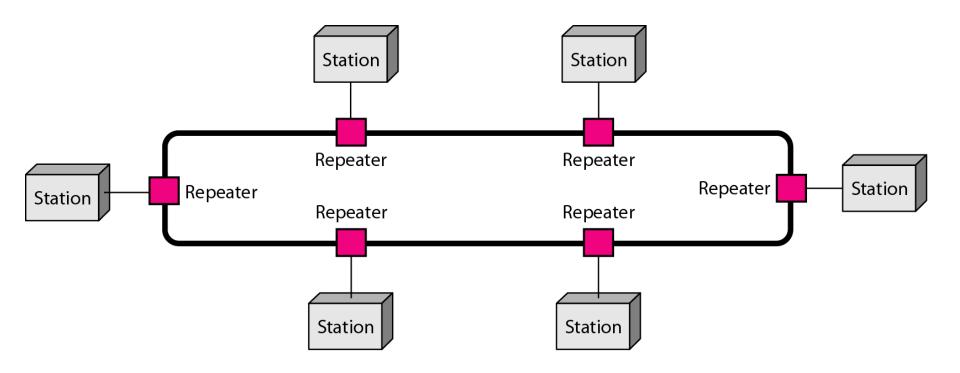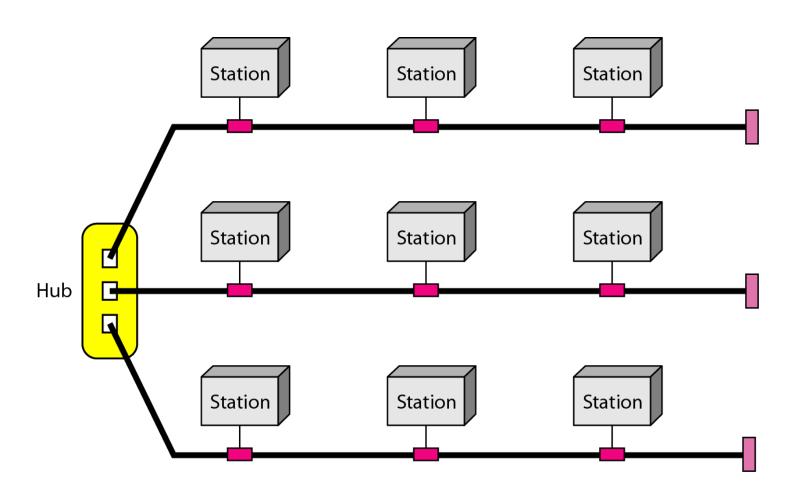# Figure 1.8 *A ring topology connecting six stations*

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

Categories of Networks

- **Local Area Networks (LANs)**
  - **Short distances**
  - **Designed to provide local interconnectivity**
- **Wide Area Networks (WANs)**
  - **Long distances**
  - **Provide connectivity over large areas**
- **Metropolitan Area Networks (MANs)**
  - **Provide connectivity over areas such as a city, a campus**

Figure 1.10 *An isolated LAN connecting 12 computers to a hub in a cl*
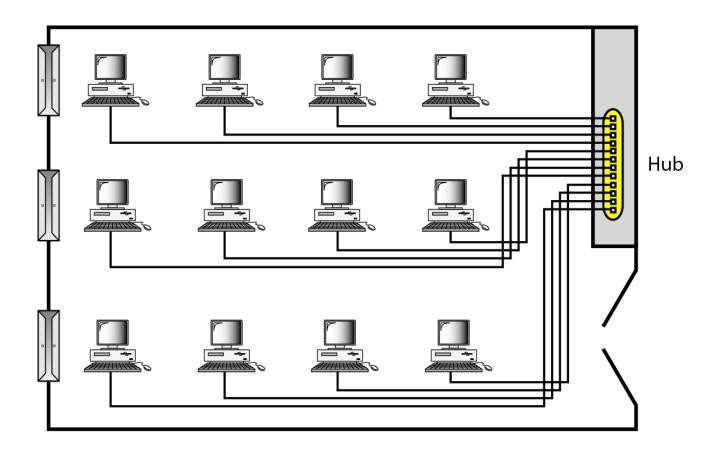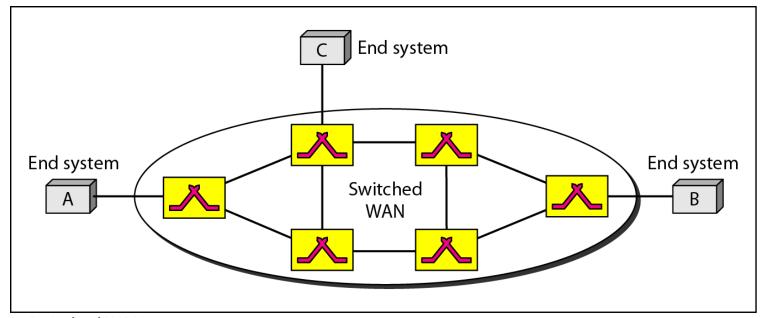
Hub
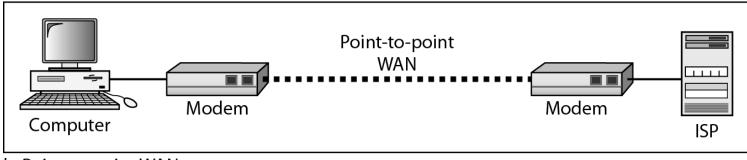
Figure 1.11 *WANs: a switched WAN and a point-to-point WAN*
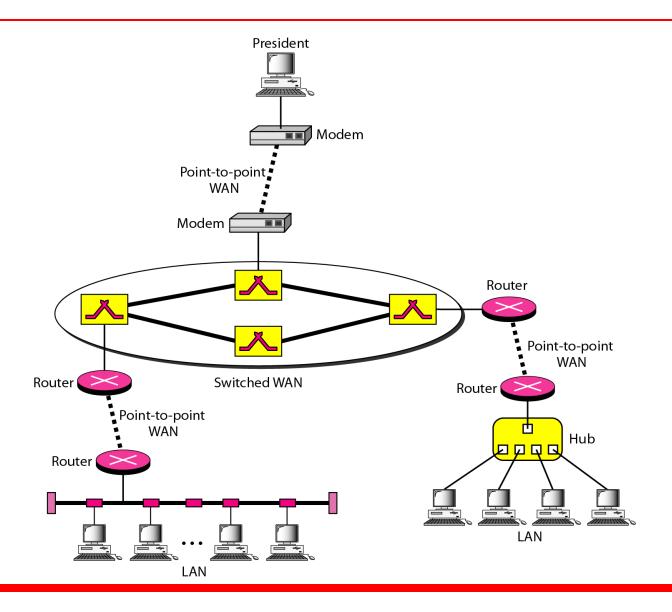
a. Switched WAN

b. Point-to-point WAN

Figure 1.12 *A heterogeneous network made of four WANs and two LA*
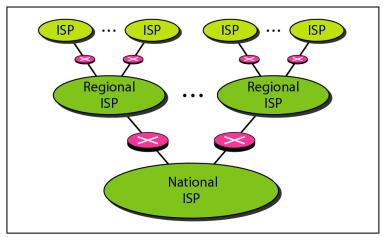
1-3   THE INTERNET

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. The Internet is a communication system that has brought a wealth of information to our fingertips and organized it for our use.
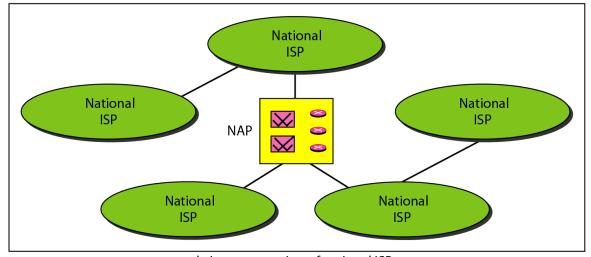
Topics discussed in this section:

**Organization of the Internet
Internet Service Providers (ISPs)**

1.21

Figure 1.13 *Hierarchical organization of the Internet*

a. Structure of a national ISP

b. Interconnection of national ISPs

1-4   PROTOCOLS

A protocol is synonymous with rule. It consists of a set of rules that govern data communications. It determines what is communicated, how it is communicated and when it is communicated. The key elements of a protocol are syntax, semantics and timing

- § **Syntax**
- § **Semantics**
- § **Timing**

1.23

Elements of a Protocol

n **Syntax**

- n **Structure or format of the data**
- n **Indicates how to read the bits - field delineation**

n **Semantics**

- n **Interprets the meaning of the bits**
- n **Knows which fields define what action**

n **Timing**

- n **When data should be sent and what**
- n **Speed at which data should be sent or speed at which it is being received.**

Chapter 2

Network Models
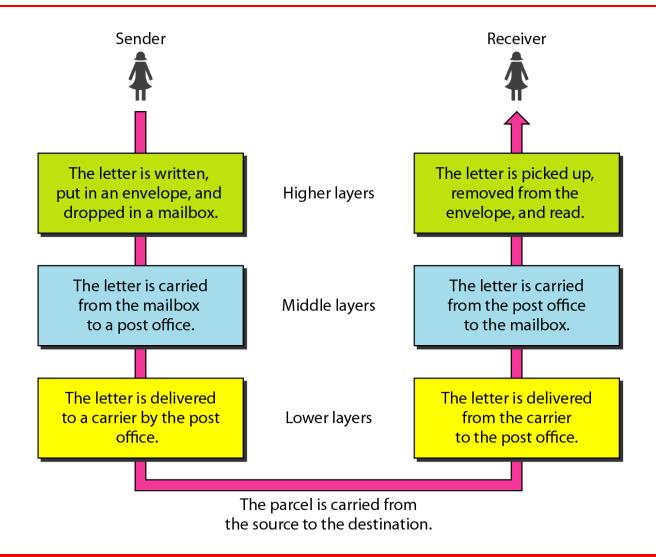
2-1   LAYERED TASKS

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.*

Topics discussed in this section:

Sender, Receiver, and Carrier
Hierarchy

2.26

Figure 2.1 Tasks involved in sending a letter

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 (OSI) model. It was first introduced in the late 1970s.

Topics discussed in this section:

Layered Architecture
Peer-to-Peer Processes
Encapsulation

Note

ISO is the organization.
OSI is the model.

Figure 2.2 *Seven layers of the OSI model*

7	Application
6	Presentation
5	Session
4	Transport
3	Network
2	Data link
1	Physical

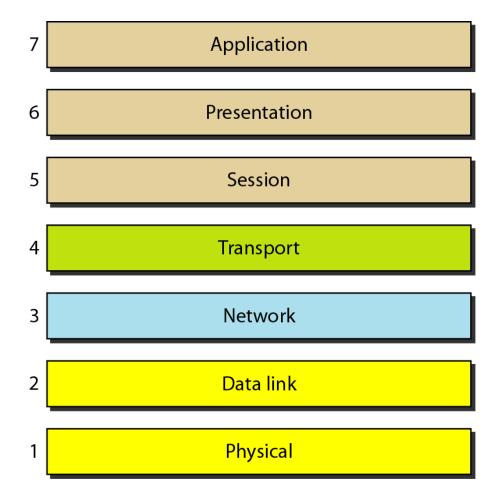# Figure 2.3 *The interaction between layers in the OSI model*
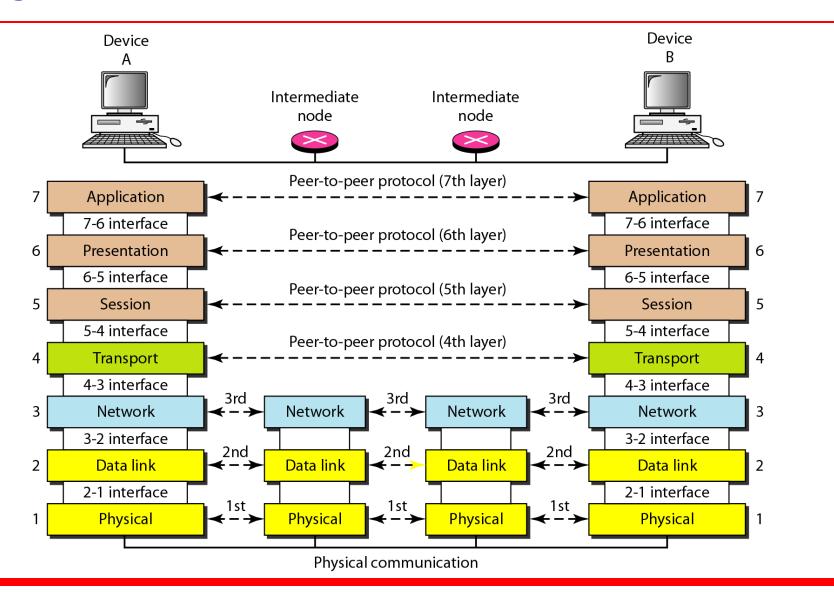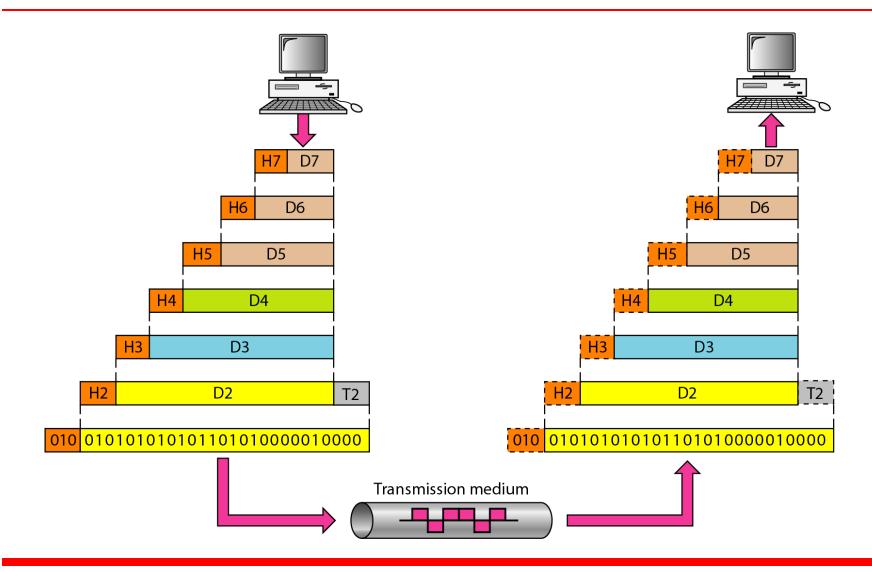
Figure 2.4 An exchange using the OSI model
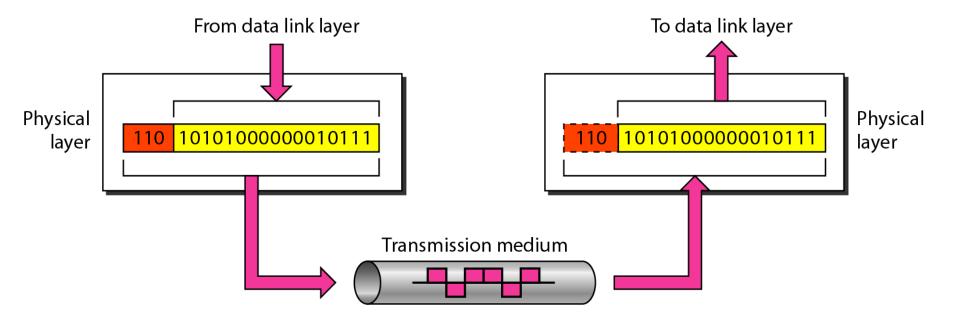
2-3   LAYERS IN THE OSI MODEL

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

Topics discussed in this section:

Physical Layer
Data Link Layer
Network Layer
Transport Layer
Session Layer
Presentation Layer
Application Layer

2.33
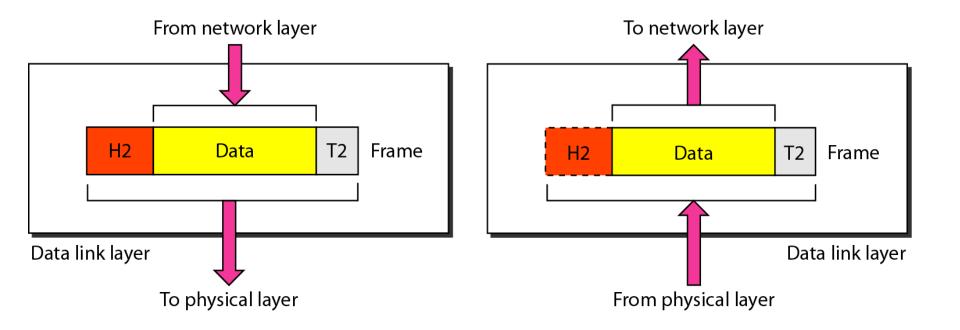
Figure 2.5 *Physical layer*

From data link layer

To data link layer

Physical layer

| 110 | 10101000000010111 |

Physical layer

| 110 | 10101000000010111 |

Transmission medium

Note

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

Figure 2.6 *Data link layer*

Note

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

Figure 2.7 *Hop-to-hop delivery*
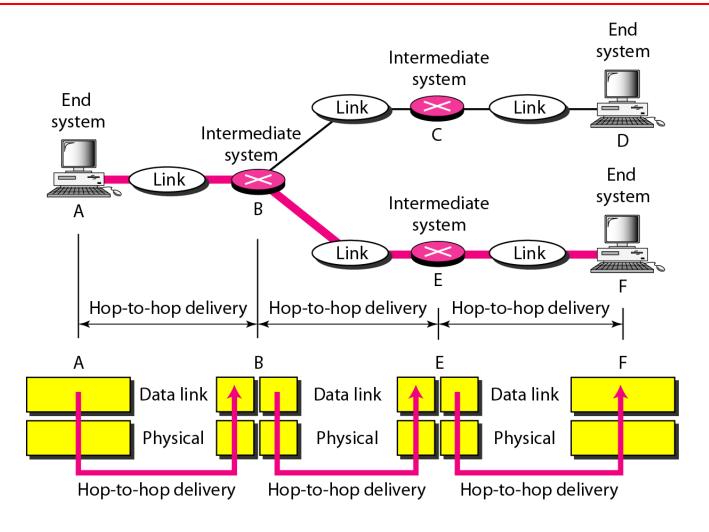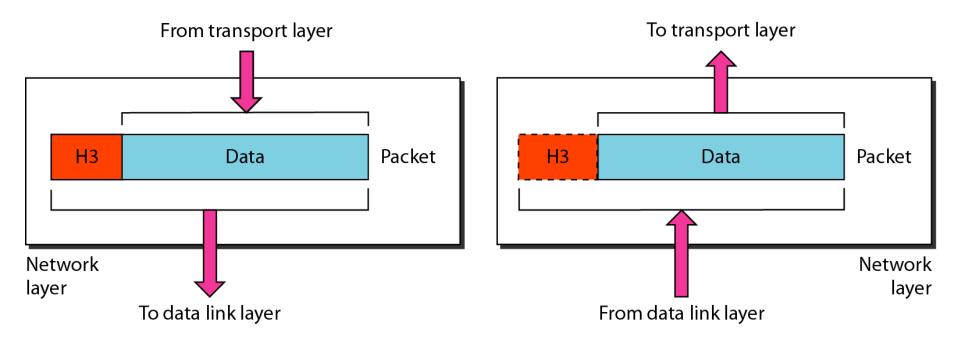
Figure 2.8 *Network layer*

Note

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

Figure 2.9 *Source-to-destination delivery*
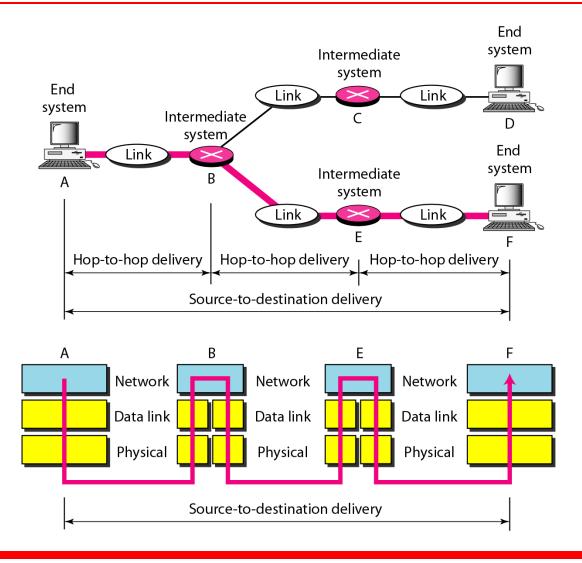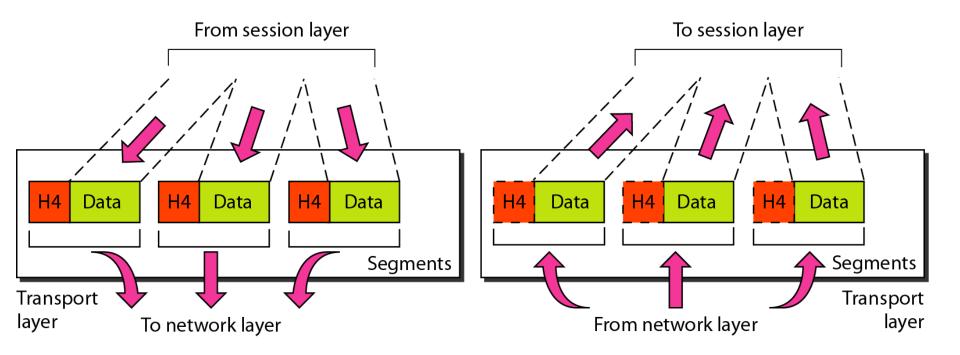
Figure 2.10 *Transport layer*

Note

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

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

Processes

Processes

An internet

Network layer
Host-to-host delivery

Transport layer
Process-to-process delivery
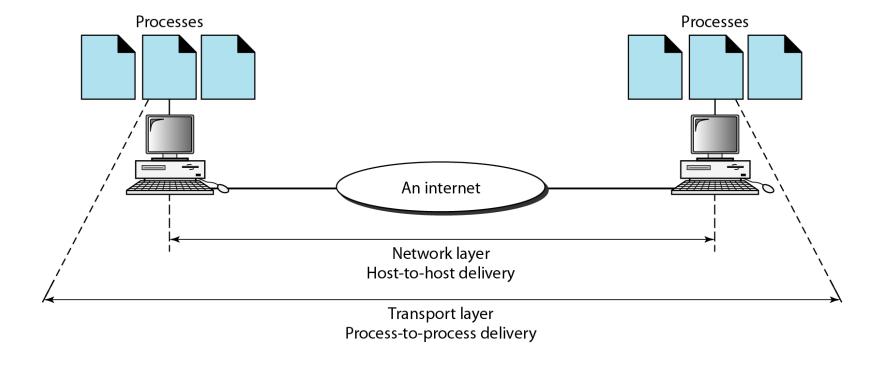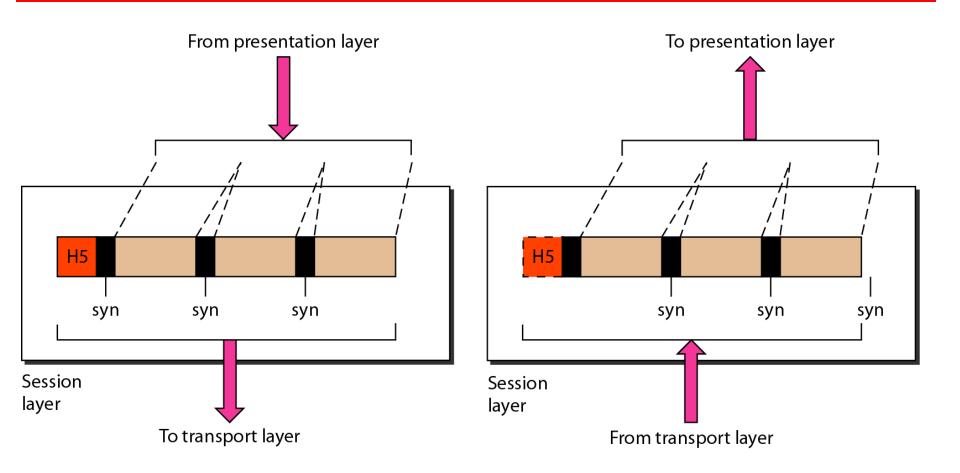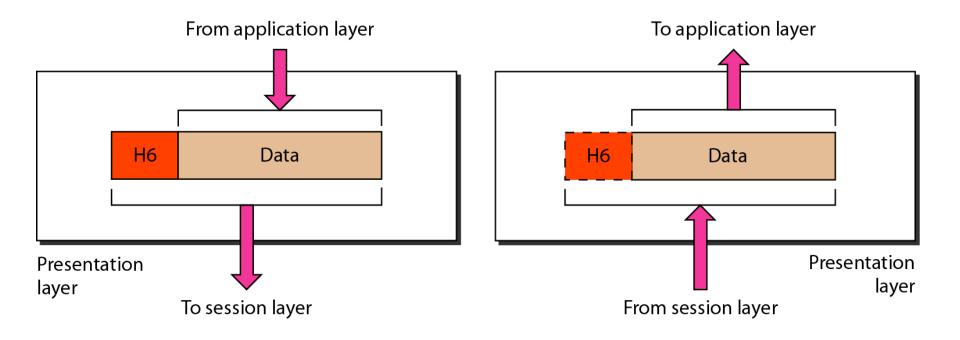
Figure 2.12 *Session layer*

Note

The session layer is responsible for dialog control and synchronization.
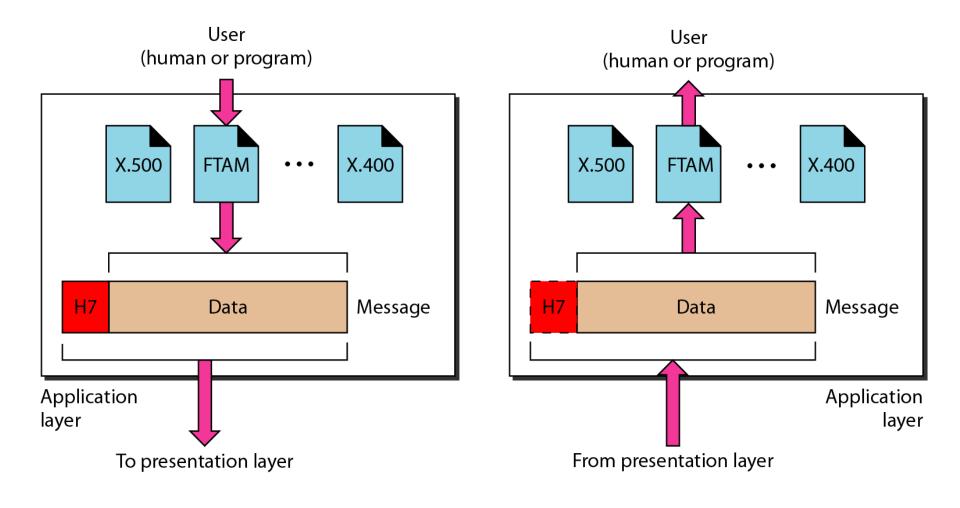
Figure 2.13 *Presentation layer*

Note

The presentation layer is responsible for translation, compression, and encryption.
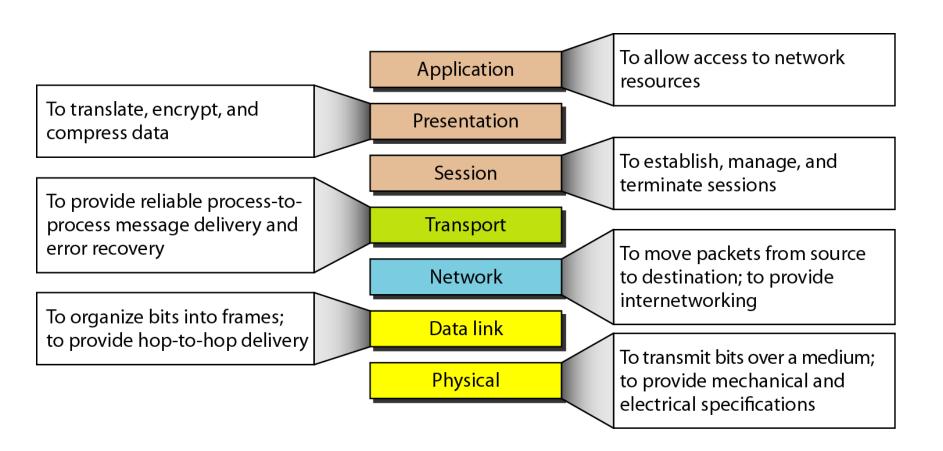
Figure 2.14 *Application layer*

Note

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

Figure 2.15 *Summary of layers*

To translate, encrypt, and compress data

Application — To allow access to network resources

Presentation

Session — To establish, manage, and terminate sessions

To provide reliable process-to-process message delivery and error recovery

Transport

Network — To move packets from source to destination; to provide internetworking

To organize bits into frames; to provide hop-to-hop delivery

Data link

Physical — To transmit bits over a medium; to provide mechanical and electrical specifications

The layers in the TCP/IP protocol suite do not exactly match those in the OSI model. The original TCP/IP protocol suite was defined as having four layers: host-to-network, internet, transport, and application. However, when TCP/IP is compared to OSI, we can say that the TCP/IP protocol suite is made of five layers: physical, data link, network, transport, and application.

Topics discussed in this section:

Physical and Data Link Layers
Network Layer
Transport Layer
Application Layer

Figure 2.16 TCP/IP and OSI model

	Applications
Application	
Presentation	SMTP FTP HTTP DNS SNMP TELNET ...
Session	

Transport	SCTP TCP UDP

Network (internet)	ICMP IGMP IP RARP ARP

Data link	Protocols defined by the underlying networks (host-to-network)
Physical	

Four levels of addresses are used in an internet employing the TCP/IP protocols: physical, logical, port, and specific.

Topics discussed in this section:

Physical Addresses
Logical Addresses
Port Addresses
Specific Addresses

Figure 2.17 *Addresses in TCP/IP*

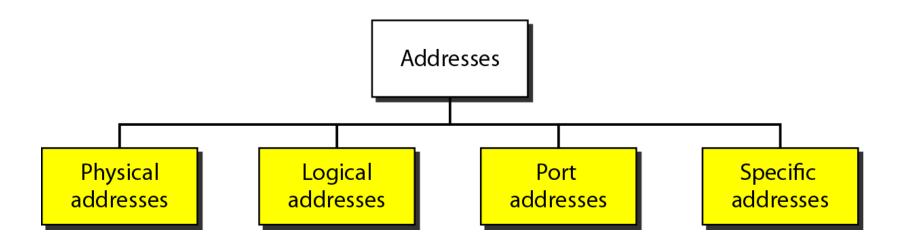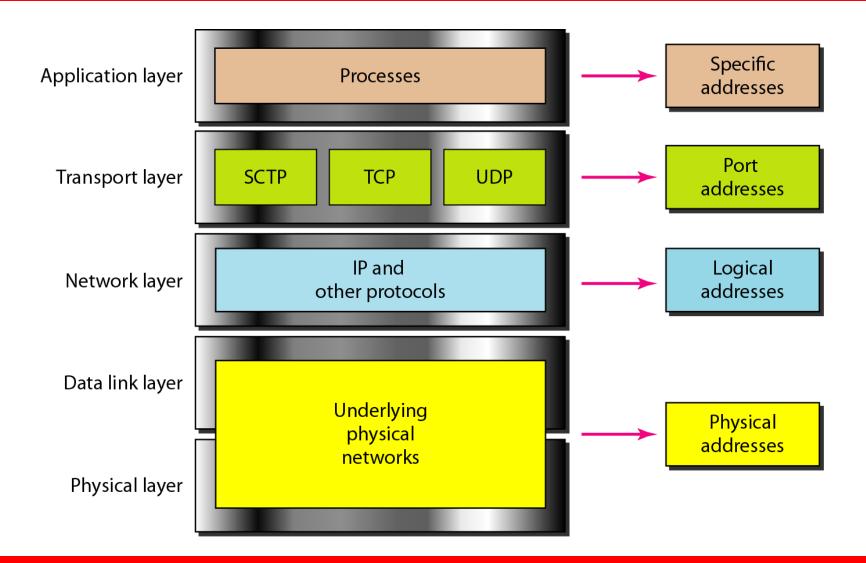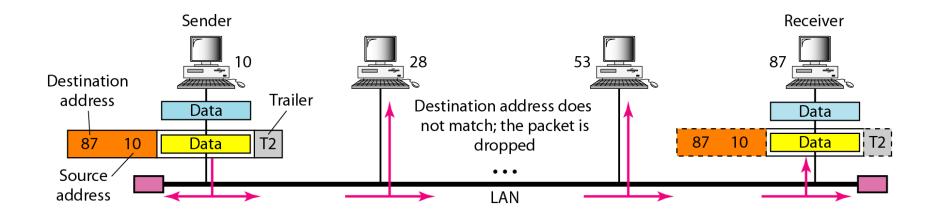# Figure 2.18 *Relationship of layers and addresses in TCP/IP*

Example 2.1

In Figure 2.19 a node with physical address 10 sends a frame to a node with physical address 87. The two nodes are connected by a link (bus topology LAN). As the figure shows, the computer with physical address 10 is the sender, and the computer with physical address 87 is the receiver.

Figure 2.19 *Physical addresses*

Example 2.2

Most local-area networks use a 48-bit (6-byte) physical address written as 12 hexadecimal digits; every byte (2 hexadecimal digits) is separated by a colon, as shown below:

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

A 6-byte (12 hexadecimal digits) physical address.

Example 2.3

Figure 2.20 shows a part of an internet with two routers connecting three LANs. Each device (computer or router) has a pair of addresses (logical and physical) for each connection. In this case, each computer is connected to only one link and therefore has only one pair of addresses. Each router, however, is connected to three networks (only two are shown in the figure). So each router has three pairs of addresses, one for each connection.

Figure 2.20 IP addresses

Example 2.4
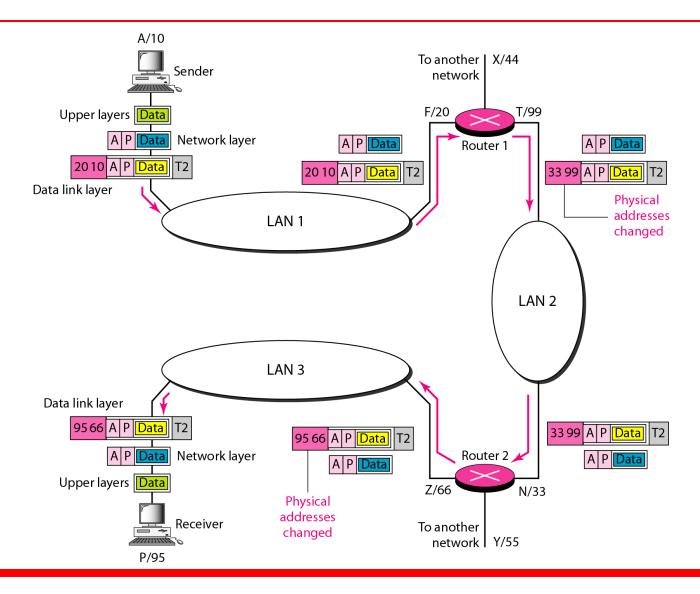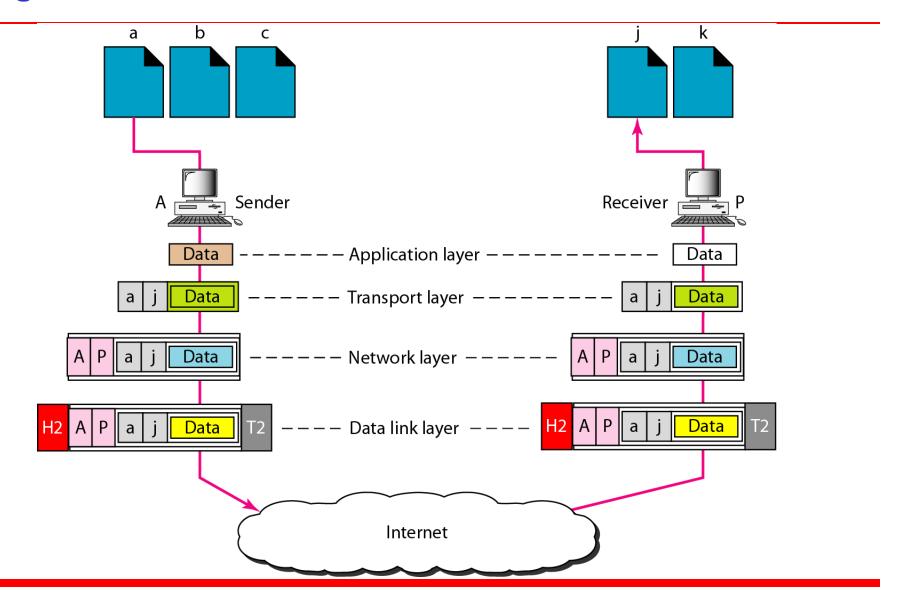
Figure 2.21 shows two computers communicating via the Internet. The sending computer is running three processes at this time with port addresses a, b, and c. The receiving computer is running two processes at this time with port addresses j and k. Process a in the sending computer needs to communicate with process j in the receiving computer. Note that although physical addresses change from hop to hop, logical and port addresses remain the same from the source to destination.

Figure 2.21 *Port addresses*

Note

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

Example 2.5

A port address is a 16-bit address represented by one decimal number as shown.

<div style="background-color: yellow; border: 2px solid black; padding: 20px; text-align: center;">

753

**A 16-bit port address represented
as one single number.**

</div>

Chapter 3

Data and Signals

Note

To be transmitted, data must be transformed to electromagnetic signals.

3-1 ANALOG AND DIGITAL

Data can be *analog* *or* *digital**. The term* *analog data* *refers to information that is continuous;* *digital data* *refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.*

Topics discussed in this section:

§ **Analog and Digital Data**
§ **Analog and Digital Signals**
§ **Periodic and Nonperiodic Signals**

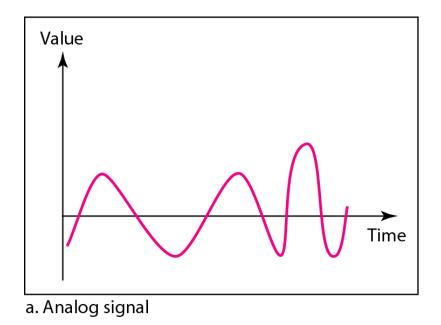# **Analog and Digital Data**
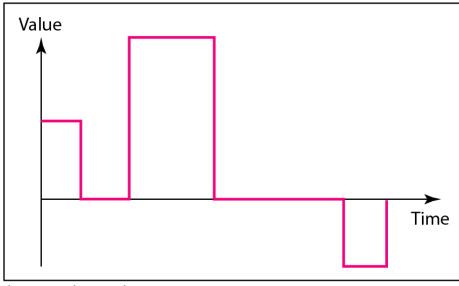
§ Data can be analog or digital.

§ Analog data are continuous and take continuous values.

§ Digital data have discrete states and take discrete values.

Analog and Digital Signals

- Signals can be analog or digital.
- Analog signals can have an infinite number of values in a range.
- Digital signals can have only a limited number of values.

Figure 3.1 *Comparison of analog and digital signals*

a. Analog signal

b. Digital signal

3-2   PERIODIC ANALOG SIGNALS

In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

Periodic analog signals can be classified as simple or composite. A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals. A composite

periodic analog signal is composed of multiple sine waves.

Topics discussed in this section:

§ **Sine Wave**
§ **Wavelength**
§ **Time and Frequency Domain**
§ **Composite Signals**
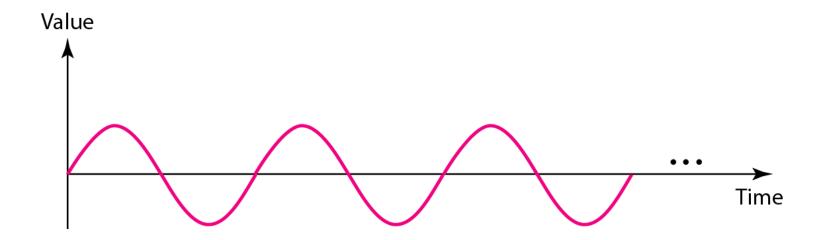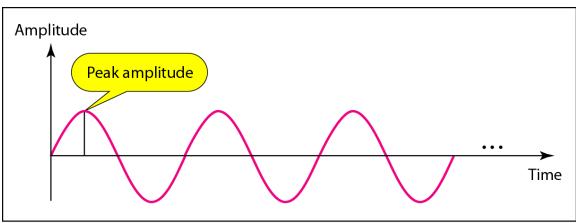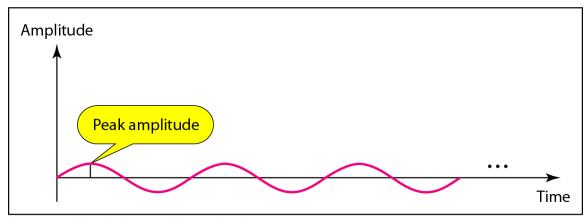§ **Bandwidth**

3.72

Figure 3.2 *A sine wave*

Figure 3.3 Two signals with the same phase and frequency, but different amplitudes

a. A signal with high peak amplitude
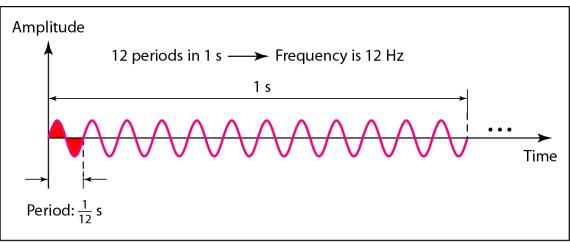
b. A signal with low peak amplitude

Note
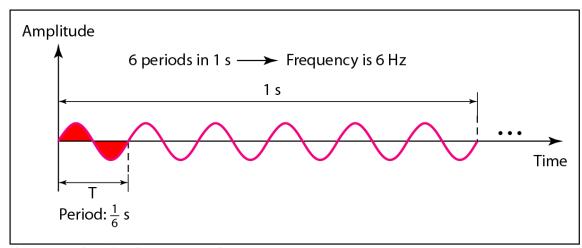
Frequency and period are the inverse of each other.

$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Figure 3.4 *Two signals with the same amplitude and phase, but different frequencies*

Amplitude

12 periods in 1 s ⟶ Frequency is 12 Hz

1 s

Time

Period: $\frac{1}{12}$ s

a. A signal with a frequency of 12 Hz

Amplitude

6 periods in 1 s ⟶ Frequency is 6 Hz

1 s

Time

T

Period: $\frac{1}{6}$ s

b. A signal with a frequency of 6 Hz

Table 3.1 Units of period and frequency

Unit	Equivalent	Unit	Equivalent
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^3 Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^6 Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^9 Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Example 3.1

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166 \text{ s} = 0.0166 \times 10^3 \text{ ms} = 16.6 \text{ ms}$$

Example 3.2

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$
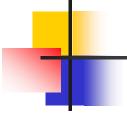
Frequency

- Frequency is the rate of change with respect to time.
- Change in a short span of time means high frequency.
- Change over a long span of time means low frequency.

3.80

Note

If a signal does not change at all, its frequency is zero.
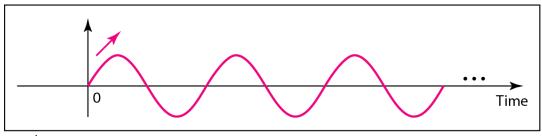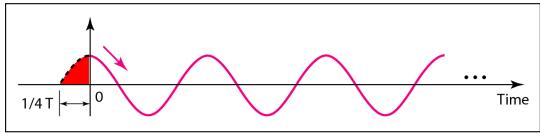If a signal changes instantaneously, its frequency is infinite.

Note

Phase describes the position of the waveform relative to time 0.
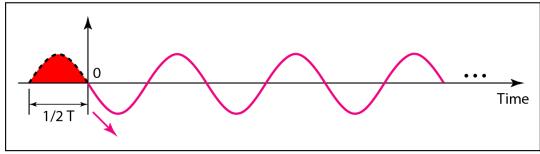
Figure 3.5 Three sine waves with the same amplitude and frequency, but different phases

a. 0 degrees

b. 90 degrees

c. 180 degrees

Example 3.3

A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

Solution

We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is

$$\frac{1}{6} \times 360 = 60° = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

Figure 3.6 *Wavelength and period*
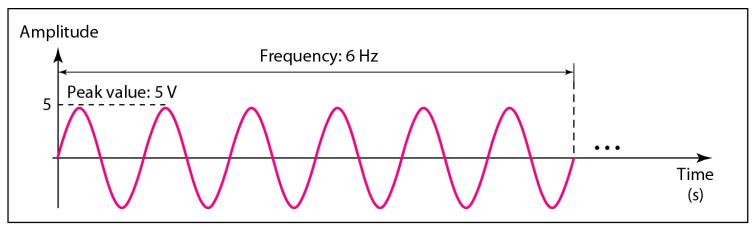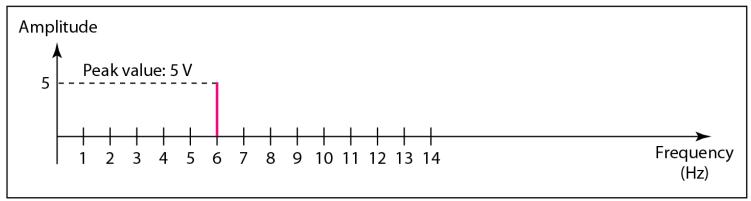
Figure 3.7 *The time-domain and frequency-domain plots of a sine wav*

a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)
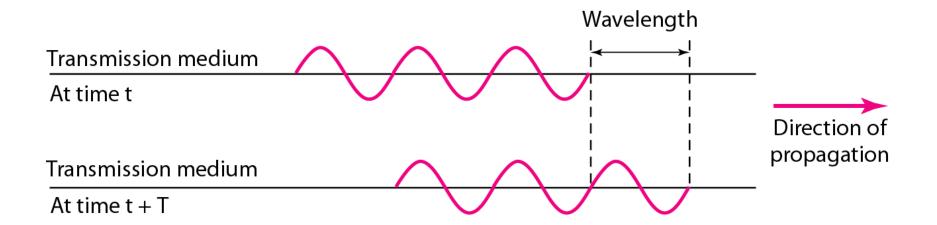

b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)
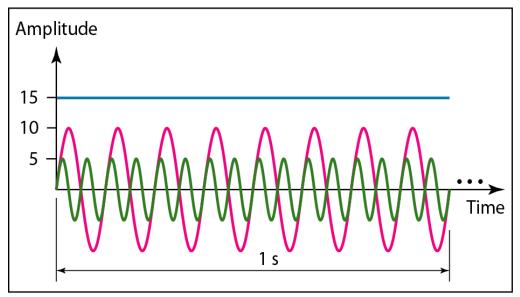
Note

A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Example 3.7
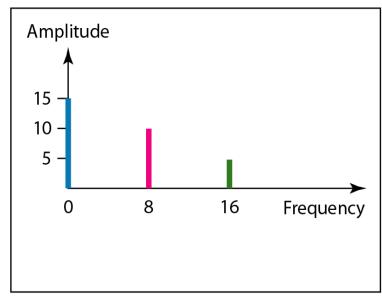
The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure 3.8 shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.

Figure 3.8 *The time domain and frequency domain of three sine waves*

a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

Signals and Communication

n A single-frequency sine wave is not useful in data communications

n We need to send a composite signal, a signal made of many simple sine waves.

n According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Composite Signals and Periodicity

n If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies.

n If the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

Example 3.4

Figure 3.9 shows a periodic composite signal with frequency f. This type of signal is not typical of those found in data communications. We can consider it to be three alarm systems, each with a different frequency. The analysis of this signal can give us a good understanding of how to decompose signals.

Figure 3.9 *A composite periodic signal*

Time
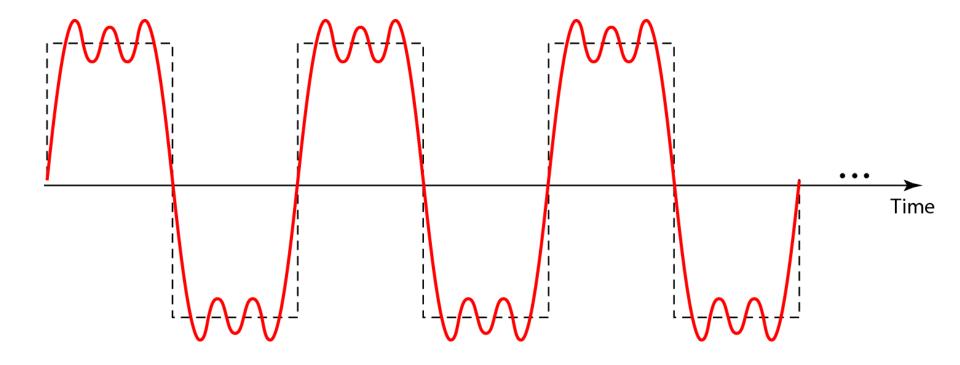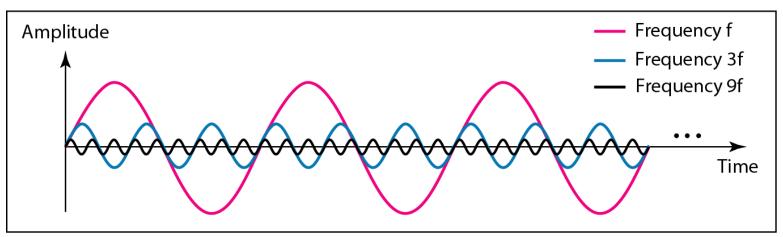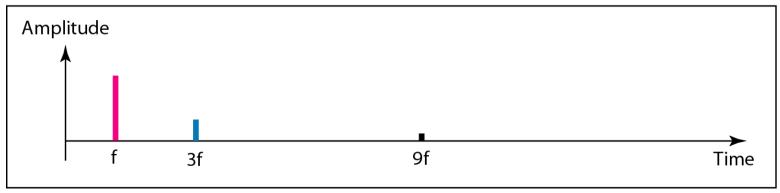
Figure 3.10 *Decomposition of a composite periodic signal in the time frequency domains*
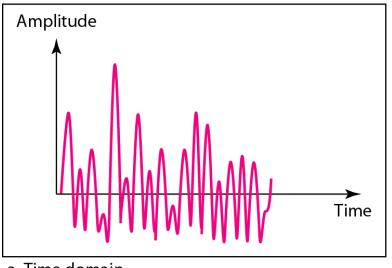
a. Time-domain decomposition of a composite signal
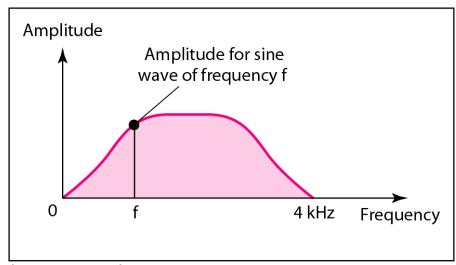
b. Frequency-domain decomposition of the composite signal

Example 3.5

Figure 3.11 shows a nonperiodic composite signal. It can be the signal created by a microphone or a telephone set when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.

Figure 3.11 *The time and frequency domains of a nonperiodic signal*

a. Time domain
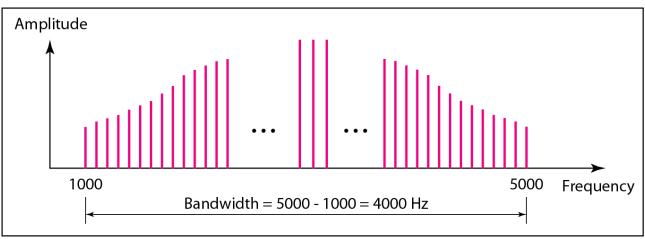
b. Frequency domain
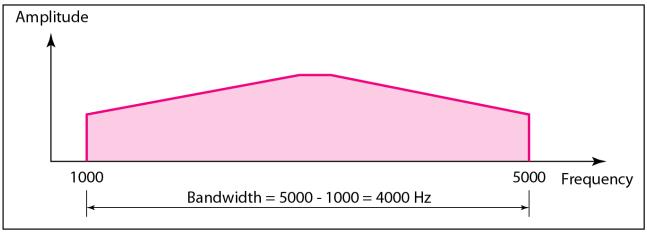
Bandwidth and Signal Frequency

n The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

Figure 3.12   *The bandwidth of periodic and nonperiodic composite sig*

a. Bandwidth of a periodic signal

b. Bandwidth of a nonperiodic signal

Example 3.6

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.
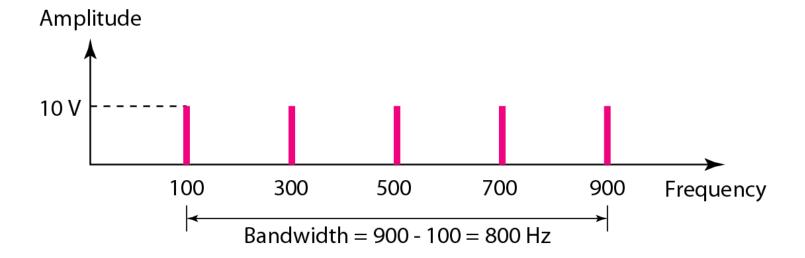
Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz (see Figure 3.13).

Figure 3.13 *The bandwidth for Example 3.6*

Example 3.7

A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Solution
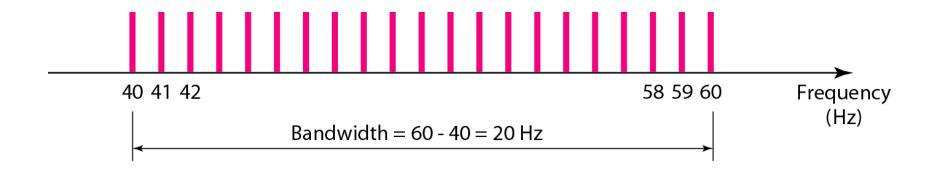
Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l \implies 20 = 60 - f_l \implies f_l = 60 - 20 = 40 \text{ Hz}$$

The spectrum contains all integer frequencies. We show this by a series of spikes (see Figure 3.14).

Figure 3.14 *The bandwidth for Example 3.7*

Bandwidth = 60 - 40 = 20 Hz

Example 3.8
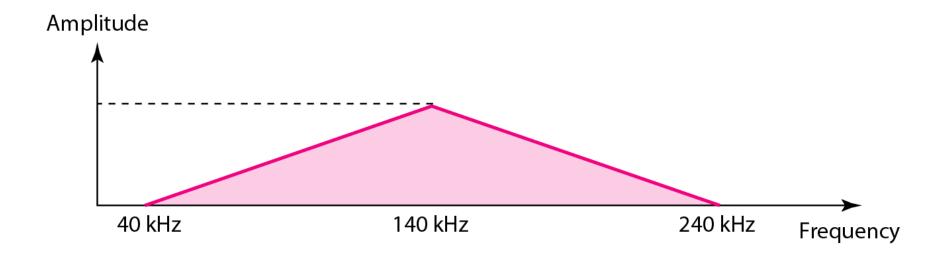
A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Solution

The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure 3.15 shows the frequency domain and the bandwidth.

Figure 3.15 *The bandwidth for Example 3.8*

Example 3.9

An example of a nonperiodic composite signal is the signal propagated by an AM radio station. In the United States, each AM radio station is assigned a 10-kHz bandwidth. The total bandwidth dedicated to AM radio ranges from 530 to 1700 kHz. We will show the rationale behind this 10-kHz bandwidth in Chapter 5.

Example 3.10

Another example of a nonperiodic composite signal is the signal propagated by an FM radio station. In the United States, each FM radio station is assigned a 200-kHz bandwidth. The total bandwidth dedicated to FM radio ranges from 88 to 108 MHz. We will show the rationale behind this 200-kHz bandwidth in Chapter 5.

Example 3.11

Another example of a nonperiodic composite signal is the signal received by an old-fashioned analog black-and-white TV. A TV screen is made up of pixels. If we assume a resolution of 525 × 700, we have 367,500 pixels per screen. If we scan the screen 30 times per second, this is 367,500 × 30 = 11,025,000 pixels per second. The worst-case scenario is alternating black and white pixels. We can send 2 pixels per cycle. Therefore, we need 11,025,000 / 2 = 5,512,500 cycles per second, or Hz. The bandwidth needed is 5.5125 MHz.

Chapter 3

Data and Signals
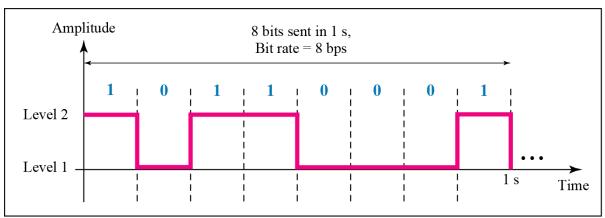
3-3 DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a *digital signal**. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.*

Topics discussed in this section:
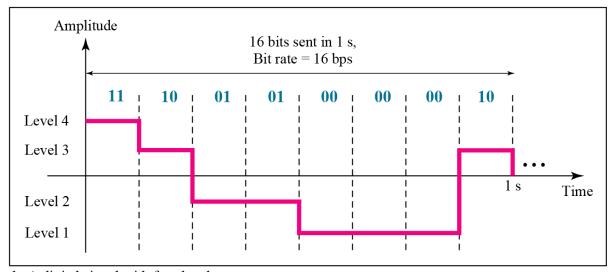
§ **Bit Rate**
§ **Bit Length**
§ **Digital Signal as a Composite Analog Signal**
§ **Application Layer**

Figure 3.16 **Two digital signals: one with two signal levels and the oth with four signal levels**

a. A digital signal with two levels

b. A digital signal with four levels

Example 3.16

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\text{Number of bits per level} = \log_2 8 = 3$$

Each signal level is represented by 3 bits.

Example 3.17

A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

Example 3.18

Assume we need to download text documents at the rate of 100 pages per sec*. What is the required bit rate of the channel?*

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits (ascii), the bit rate is

$$100 \times 24 \times 80 \times 8 = 1,636,000 \text{ bps} = 1.636 \text{ Mbps}$$

Example 3.19

A digitized voice channel, as we will see in Chapter 4, is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

$$2 \times 4000 \times 8 = 64{,}000 \text{ bps} = 64 \text{ kbps}$$

Example 3.20
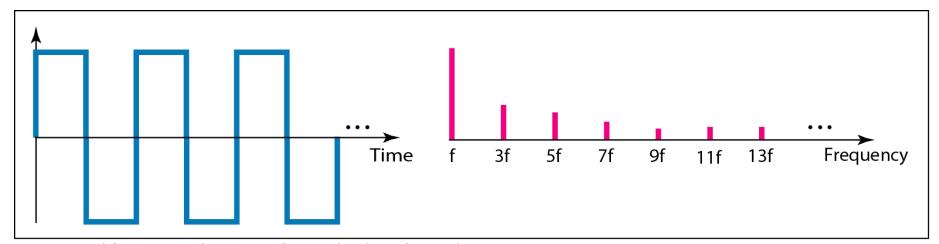
What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel.

$$1920 \times 1080 \times 30 \times 24 = 1,492,992,000 \text{ or } 1.5 \text{ Gbps}$$

The TV stations reduce this rate to 20 to 40 Mbps through compression.

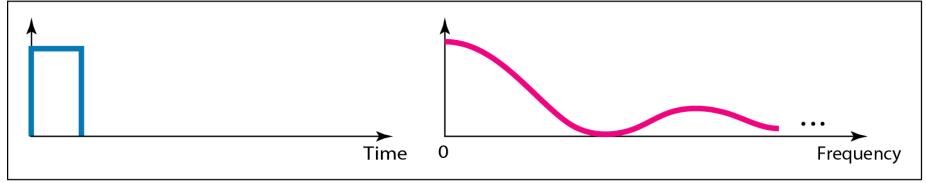**Figure 3.17** *The time and frequency domains of periodic and nonperiodic digital signals*

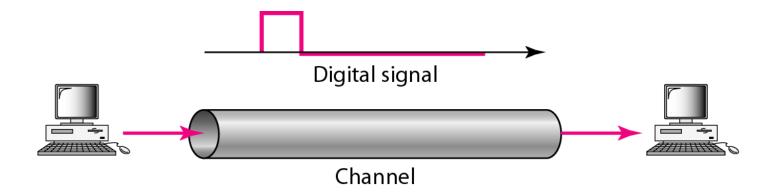a. Time and frequency domains of periodic digital signal

b. Time and frequency domains of nonperiodic digital signal
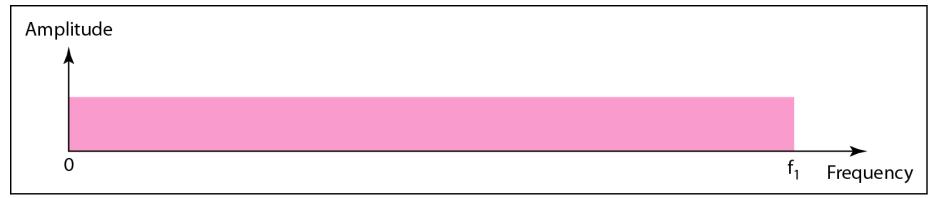
Figure 3.18 *Baseband transmission*

Digital signal

Channel

Note

A digital signal is a composite analog signal with an infinite bandwidth.

Figure 3.19 *Bandwidths of two low-pass channels*
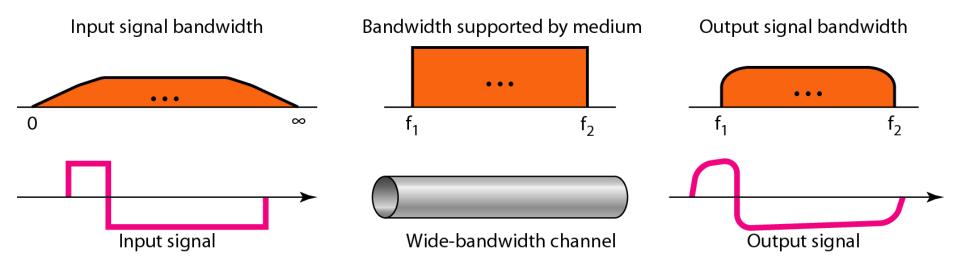
a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth

Figure 3.20 Baseband transmission using a dedicated medium

Input signal bandwidth

0 ∞

Input signal

Bandwidth supported by medium

f_1 f_2

Wide-bandwidth channel

Output signal bandwidth

f_1 f_2

Output signal

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

Example 3.21
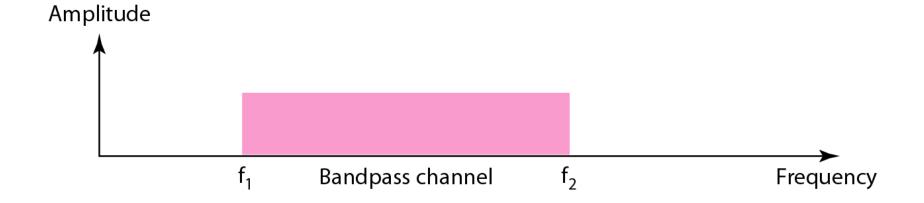
An example of a dedicated channel where the entire bandwidth of the medium is used as one single channel is a LAN. Almost every wired LAN today uses a dedicated channel for two stations communicating with each other. In a bus topology LAN with multipoint connections, only two stations can communicate with each other at each moment in time (timesharing); the other stations need to refrain from sending data. In a star topology LAN, the entire channel between each station and the hub is used for communication between these two entities.

In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth.
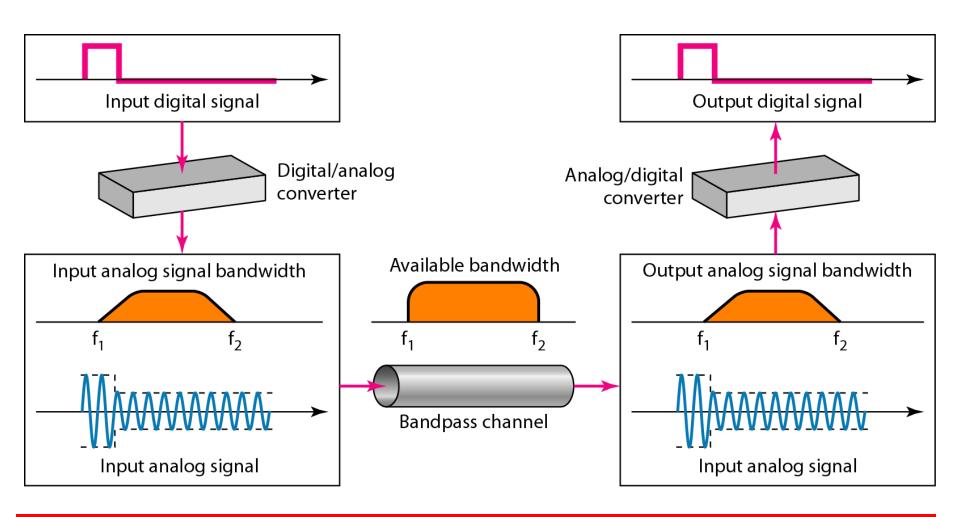
Figure 3.23 *Bandwidth of a bandpass channel*

If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

Figure 3.24 *Modulation of a digital signal for transmission on a bandpass channel*

Example 3.24

An example of broadband transmission using modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel. We convert the digital signal from the computer to an analog signal, and send the analog signal. We can install two converters to change the digital signal to analog and vice versa at the receiving end. The converter, in this case, is called a modem which we discuss in detail in Chapter 5.

Example 3.25

A second example is the digital cellular telephone. For better reception, digital cellular phones convert the analog voice signal to a digital signal (see Chapter 16). Although the bandwidth allocated to a company providing digital cellular phone service is very wide, we still cannot send the digital signal without conversion. The reason is that we only have a bandpass channel available between caller and callee. We need to convert the digitized voice to a composite analog signal before sending.
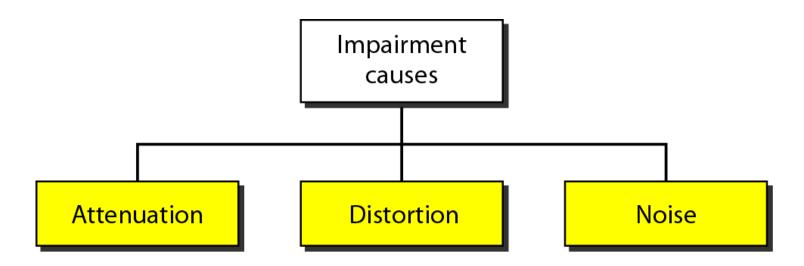
Chapter 3

Data and Signals

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.

Topics discussed in this section:
- § **Attenuation**
- § **Distortion**
- § **Noise**

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Figure 3.25 *Causes of impairment*

Attenuation

- n Means loss of energy -> weaker signal

- n When a signal travels through a medium it loses energy overcoming the resistance of the medium

- n Amplifiers are used to compensate for this loss of energy by amplifying the signal.
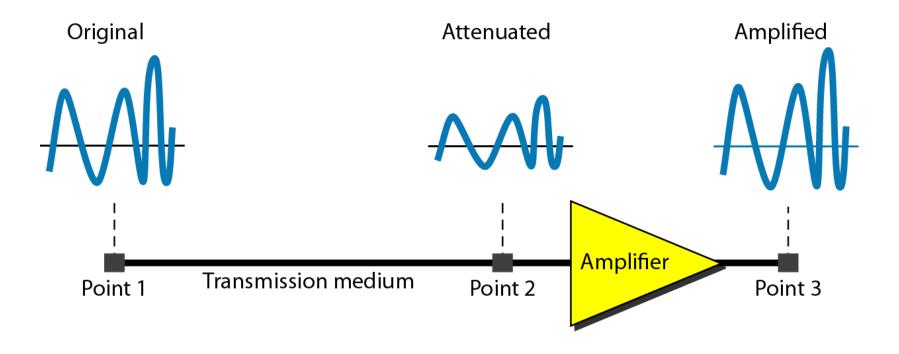
Measurement of Attenuation

n To show the loss or gain of energy the unit "decibel" is used.

$$dB = 10\log_{10}P_2/P_1$$

P_1 - input signal

P_2 - output signal

Figure 3.26 *Attenuation*

Example 3.26

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P_2 is $(1/2)P_1$. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5\,P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

Example 3.27

A signal travels through an amplifier, and its power is increased 10 times. This means that P_2 = 10P_1 . In this case, the amplification (gain of power) can be calculated as
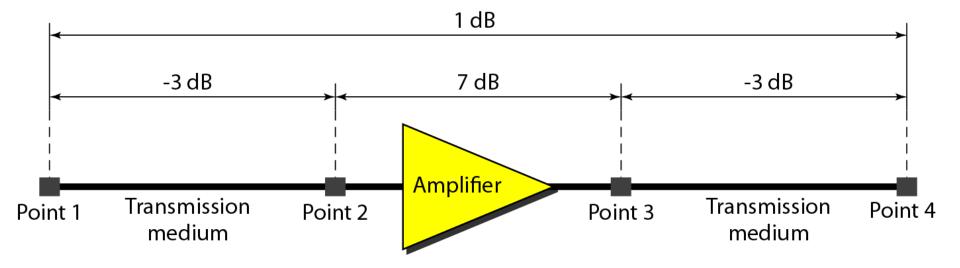
$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}$$

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Example 3.28

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure 3.27 a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as

$$dB = -3 + 7 - 3 = +1$$

Figure 3.27 *Decibels for Example 3.28*

Example 3.29

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB$_m$ and is calculated as dB$_m$ = 10 log10 P$_m$, where P$_m$ is the power in milliwatts. Calculate the power of a signal with dB$_m$ = −30.

Solution

We can calculate the power in the signal as

$$dB_m = 10 \log_{10} P_m = -30$$
$$\log_{10} P_m = -3 \qquad P_m = 10^{-3} \, mW$$

Example 3.30

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution

The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

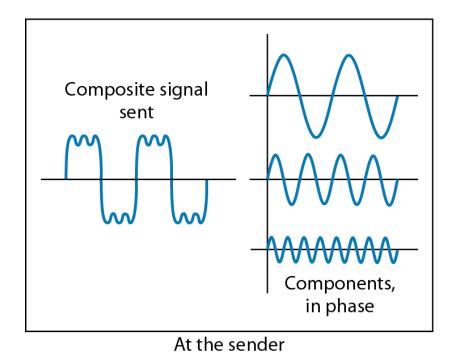$$dB = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$
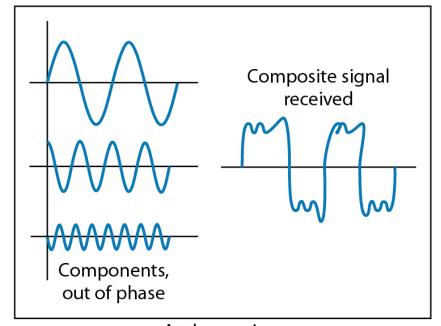
$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

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Distortion

- Means that the signal changes its form or shape

- Distortion occurs in composite signals

- Each frequency component has its own propagation speed traveling through a medium.

- The different components therefore arrive with different delays at the receiver.

- That means that the signals have different phases at the receiver than they did at the source.
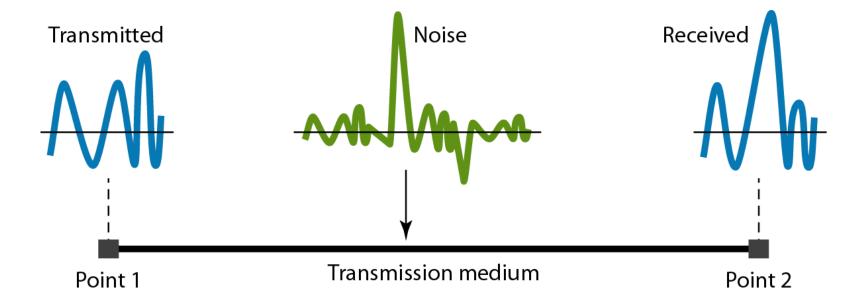
Figure 3.28 *Distortion*

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Noise

- There are different types of noise
  - **Thermal** - random noise of electrons in the wire creates an extra signal
  - **Induced** - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - **Crosstalk** - same as above but between two wires.
  - **Impulse** - Spikes that result from power lines, lighning, etc.

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Figure 3.29 *Noise*

Signal to Noise Ratio (SNR)

- n To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.

- n It is the ratio between two powers.

- n It is usually given in dB and referred to as SNR$_{dB.}$

Example 3.31

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR$_{dB}$?

Solution

The values of SNR and SNR$_{dB}$ can be calculated as follows:

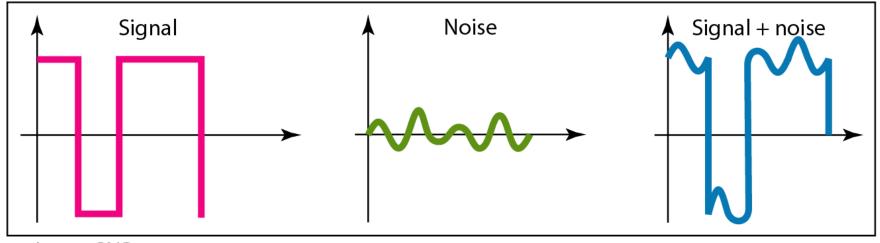Macintosh PICT image format is not supported

Example 3.32

The values of SNR and SNR$_{dB}$ for a noiseless channel are

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We can never achieve this ratio in real life; it is an ideal.

Figure 3.30   *Two cases of SNR: a high SNR and a low SNR*