Data Communications and Networking

DIT L100

Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable. For data communications to occur, the communicating devices must be part of a communication system made up of a combination of hardware (physical equipment) and software (programs)

The effectiveness of a data communications system depends on four fundamental characteristics: delivery, accuracy, timeliness, and jitter.

1. **Delivery**. The system must deliver data to the correct destination. Data must be received by the intended device or user and only by that device or user.

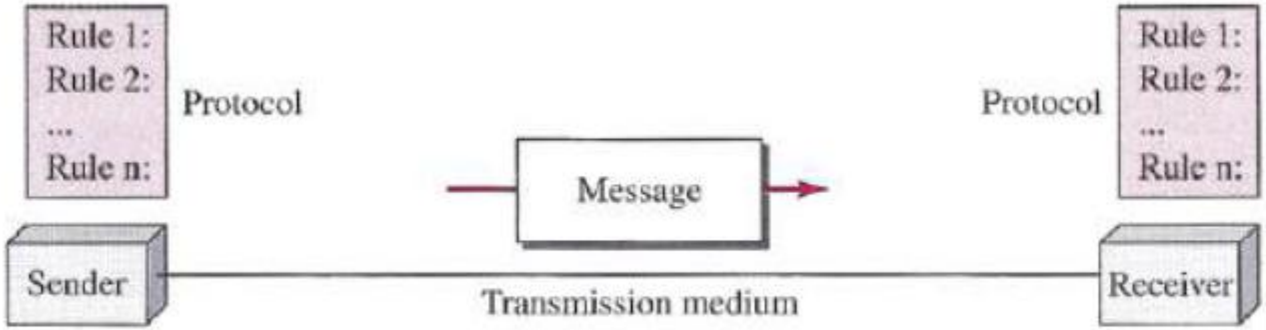
2. **Accuracy**. The system must deliver the data accurately. Data that have been altered in transmission and left uncorrected are unusable.

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

4. **Jitter**. Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets. For example, let us assume that video packets are sent every 30ms. If some of the packets arrive with 30-ms delay and others with 40-ms delay, an uneven quality in the video is the result.

Components

A data communications system has five components



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

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

4. **Transmission medium**. The transmission medium is the physical path by which a message travels from sender to receiver. Some examples of transmission media include twisted-pair wire, coaxial cable, fiber-optic cable, and radio waves.

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

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 Information Interchange (ASCII),

Numbers

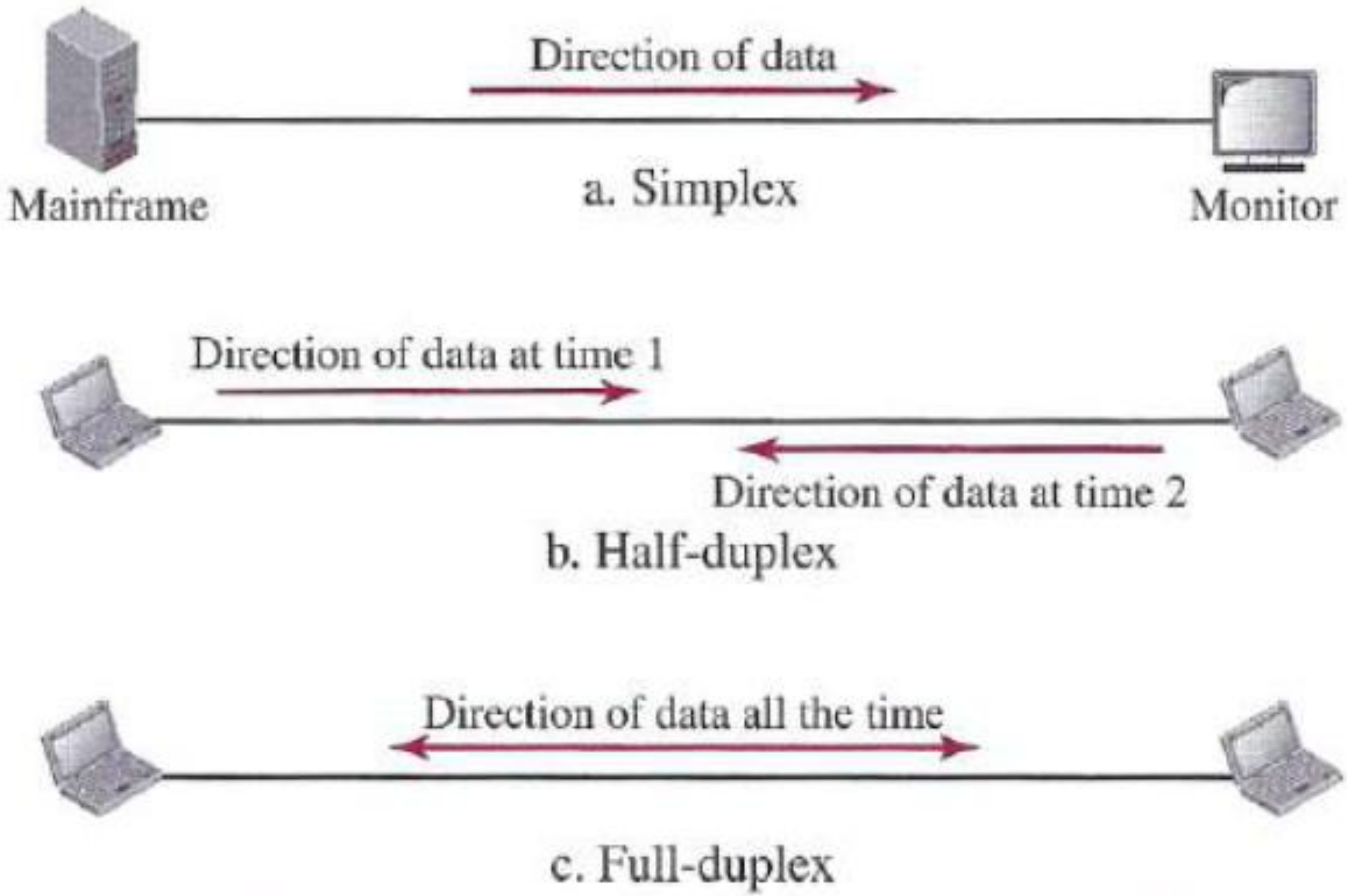
Numbers are also represented by bit patterns. However, a code such as ASCII is not used to represent numbers; the number is directly converted to a binary number to simplify mathematical operations.

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.

Data Flow

Communication between two devices can be simplex, half-duplex, or full-duplex as



NETWORKS

A network is the interconnection of a set of devices capable of communication.

In this definition, a device can be a host (or an *end system as it is sometimes called) such as a* large computer, desktop, laptop, workstation, cellular phone, or security system.

A device in this definition can also be a connecting device such as a router, which connects the network to other networks, a switch, which connects devices together, a modem (modulator-demodulator), which changes the form of data, and so on.

These devices in a network are connected using wired or wireless transmission media such as cable or air. When we connect two computers at home using a plug-and-play router, we have created a network, although very small.

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 can be measured in many ways, including transit time and response time.

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.

Type of Connection

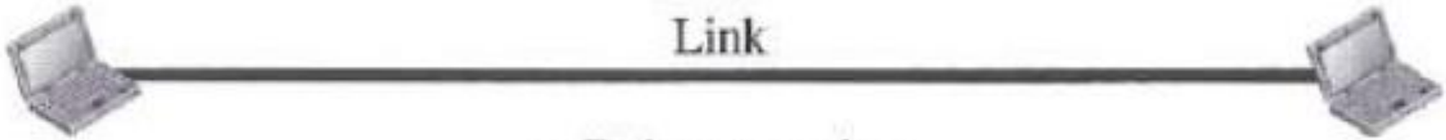
A network is two or more devices connected through links. A link is a communications pathway that transfers data from one device to another.

Point-to-Point

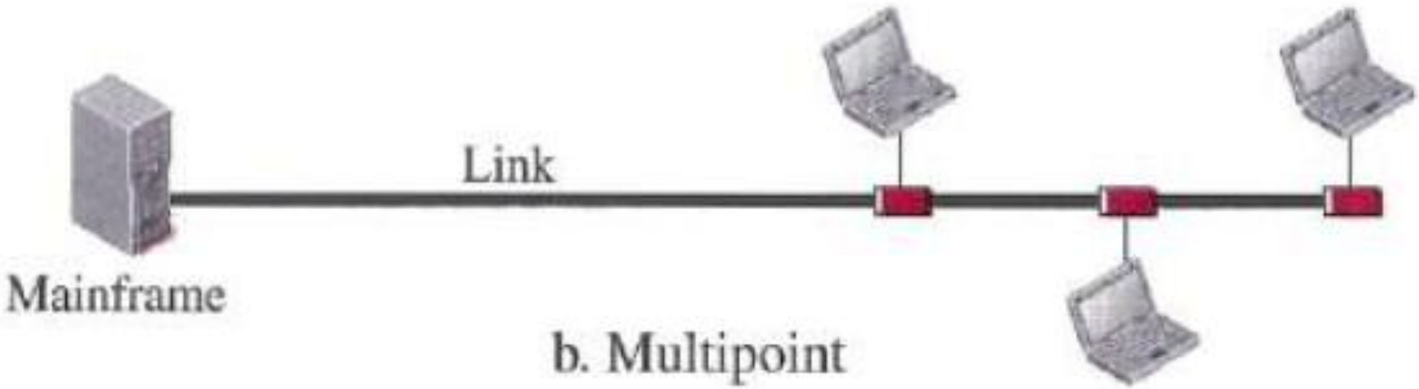
A point-to-point connection provides a dedicated link between two devices.

Multipoint

A multipoint (also called multidrop) connection is one in which more than two specific devices share a single link



a. Point-to-point



b. Multipoint

Physical Topology

The term *physical topology refers to the way in which a network is laid out physically.*

Two or more devices connect to a link; two or more links form a topology.

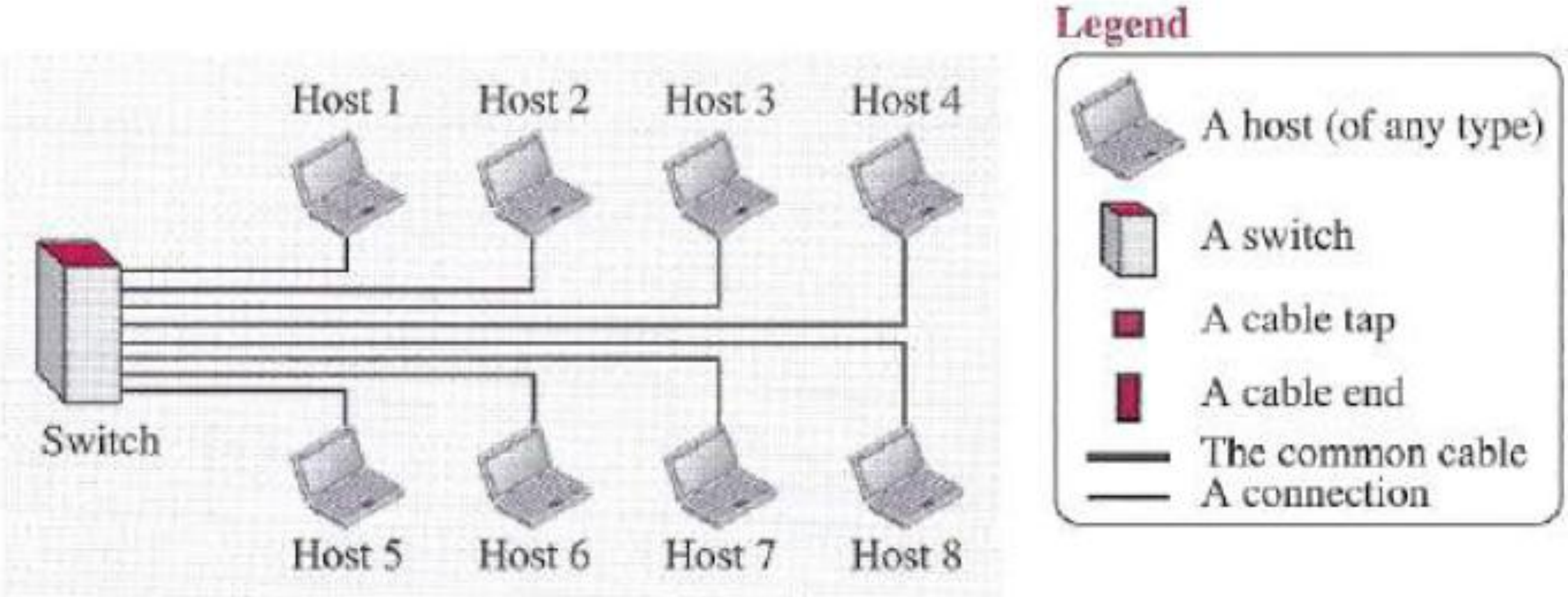
The topology of a network is the geometric representation of the relationship of all the links and linking devices (usually called *nodes) to one another.*

There are four basic topologies possible: mesh, star, bus, and ring.

NETWORK TYPES

Local Area Network

A local area network (LAN) is usually privately owned and connects some hosts in a single office, building, or campus. Depending on the needs of an organization, 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 devices. Each host in a LAN has an identifier, an address, that uniquely defines the host in the LAN. A packet sent by a host to another host carries both the source host's and the destination host's addresses.



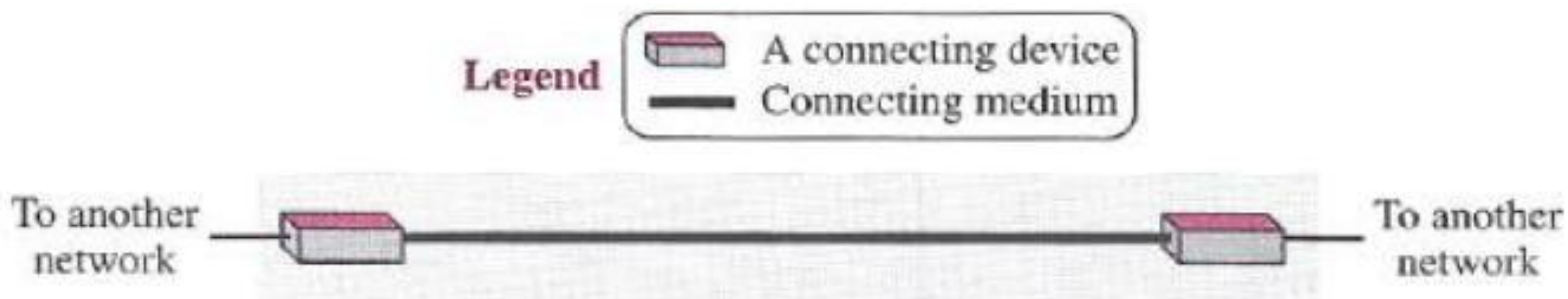
b. LAN with a switch (today)

Wide Area Network (WAN)

A wide area network (WAN) is also an interconnection of devices capable of communication.
A LAN is normally limited in size, spanning an office, a building, or a campus; a WAN has a wider geographical span, spanning a town, a state, a country, or even the world. A LAN interconnects hosts; a WAN interconnects connecting devices such as switches, routers, or modems.
A LAN is normally privately owned by the organization that uses it;
a WAN is normally created and run by communication companies and leased by an organization that uses it.
Two distinct examples of WANs today: point-to-point WANs and switched WANs.

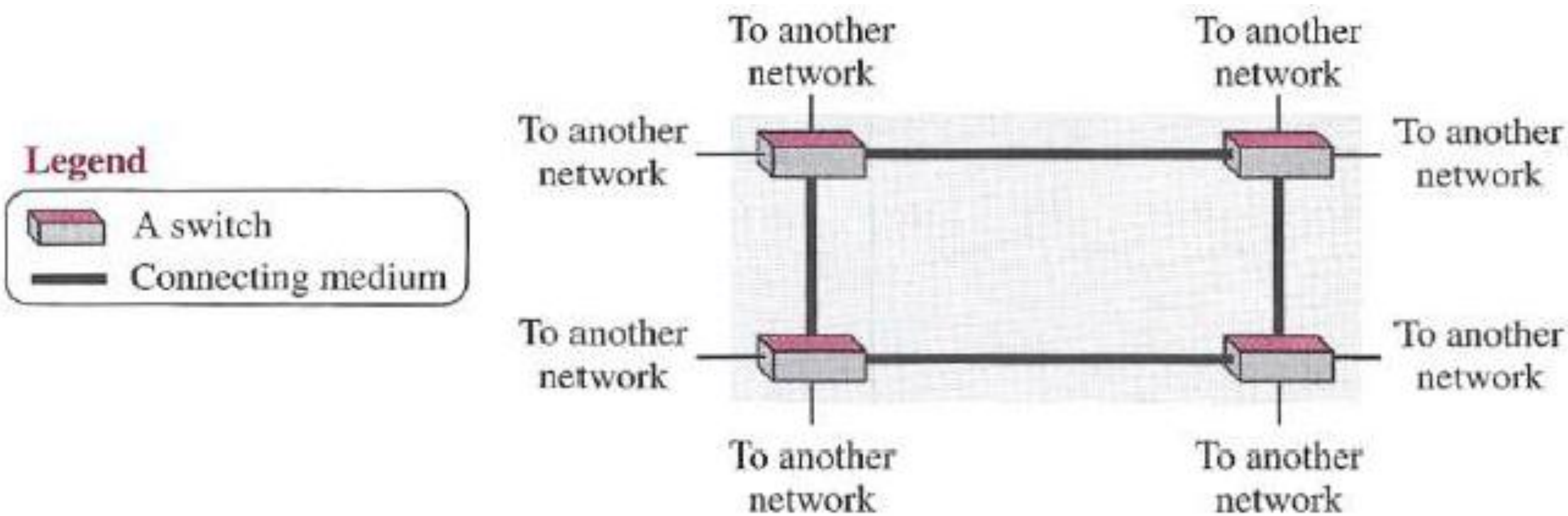
Point-to-Point WAN

A point-to-point WAN is a network that connects two communicating devices through a transmission media (cable or air).



Switched WAN

A switched WAN is a network with more than two ends.
A switched WAN is used in the backbone of global communication today.
Switched WAN is a combination of several point-to-point WANs that are connected by switches.



Switching

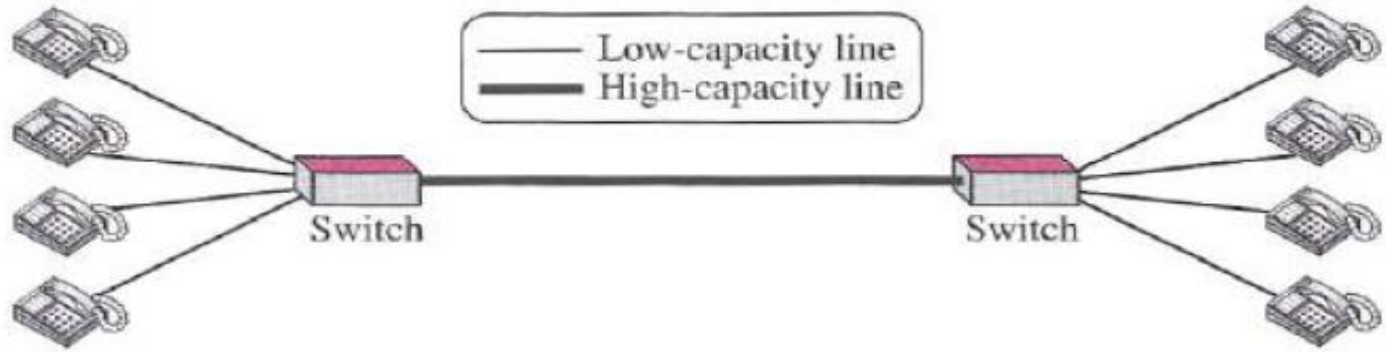
An internet is a switched network in which a switch connects at least two links together.

A switch needs to forward data from a network to another network when required.

The two most common types of switched networks are circuit-switched and packet-switched networks.

Circuit-Switched Network

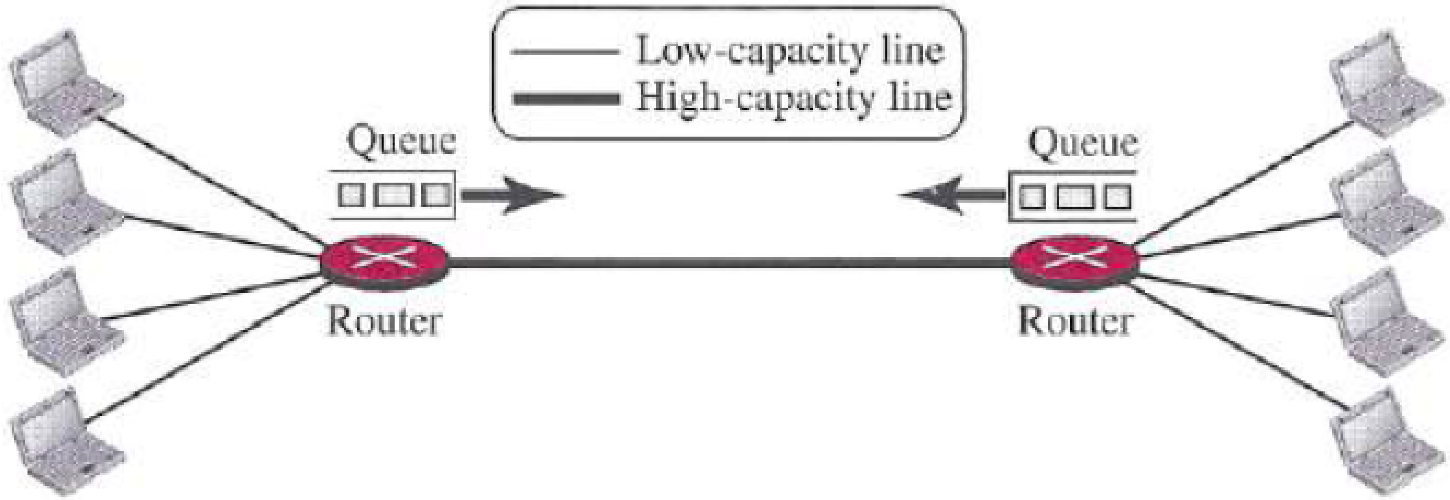
In a circuit-switched network, a dedicated connection, called a circuit, is always available between the two end systems; the switch can only make it active or inactive.



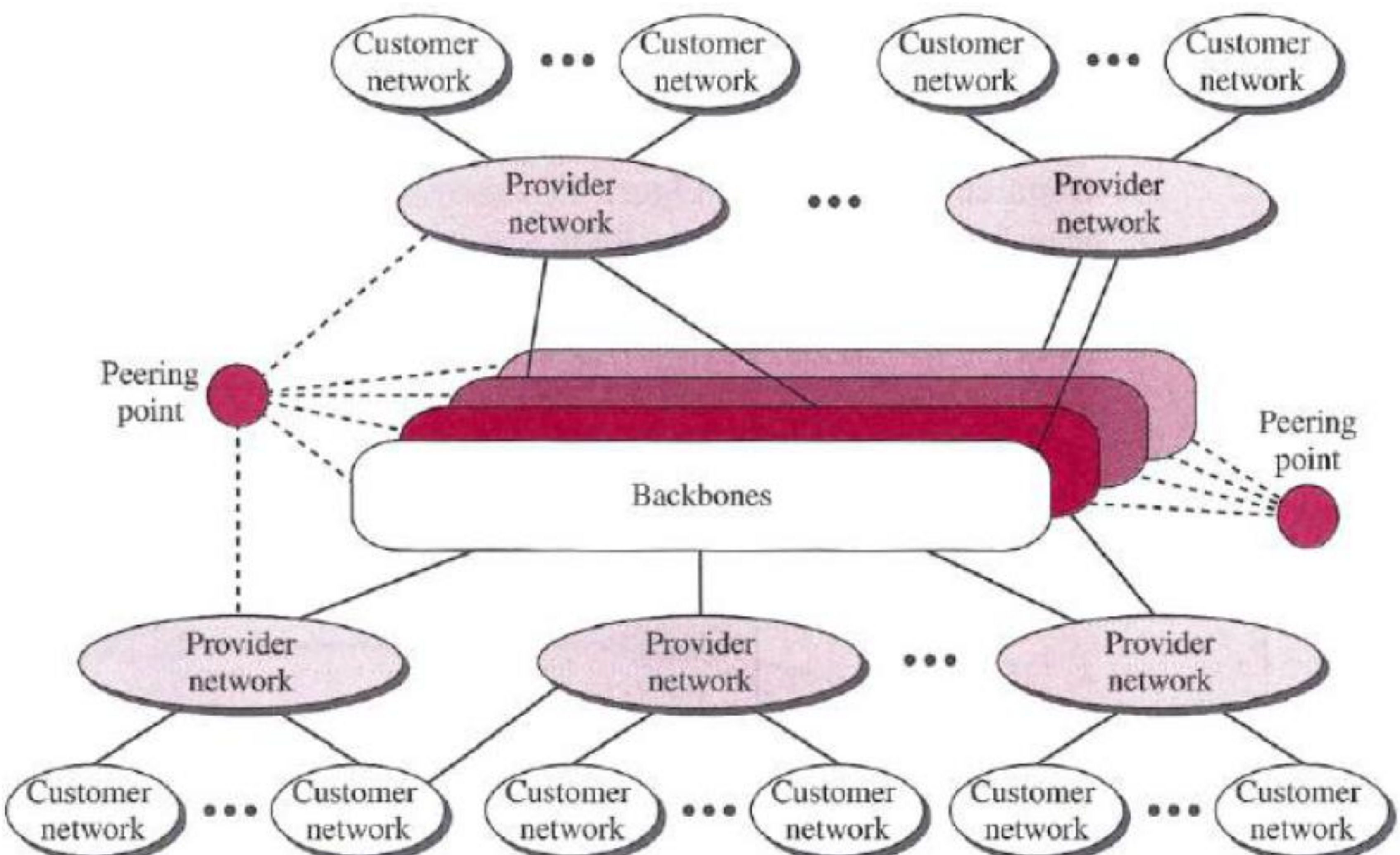
Packet-Switched Network

In a computer network, the communication between the two ends is done in blocks of data called packets. Instead of the continuous communication we see between two telephone sets when they are being used, we see the exchange of individual data packets between the two computers.

This allows us to make the switches function for both storing and forwarding because a packet is an independent entity that can be stored and sent later.


Low-capacity line
High-capacity line
Queue
Queue
Router
Router

The Internet



Accessing the Internet

Using Telephone Networks

Dial-up service.

DSL Service.

Using Cable Networks

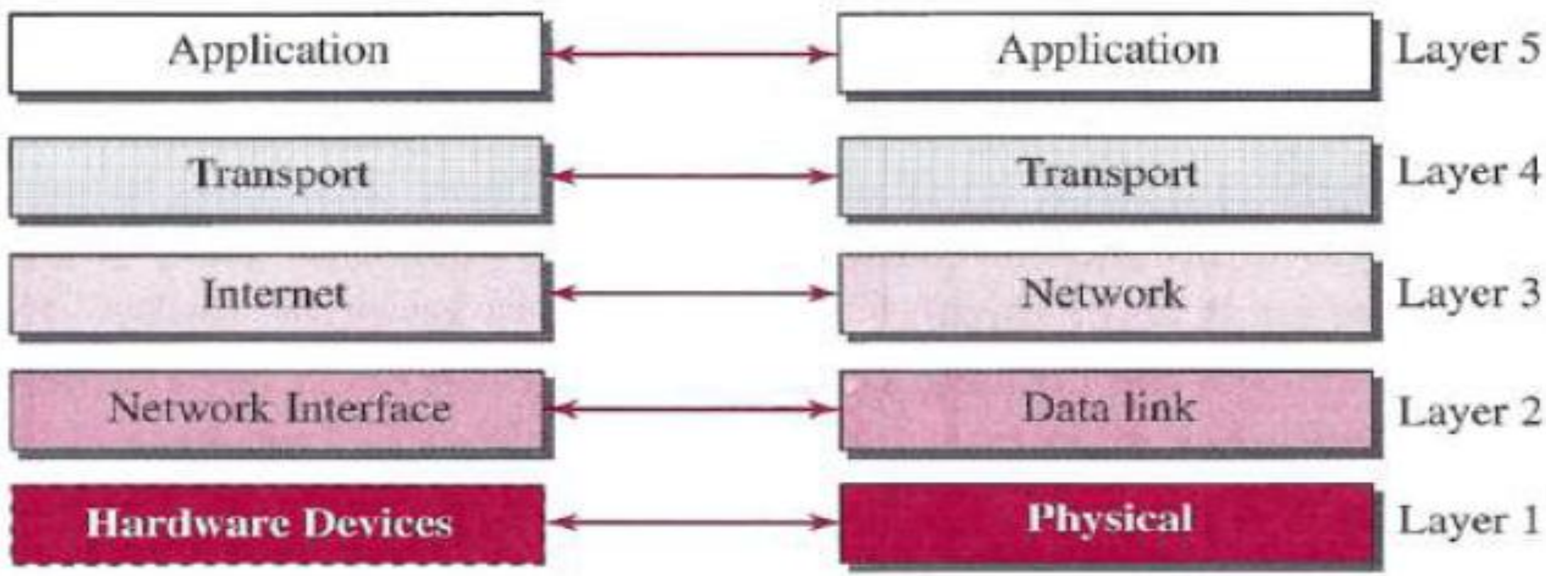
Using Wireless Networks

Direct Connection to the Internet

PROTOCOL LAYERING

In data communication and networking, a protocol defines the rules that both the sender and receiver and all intermediate devices need to follow to be able to communicate effectively.

Layers in the TCP/IP protocol suite



a. Original layers

b. Layers used in this book

The **Physical Layer** is responsible for carrying individual bits in a frame across the link.

the **Data-Link** layer is responsible for taking the datagram and moving it across the link.
The link can be a wired LAN with a link-layer switch, a wireless LAN, a wired WAN, or a wireless WAN.
We can also have different protocols used with any link type. In each case, the data-link layer is responsible for moving the packet through the link.

The **Network Layer** is responsible for creating a connection between the source computer and the destination computer.
The communication at the network layer is host-to-host.

The logical connection at the transport layer is also end-to-end. The **transport layer** at the source host gets the message from the application layer, encapsulates it in a transport layer packet (called a *segment or a user datagram in different protocols) and sends it,* through the logical (imaginary) connection, to the transport layer at the destination host.
In other words, the transport layer is responsible for giving services to the application layer: to get a message from an application program running on the source host and deliver it to the corresponding application program on the destination host.

Application Layer

shows, the logical connection between the two application layers is end to-end. The two application layers exchange *messages between each other as though* there were a bridge between the two layers. However, communication is done through all the layers.

Communication at the application layer is between two *processes (two programs* running at this layer).

Figure 2.5 *Communication through an internet*

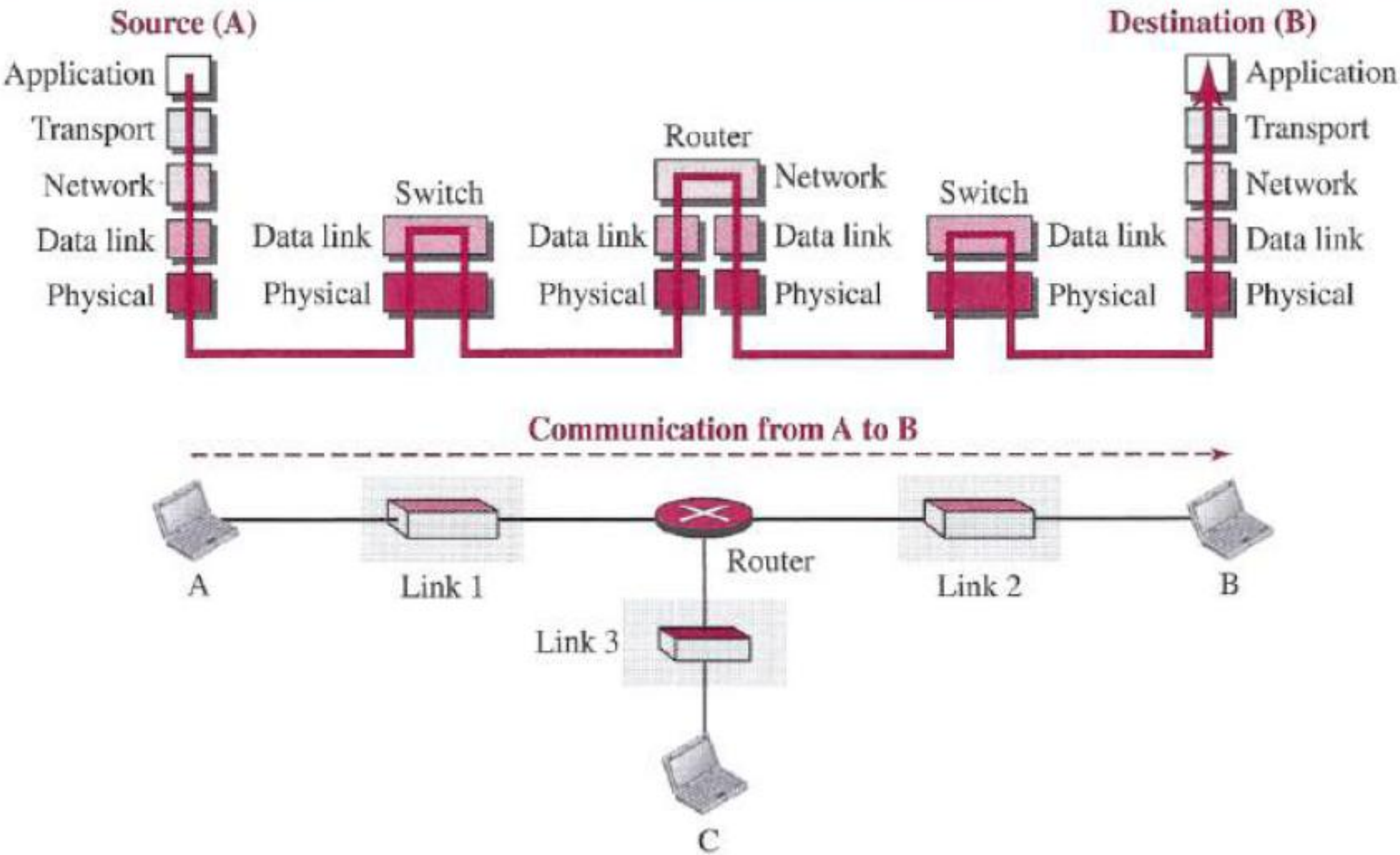
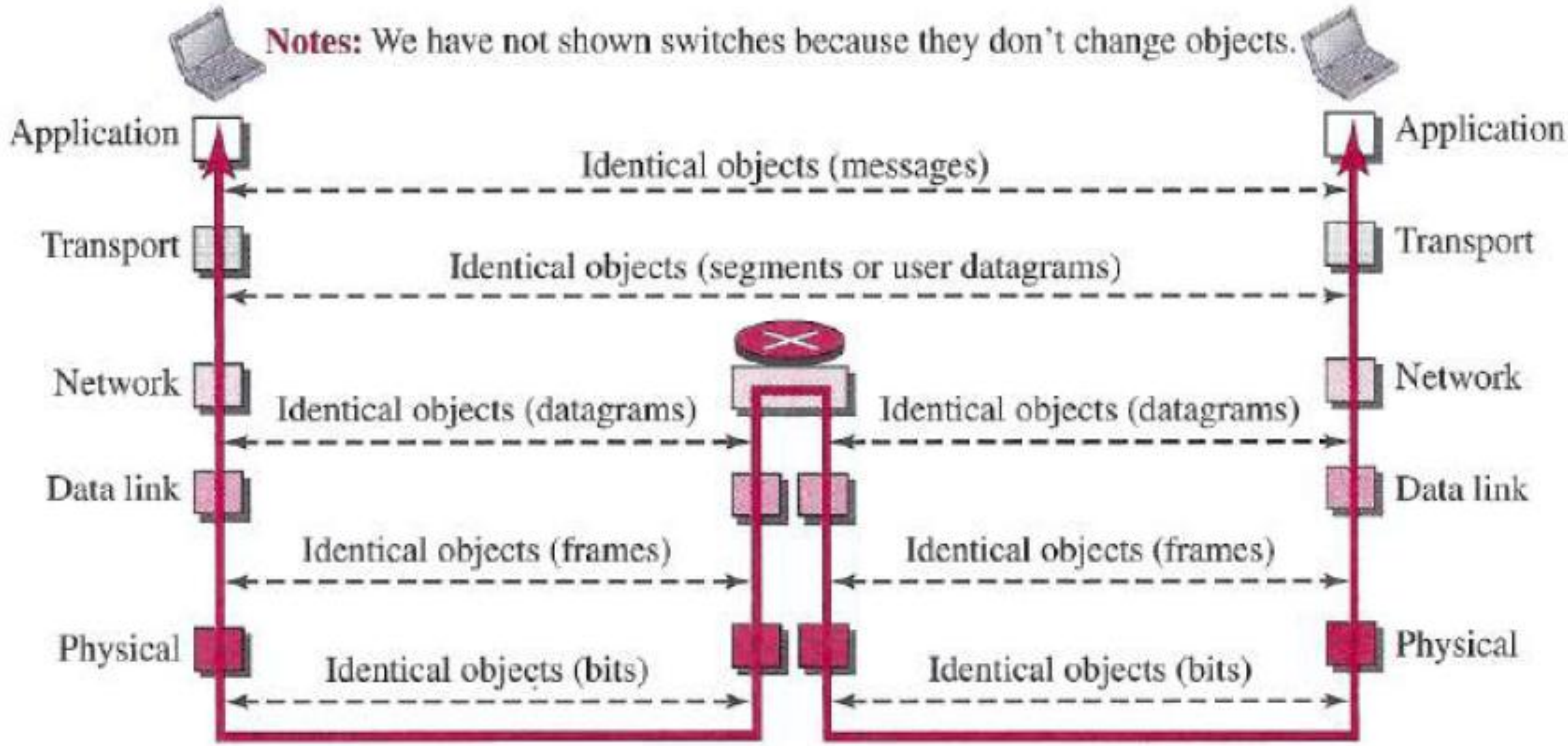


Figure 2.7 *Identical objects in the TCP/IP protocol suite*

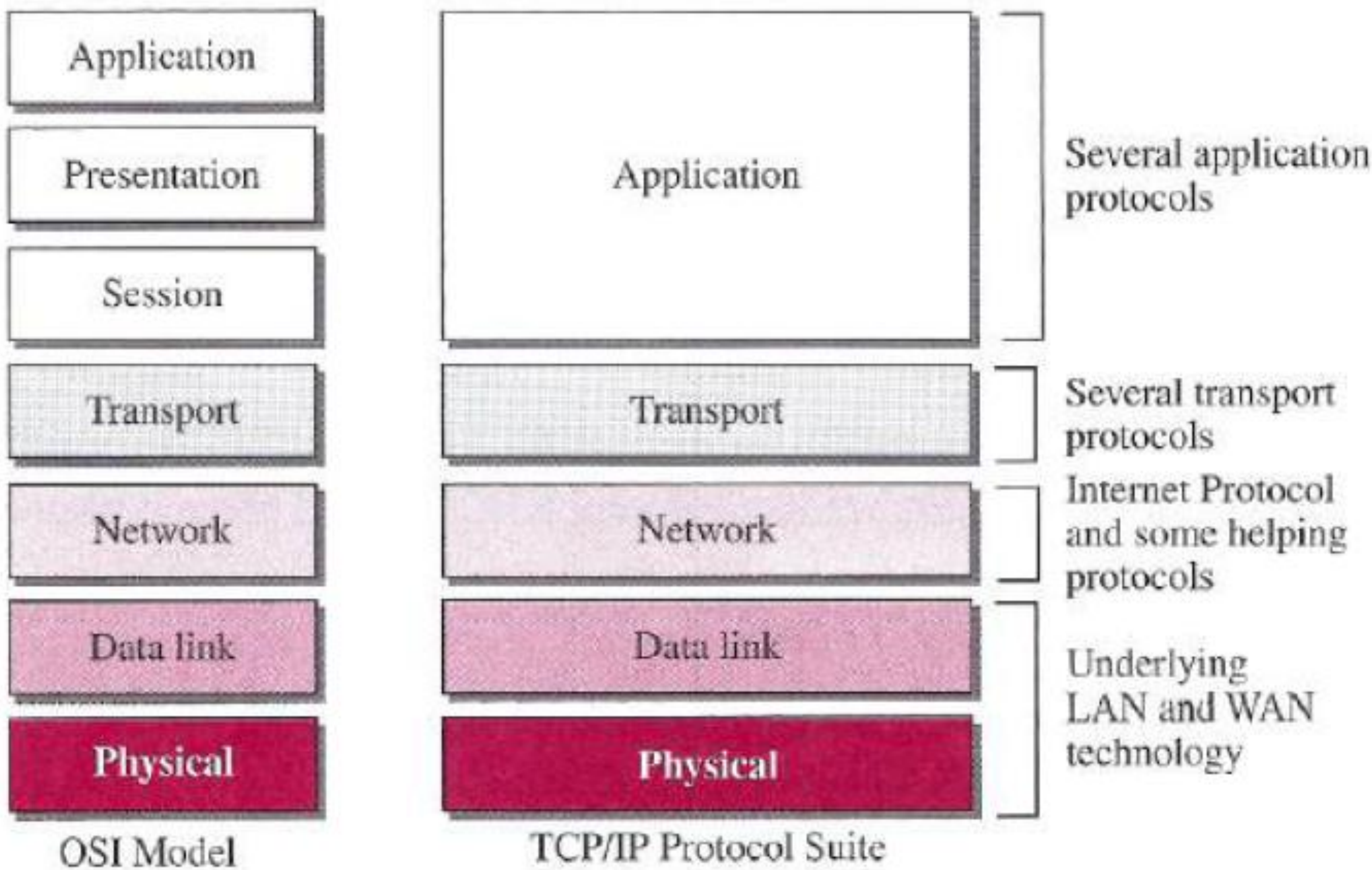


"Datagram: A self-contained, independent entity of data carrying sufficient information to be routed from the source to the destination computer without reliance on earlier exchanges between this source and destination computer and the transporting network."

Addressing in the TCP/IP protocol suite

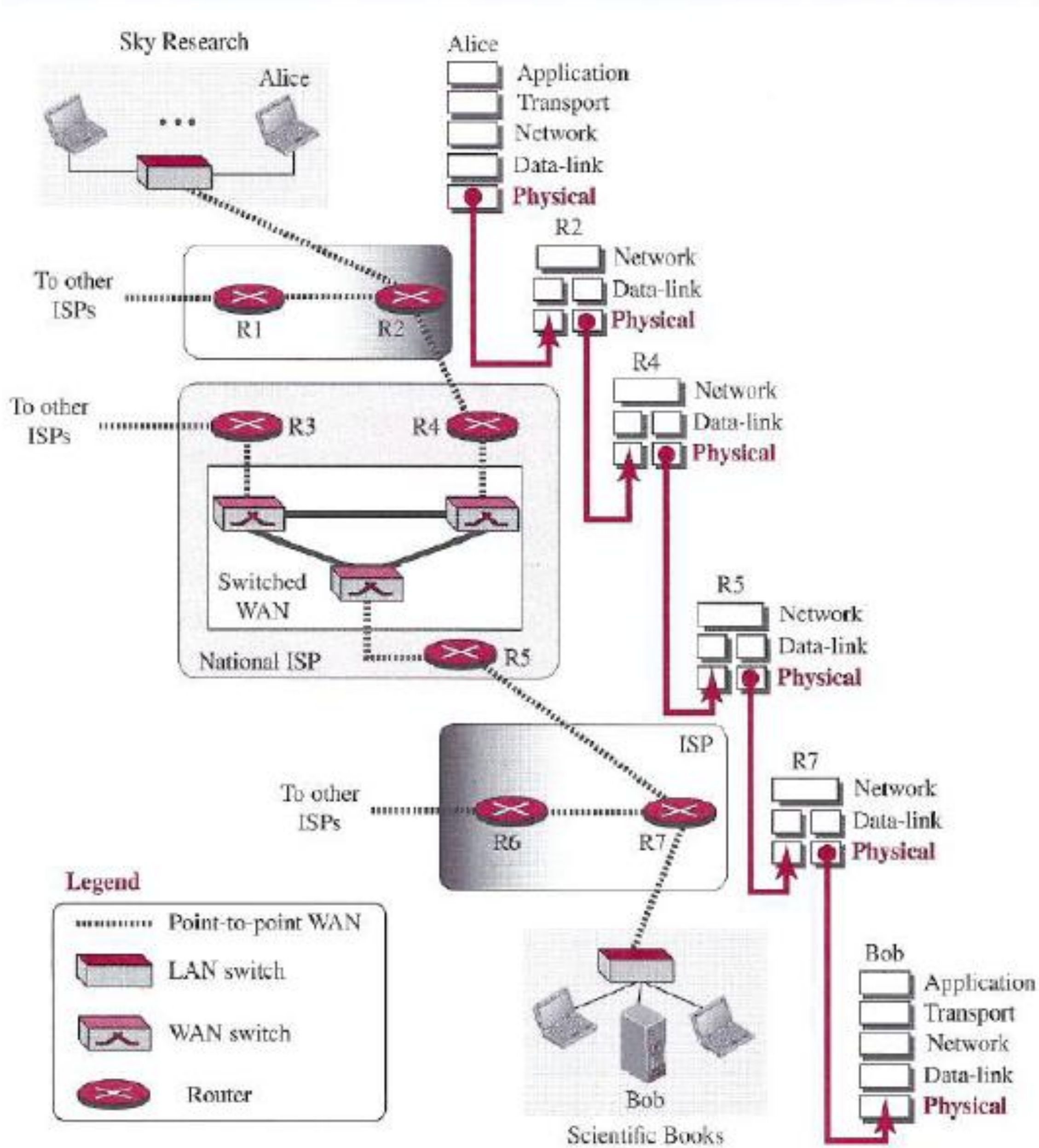
Packet names	Layers	Addresses
Message	Application layer	Names
Segment / User datagram	Transport layer	Port numbers
Datagram	Network layer	Logical addresses
Frame	Data-link layer	Link-layer addresses
Bits	Physical layer	

2.12 *TCP/IP and OSI model*



Introduction to Physical Layer

Figure 3.1 *Communication at the physical layer*



Analog and Digital Data

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.
For example, an analog clock that has hour, minute, and second hands gives information in a continuous form; the movements of the hands are continuous.

On the other hand, a digital clock that reports the hours and the minutes will change suddenly from 8:05 to 8:06.

Analog data, such as the sounds made by a human voice, take on continuous values.

When someone speaks, an analog wave is created in the air. This can be captured by a microphone and converted to an analog signal or sampled and converted to a digital signal.

Digital data take on discrete values. For example, data are stored in computer memory in the form of Os and Is. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.

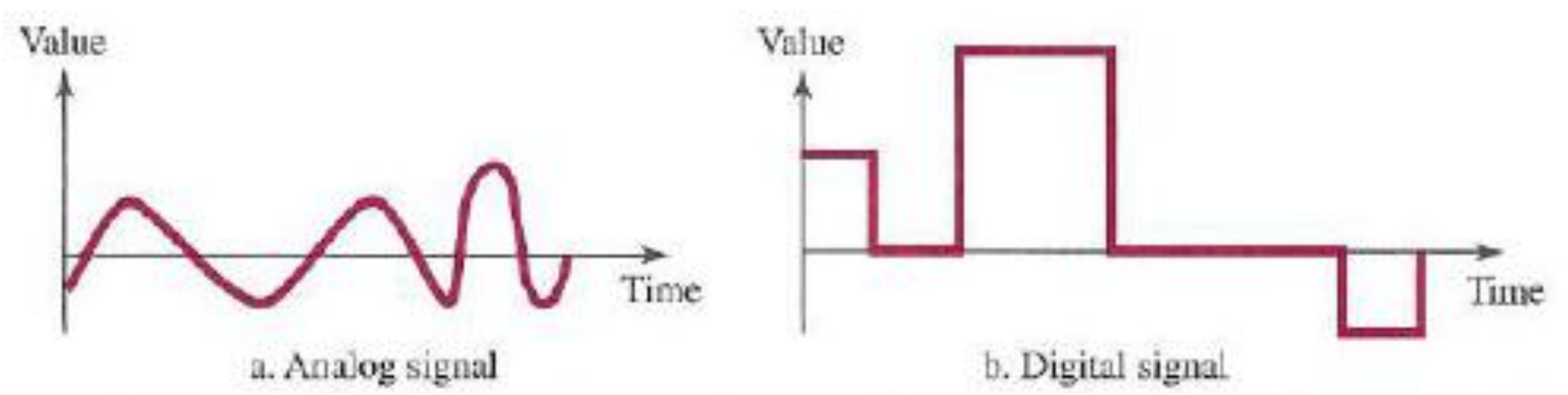
Analog and Digital Signals

signals can be either analog or digital.

An analog signal has infinitely many levels of intensity over a period of time. As the wave moves from value *A to value B, it passes through and includes an infinite number of values along its* path.

A **digital signal,** on the other hand, can have only a limited number of defined values. Although each value can be any number, it is often as simple as 1 and O.

gure 3.2 Comparison of analog and digital signals



Periodic and Nonperiodic

Both analog and digital signals can take one of two forms: *periodic or nonperiodic* (sometimes referred to as *aperiodic;).*

A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods.

The completion of one full pattern is called a cycle.
A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time.
Both analog and digital signals can be periodic or nonperiodic.
In data communications, we commonly use periodic analog signals and nonperiodic digital signals,

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

PERIODIC ANALOG 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.

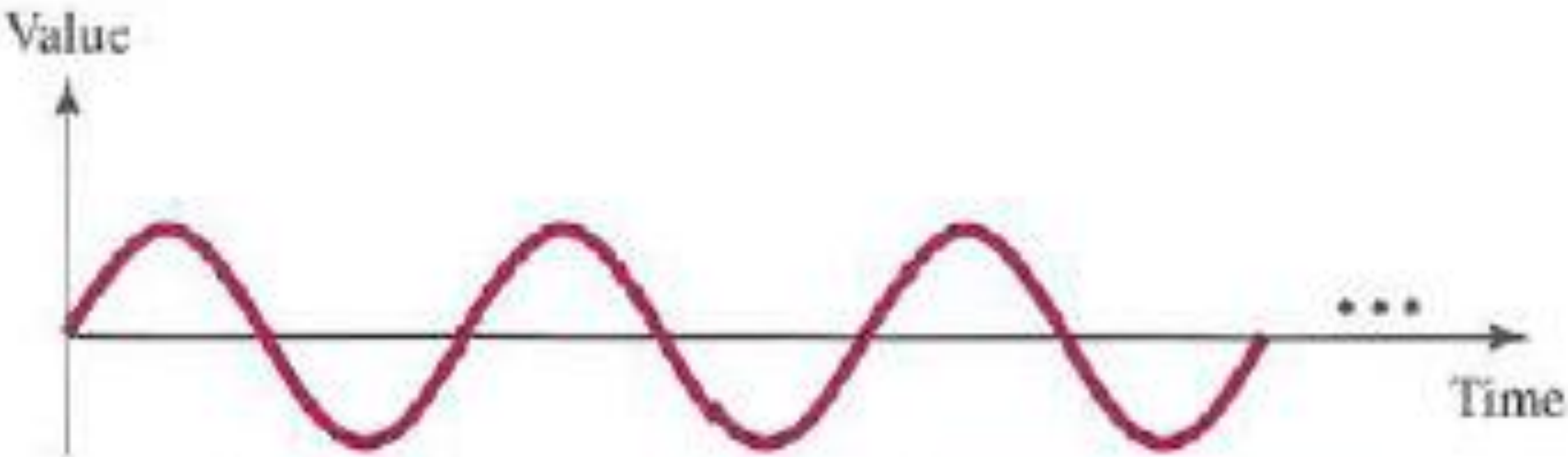
A composite periodic analog signal is composed of multiple sine waves.

Sine Wave

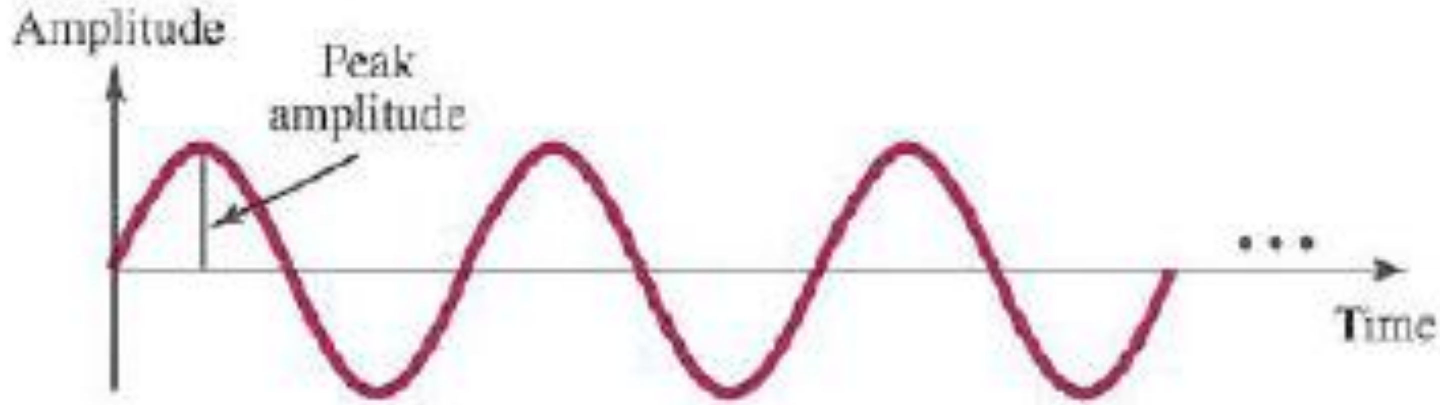
The sine wave is the most fundamental form of a periodic analog signal.

When we visualize it as a simple oscillating curve, its change over the course of a cycle is smooth and consistent, a continuous, rolling flow. Each cycle consists of a single arc above the time axis followed by a single arc below it.

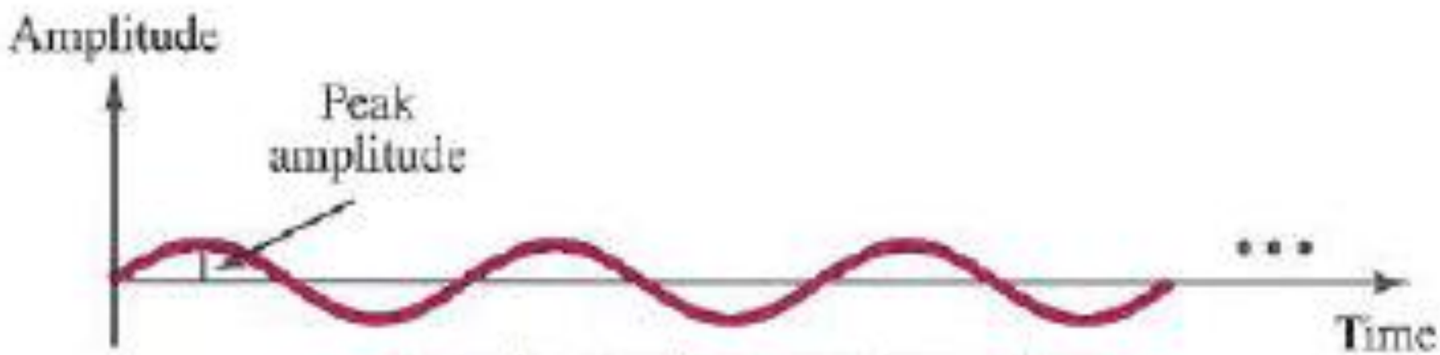
A sine wave



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

Period and Frequency

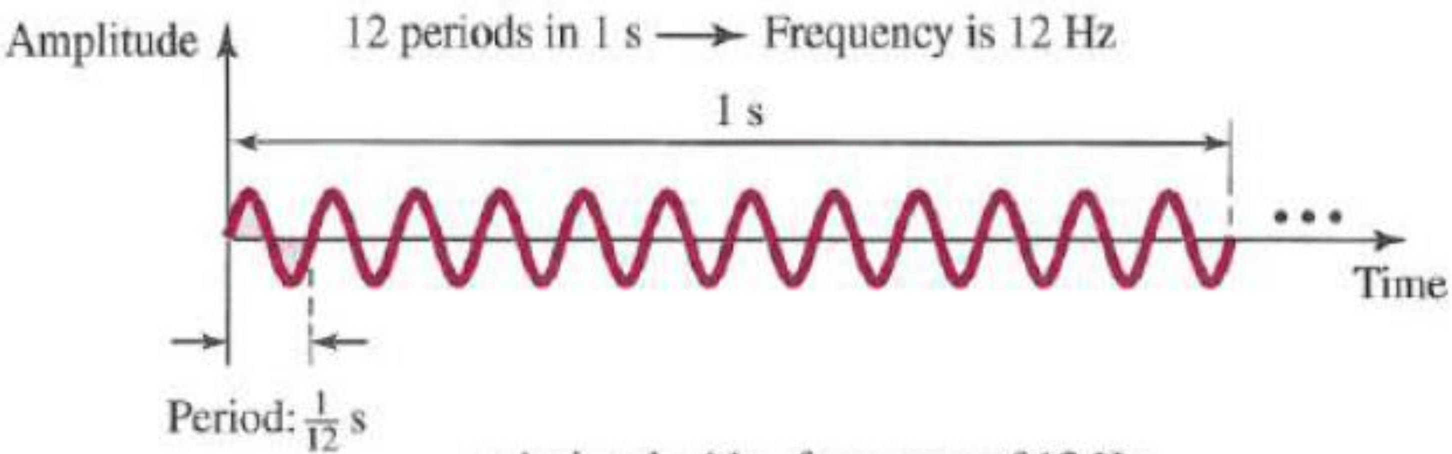
Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle.

Frequency refers to the number of periods in 1 s. Note that period and frequency are just one characteristic defined in two ways. Period is the inverse of frequency, and frequency is the inverse of period, as the following formulas show.

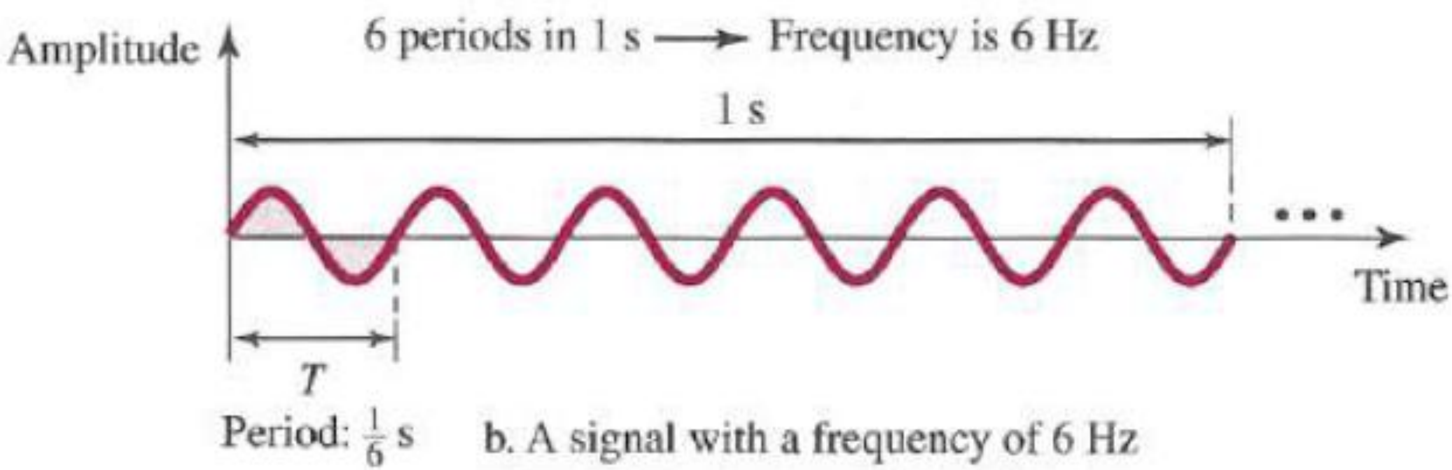
$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

Frequency and period are the inverse of each other.

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



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Table 3.1 *Units of period and frequency*

Period		*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

Eg.

The power we use at home has a frequency of 60 Hz (50Hz in Europe).

The period of this sine wave can be determined as follows:

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

This means that the period of the power for our lights at home is 0.0116 s, or 16.6 ms.
Our eyes are not sensitive enough to distinguish these rapid changes in amplitude.

Another Definition of **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.

If the value of a signal changes over a very short span of time, its frequency is high.
If it changes over a long span of time, its frequency is low.

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

Phase

The term phase, or phase shift, describes the position of the waveform relative to time 0.

If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift. It indicates the status of the first cycle.

Phase describes the position of the waveform relative to time 0.

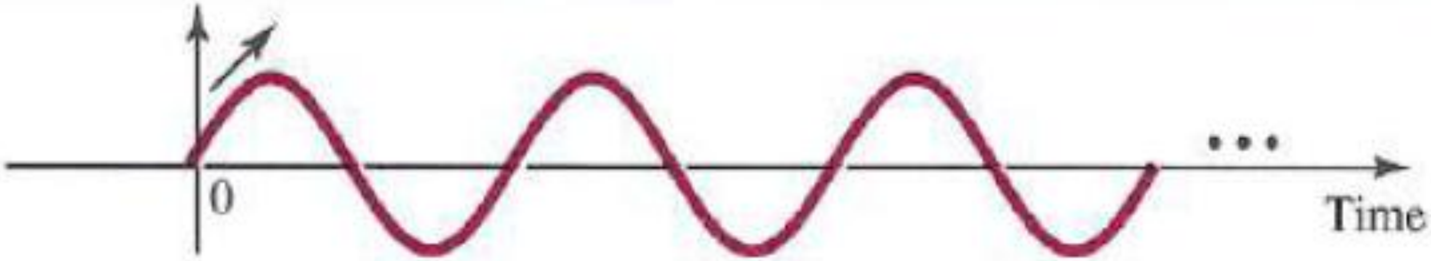
Phase is measured in degrees or radians [360° is *2n rad;*
1° is 2n/360 rad, and 1 rad is *360/(2n)].*

A phase shift of 360° corresponds to a shift of a complete period;

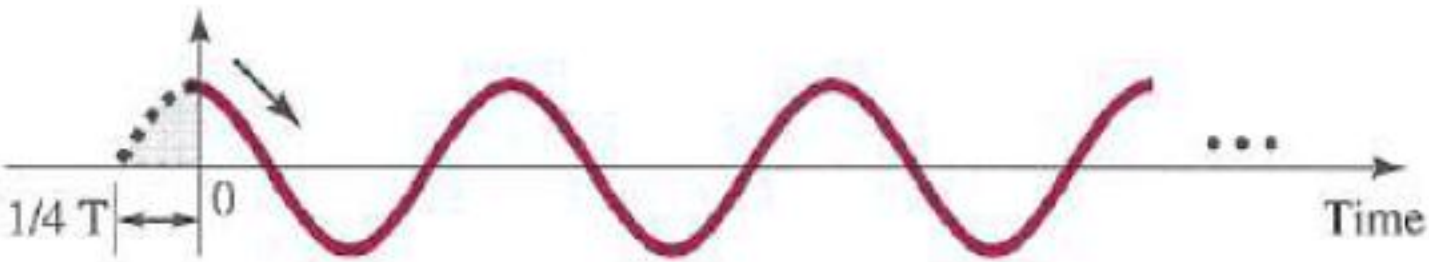
a phase shift of 180° corresponds to a shift of one-half of a period;

and a phase shift of 90° corresponds to a shift of one-quarter of a period

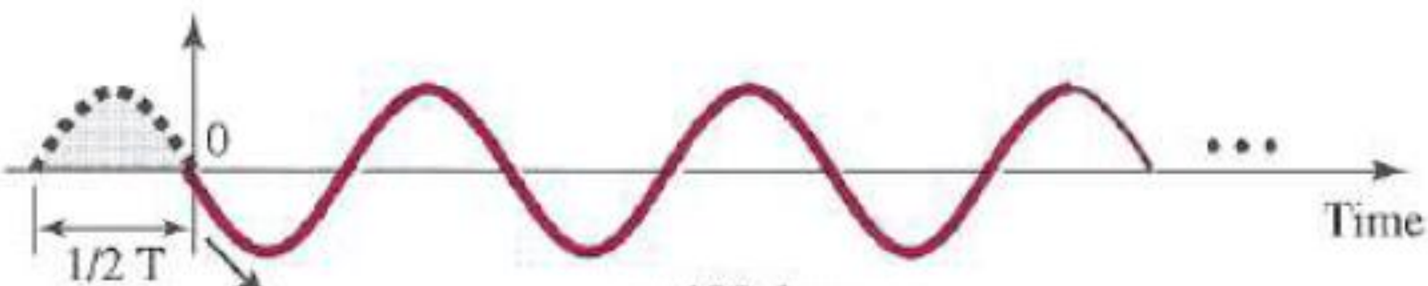
Three sine waves with the same amplitude and frequency, but different phases



a. 0 degrees



b. 90 degrees



c. 180 degrees

Looking at Figure , we can say that

a. A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.

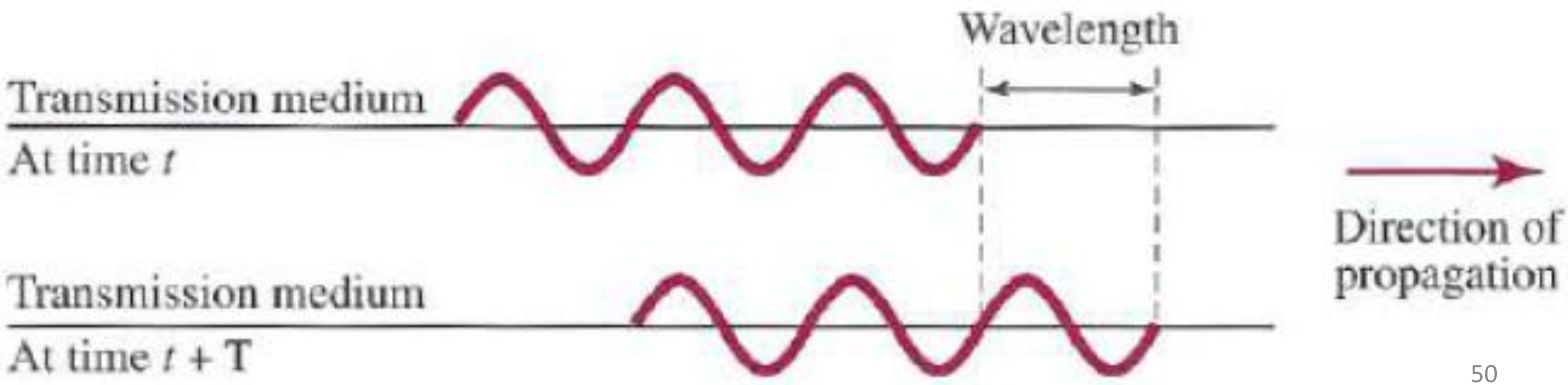
b. A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.

c. A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.

Wavelength

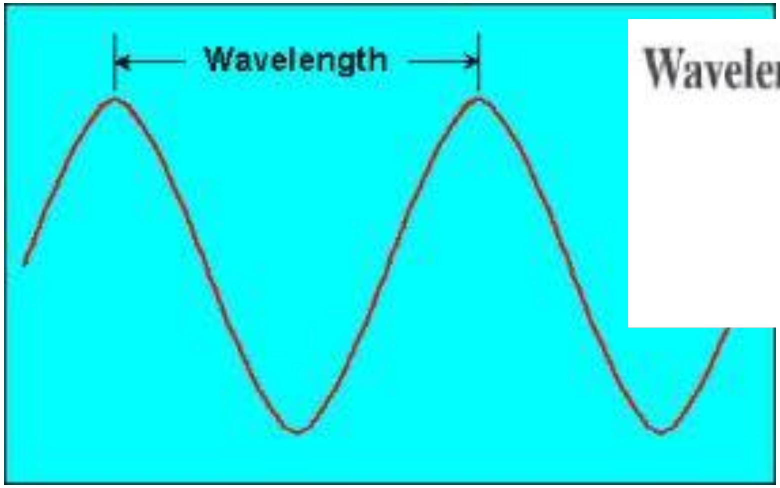
The wavelength is the distance a simple signal can travel in one period. Wavelength is another characteristic of a signal traveling through a transmission medium. Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium.

7 *Wavelength and period*



Wavelength is the distance between identical points in the adjacent cycles of a waveform signal propogated in space or along a wire, as shown in the illustration. In wireless systems, this length is usually specified in meters, centimeters, or millimeters. source : wikipedia

Or Distance between 2 points of corresponding phase.



$$\text{Wavelength} = (\text{propagation speed}) \times \text{period} = \frac{\text{propagation speed}}{\text{frequency}}$$

$$\lambda = \frac{c}{f}$$

Where C is speed of light

Composite Signals

Application of sine waves in daily life.

1. We can send a single sine wave to carry electric energy from one place to another. For example, the power company sends a single sine wave with a frequency of 60 Hz to distribute electric energy to houses and businesses.
2. As another example, we can use a single sine wave to send an alarm to a security center when a burglar opens a door or window in the house.

In the first case, the sine wave is carrying energy; in the second, the sine wave is a signal of danger.

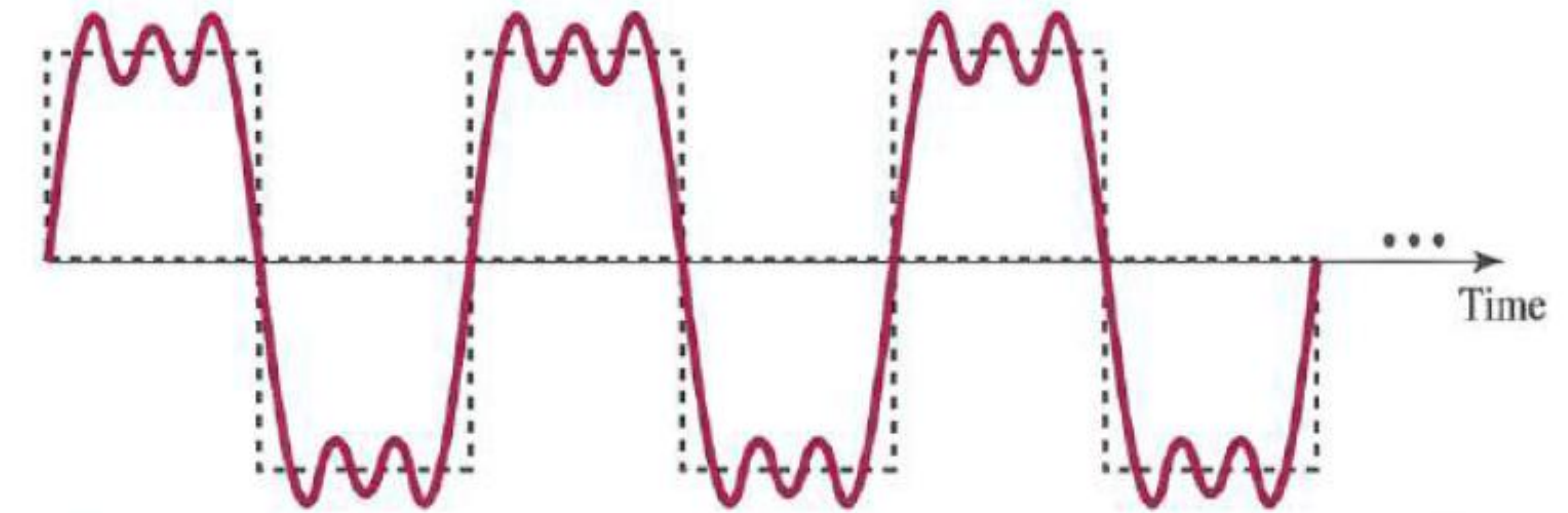
Composite Signals

A single-frequency sine wave is not useful in data communications;
we need to send a composite signal, a signal made of many simple sine waves.

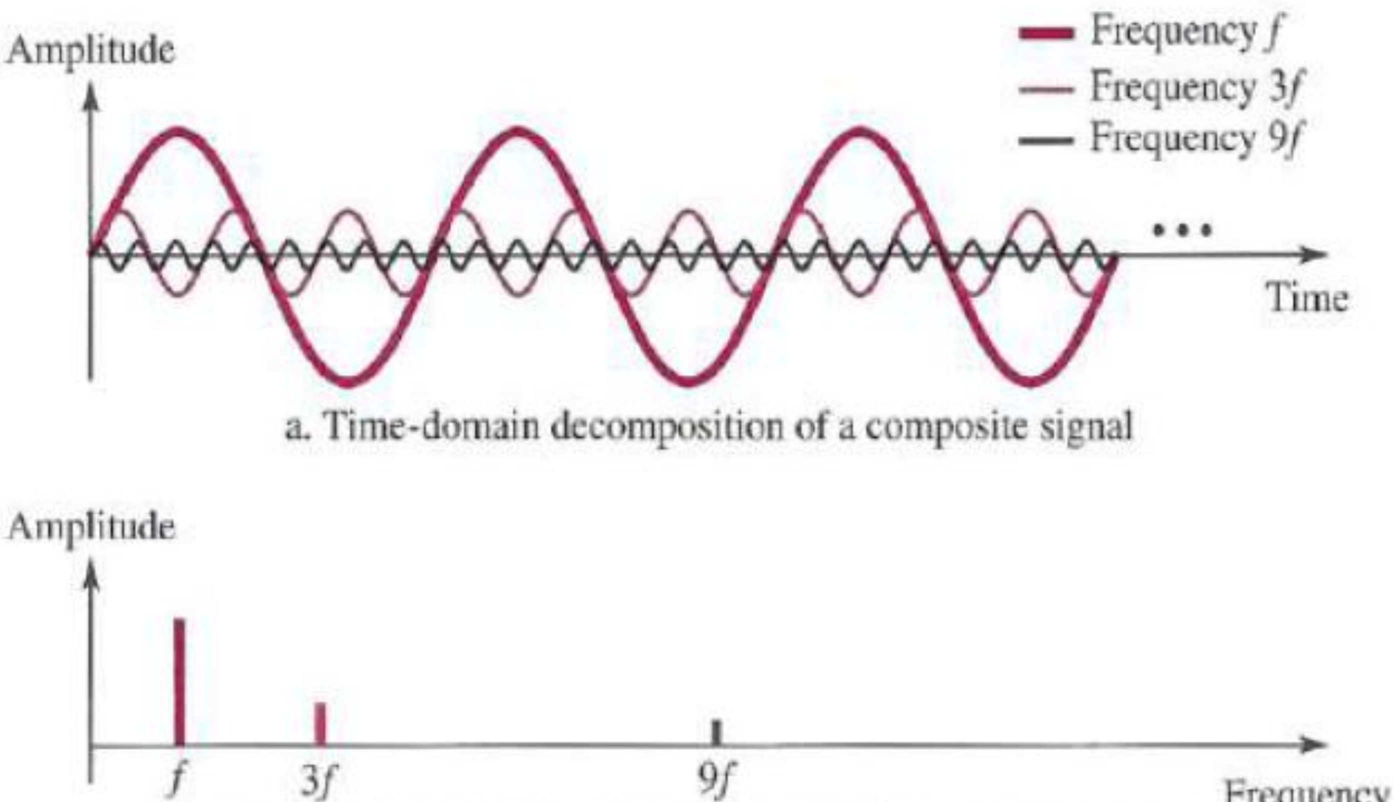
Jean-Baptiste Fourier showed that any composite signal is actually a combination of simple sine waves with different frequencies, amplitudes, and phases.

A composite signal can be periodic or nonperiodic.
A periodic composite signal can be decomposed into a series of simple sine waves with discrete frequencies - frequencies that have integer values (1, 2, 3, and so on).
A nonperiodic composite signal can be decomposed into a combination of an infinite number of simple sine waves with continuous frequencies, frequencies that have real values.

ure 3.10 *A composite periodic signal*



3.11 *Decomposition of a composite periodic signal in the time and frequency domains*



a. Time-domain decomposition of a composite signal

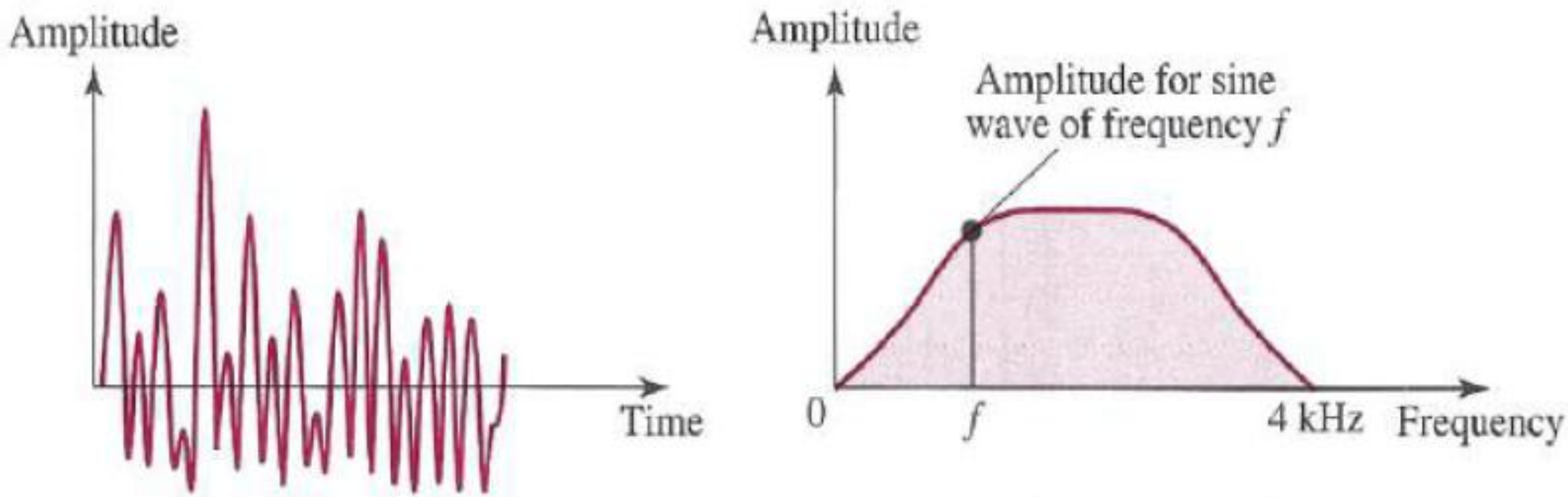
b. Frequency-domain decomposition of the composite signal

The frequency of the sine wave with frequency *f is the same as the frequency of the composite signal; it* is called the **fundamental frequency, or first harmonic. The sine wave with frequency *3f*** has a frequency of 3 times the fundamental frequency; it is called the third harmonic.

The third sine wave with frequency *9f has a frequency of 9 times the fundamental frequency; it is called the* ninth harmonic.

Note that the frequency decomposition of the signal is discrete; it has frequencies f, *3f, and 9f. Because f is an integral number, 3f and 9f are also integral numbers. There are no frequencies* such as *1.2f or 2.6f The frequency domain of a periodic composite signal is always made of discrete* spikes.

Figure 3.12 *The time and frequency domains of a nonperiodic signal*



a. Time domain

b. Frequency domain

In a time-domain representation of this composite signal, there are an infinite number of simple sine frequencies. Although the number of frequencies in a human voice is infinite, the range is limited. A normal human being can create a continuous range of frequencies between 0 and 4 kHz.

Note that the frequency decomposition of the signal yields a continuous curve.

There are an infinite number of frequencies between 0.0 and 4000.0 (real values).

To find the amplitude related to frequency *f, we draw a vertical line at f to intersect the envelope* curve. The height of the vertical line is the amplitude of the corresponding frequency.

A composite signal is made of many simple sine waves.

What will happen if we use simple sine wave to carry a conversation ?

A single-frequency sine wave is not useful in data communications; we need to send a composite signal, a signal made of many simple sine waves.

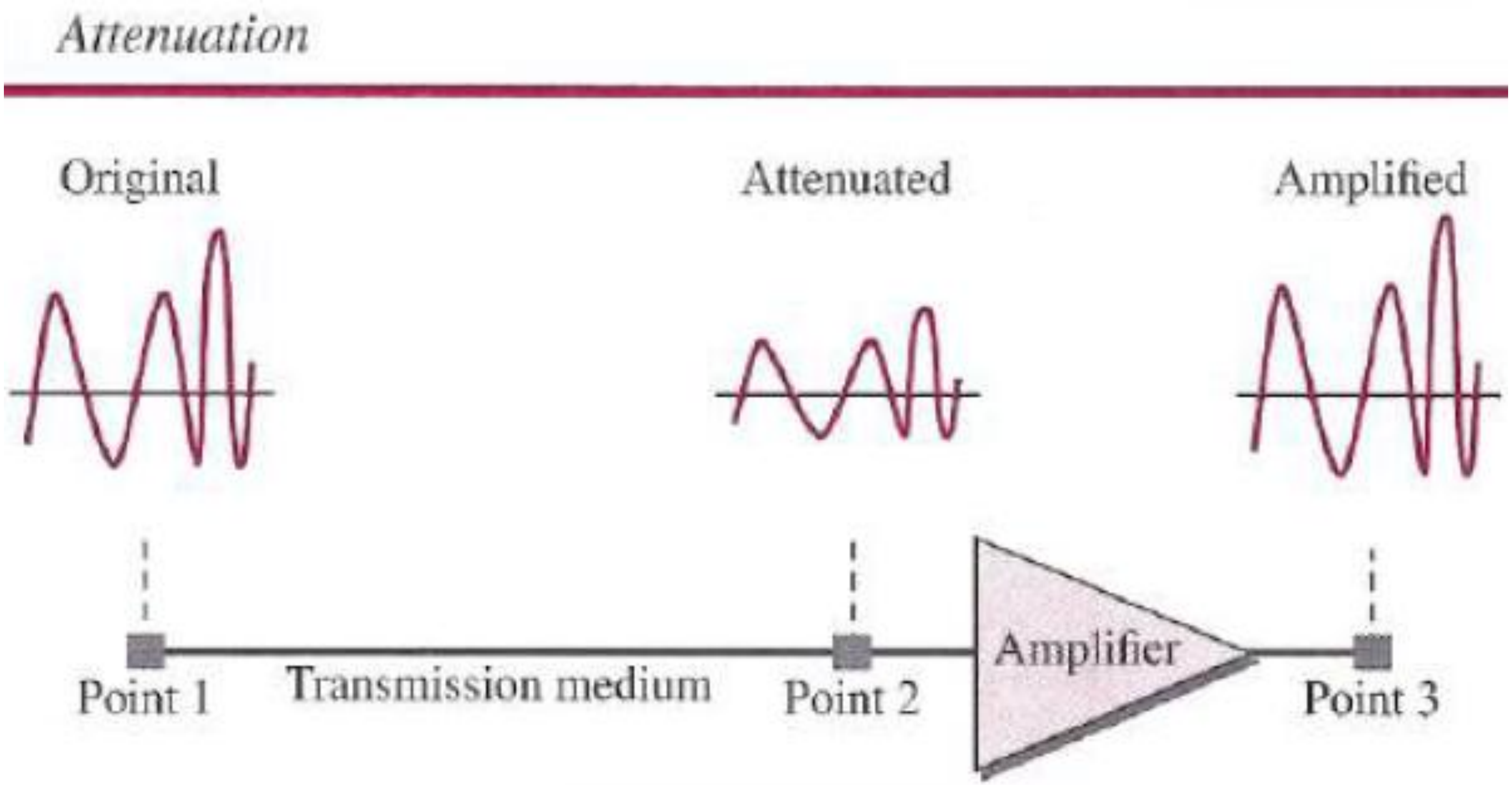
According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

TRANSMISSION IMPAIRMENT

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**

Attenuation means a loss of energy.
When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.

That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat. To compensate for this loss, amplifiers are used to amplify the signal.



Decibel

To show that a signal has lost or gained strength, engineers use the unit of the decibel.

The **decibel** (**dB**) measures the relative strengths of two signals or one signal at two different points.

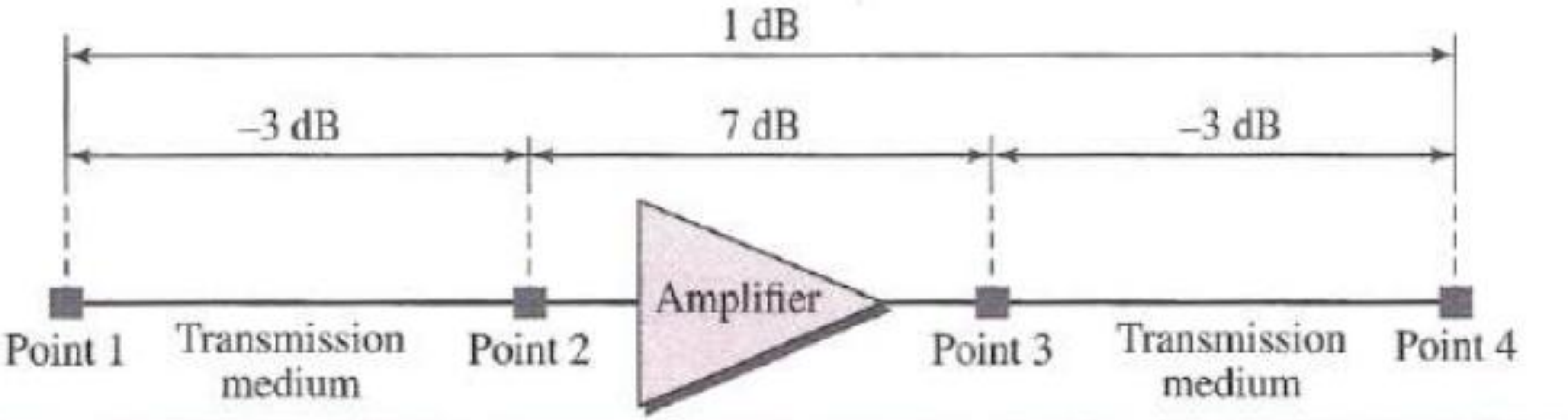
Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

$$\mathrm{dB} = 10 \log_{10} \frac{P_2}{P_1}$$

Variables *PI and P2 are the powers of a signal at points I and 2, respectively.*

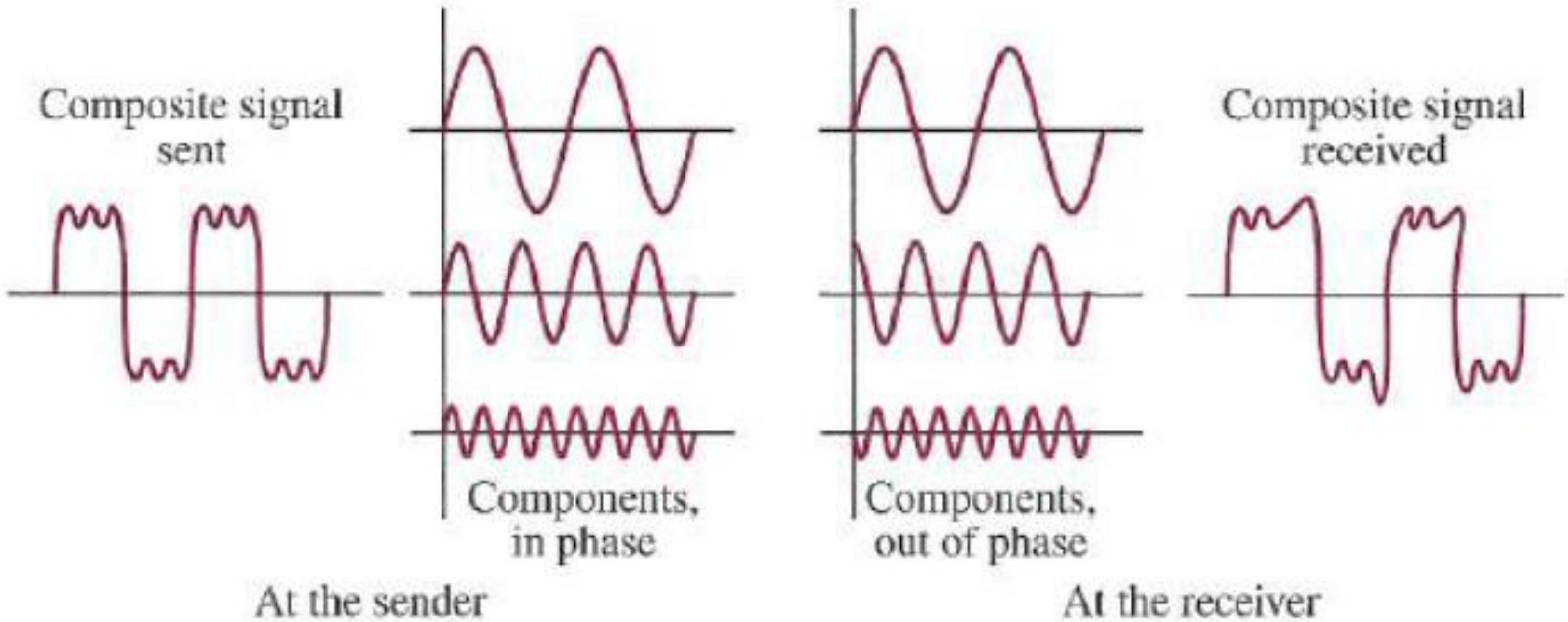
Note that some engineering books define the decibel in terms of voltage instead of power.

In this case, because power is proportional to the square of the voltage, the formula is dB = 20 log 10 *(V2/VI). In this text, we express dB in terms of power.*


1 dB
–3 dB
7 dB
–3 dB
Amplifier
Point 1
Transmission medium
Point 2
Point 3
Transmission medium
Point 4

Distortion

Distortion means that the signal changes its form or shape. Distortion can occur in a composite signal made of different frequencies. Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination. Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
signal components at the receiver have phases different from what they had at the sender.
The shape of the composite signal is not the same.


Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

Noise

Noise is another cause of impairment.

Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.

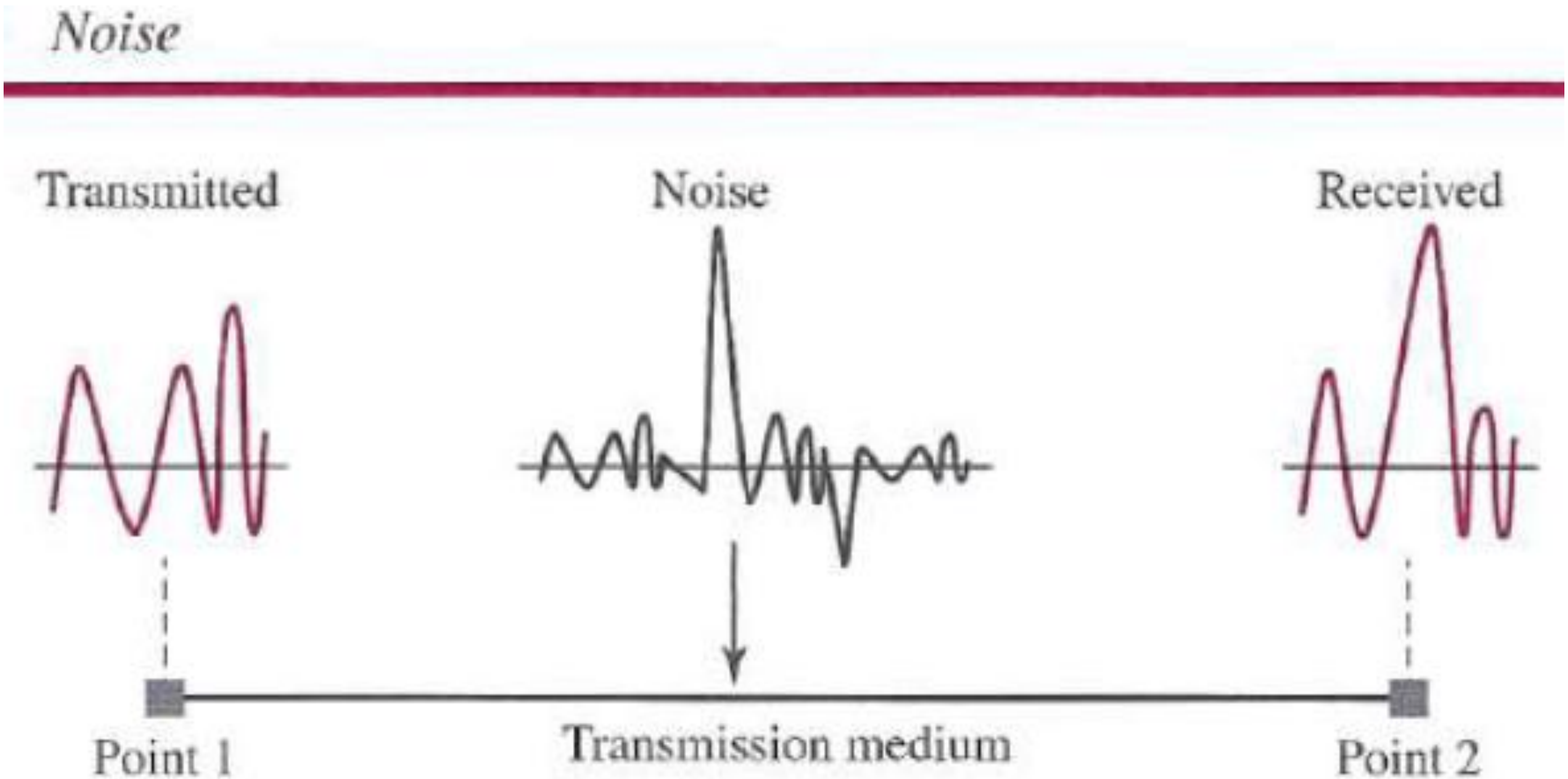
Thermal noise is the random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter.

Induced noise comes from sources such as motors and appliances.

These devices act as a sending antenna, and the transmission medium acts as the receiving antenna.

Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.

Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.



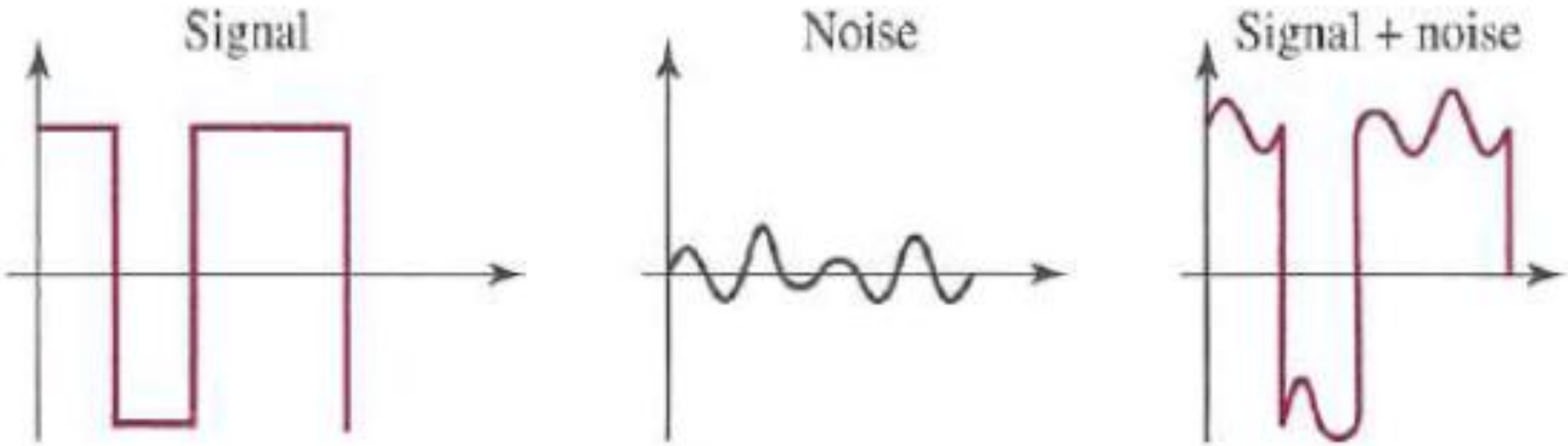
Signal-to-Noise Ratio (SNR)

The signal-to-noise ratio is defined as

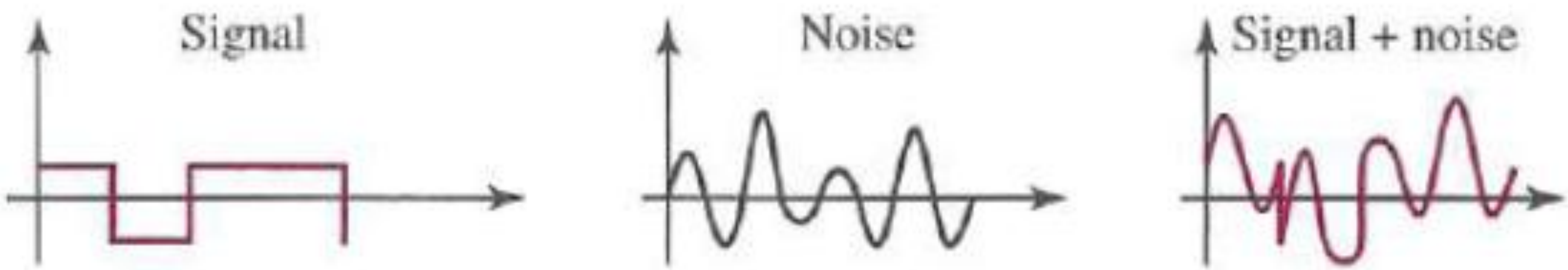
$$\text{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$

We need to consider the average signal power and the average noise power because these may change with time.

Two cases of SNR: a high SNR and a low SNR



a. High SNR



b. Low SNR

SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).

A high SNR means the signal is less corrupted by noise; a low SNR means the signal is more corrupted by noise. Because SNR is the ratio of two powers, it is often described in decibel units,
SNRdB, defined as

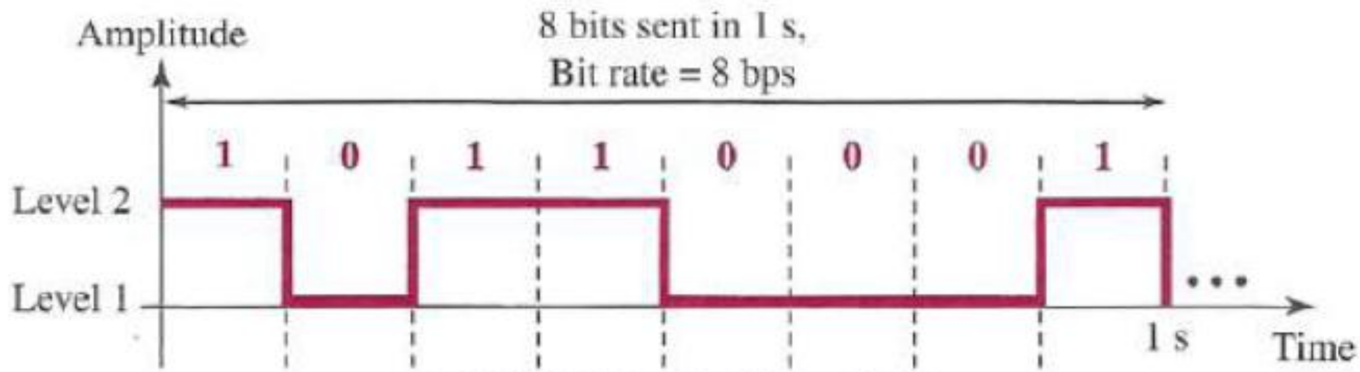
$$SNR_{dB} = 10 \log_{10} SNR$$

DIGITAL SIGNALS

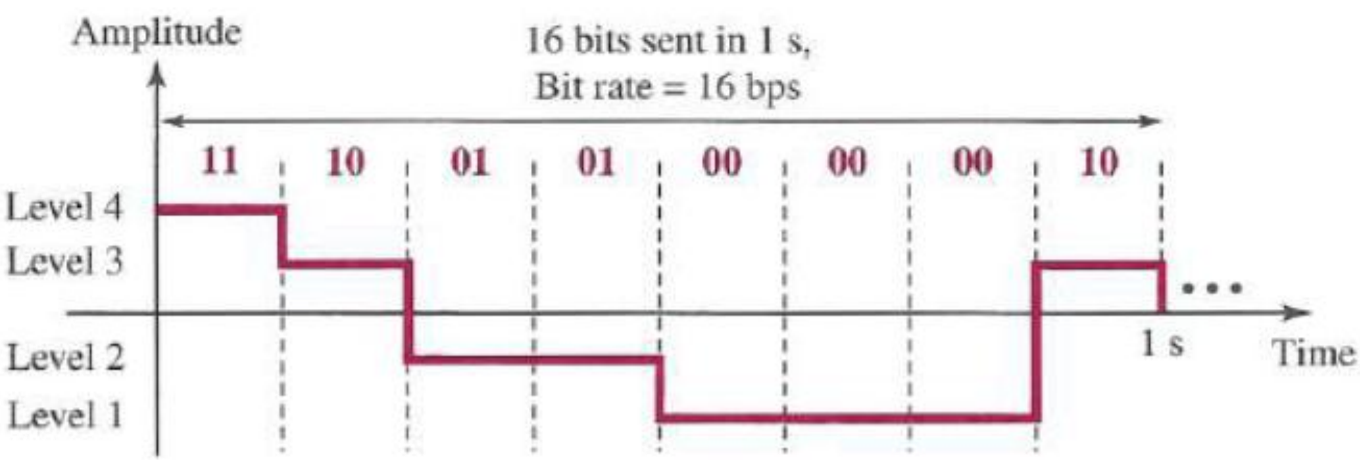
In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage.

A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

3.17 *Two digital signals: one with two signal levels and the other with four signal levels*



a. A digital signal with two levels



b. A digital signal with four levels

Bit Rate

Most digital signals are nonperiodic, and thus period and frequency are not appropriate characteristics. Another *term-bit rate (instead of frequency)-is used to describe* digital signals. The bit rate is the number of bits sent in Is, expressed in bits per second (bps). The above figure shows the bit rate for two signals.

Bit Length **Bit length = propagation speed x bit duration**

We discussed the concept of the wavelength for an analog signal: the distance one cycle occupies on the transmission medium.

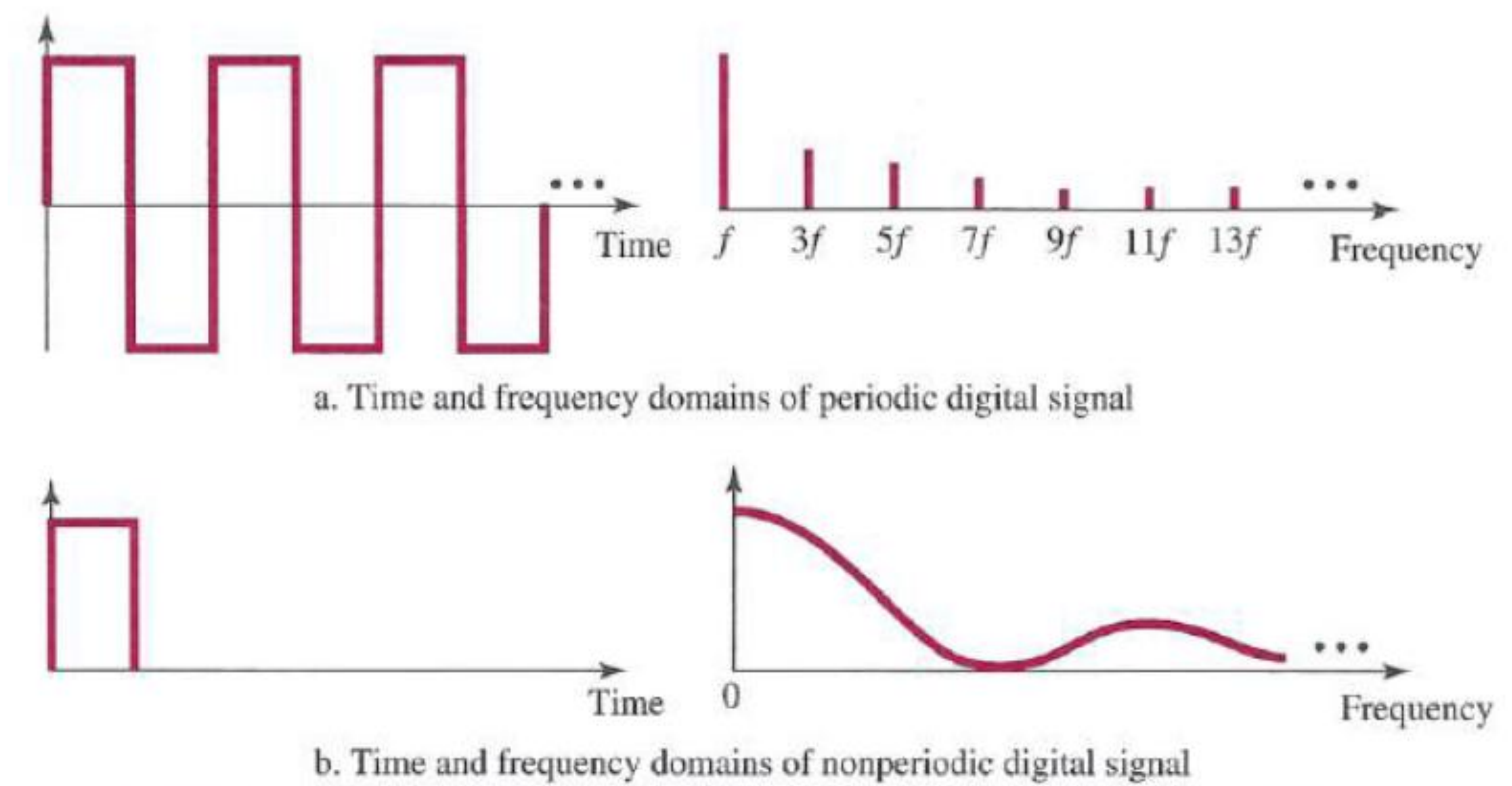
We can define something similar for a digital signal: the bit length.

The bit length is the distance one bit occupies on the transmission medium.

Fourier analysis can be used to decompose a digital signal. If the digital signal is periodic, which is rare in data communications, the decomposed signal has a frequency domain representation with an infinite bandwidth and discrete frequencies.

If the digital signal is nonperiodic, the decomposed signal still has an infinite bandwidth, but the frequencies are continuous.

igure 3.18 *The time and frequency domains of periodic and nonperiodic digital signals*



Note that both bandwidths are infinite, but the periodic signal has discrete frequencies while the nonperiodic signal has continuous frequencies.

Digital Signal as a Composite Analog Signal

A digital signal is a composite analog signal.

The bandwidth is infinite.

A digital signal, in the time domain, comprises connected vertical and horizontal line segments.

A vertical line in the time domain means a frequency of infinity (sudden change in time);

a horizontal line in the time domain means a frequency of zero (no change in time). Going from a frequency of zero to a frequency of infinity (and vice versa) implies all frequencies in between are part of the domain.

DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. The bandwidth available
2. The level of the signals we use
3. The quality of the channel (the level of noise)

Two theoretical formulas were developed to calculate the data rate: one by Nyquist for a noiseless channel, another by Shannon for a noisy channel.

Noiseless Channel: Nyquist Bit Rate

For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate
BitRate = 2 x bandwidth x $\log_2 L$

where, bandwidth is the bandwidth of the channel, *L is the number of signal* levels used to represent data, and BitRate is the bit rate in bits per second.

increasing the levels of a signal reduces the reliability of the system.

Noisy Channel: ***Shannon Capacity***

In reality, we cannot have a noiseless channel;
the channel is always noisy.

Shannon capacity, to determine the theoretical highest data rate for a noisy channel:

$$\text{Capacity} = \text{bandwidth} \times \log_2(1 + \text{SNR})$$

Where bandwidth is the bandwidth of the channel,
SNR is the signal-to-noise ratio, and
capacity is the capacity of the channel in bits per second.

there is no indication of the signal level, which means that no matter how many levels we have, we cannot achieve a data rate higher than the capacity of the channel. In other words, the formula defines a

Using **Both Limits**

In practice, we need to use both methods to find the limits and signal levels.

**The Shannon capacity gives us the upper limit;
the Nyquist formula tells us how many signal levels we need.**

PERFORMANCE

Bandwidth

One characteristic that measures network performance is bandwidth. However, the term can be used in two different contexts with two different measuring values: bandwidth in hertz and bandwidth in bits per second.

Bandwidth in Hertz

We have discussed this concept. Bandwidth in hertz is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass. For example, we can say the bandwidth of a subscriber telephone line is 4 kHz.

Bandwidth in Bits per Seconds

The term *bandwidth can also refer to the number of bits per second that a channel, a* link, or even a network can transmit. For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps.

This means that this network can send 100 Mbps.

Relationship

There is an explicit relationship between the bandwidth in hertz and bandwidth in bits per second.

Basically, an increase in bandwidth in hertz means an increase in bandwidth in bits per second.

In networking, we use the term *bandwidth* in two contexts.

- The first, *bandwidth in hertz*, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.
- The second, *bandwidth in bits per second*, refers to the speed of bit transmission in a channel or link.

Throughput

The throughput is a measure of how fast we can actually send data through a network.

For example, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.

Latency (Delay)

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

Latency is made of four components: propagation time, transmission time, queuing time and processing delay.

Latency = propagation time + transmission time + queuing time + processing delay

Propagation Time

Propagation time measures the time required for a bit to travel from the source to the destination. The propagation time is calculated by dividing the distance by the propagation speed.

Propagation time = Distance *I (Propagation Speed)*

Transmission Time

The transmission time of a message depends on the size of the message and the bandwidth of the channel.

Transmission time = (Message size) / Bandwidth

Queuing Time

the time needed for each intermediate or end device to hold the message before it can be processed.

The queuing time is not a fixed factor; it changes with the load imposed on the network. When there is heavy traffic on the network, the queuing time increases. An intermediate device, such as a router, queues the arrived messages and processes them one by one. If there are many messages, each message will have to wait.

ASSIGNMENT

Bandwidth-Delay Product

JITTER

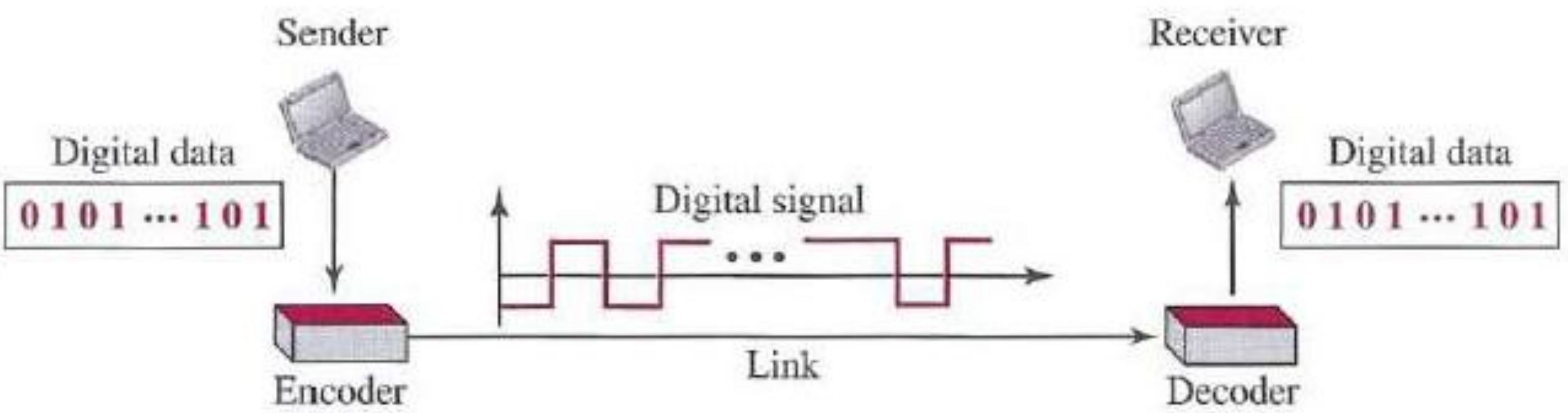
Digital Transmission

Digital-to-Digital Transmission

This conversion involves, three techniques;
Line coding, Block coding and scrambling.

Line Coding: is the process of converting digital data to digital signal. Data which is in the form of text, numbers, graphical images, audio are stored in the computer memory as sequence of bits.
It converts sequence of bits to digital signals. At the sender digital data are encoded into digital signals.
At the receiver the digital data are recreated by decoding the digital signals.

igure 4.1 *Line coding and decoding*

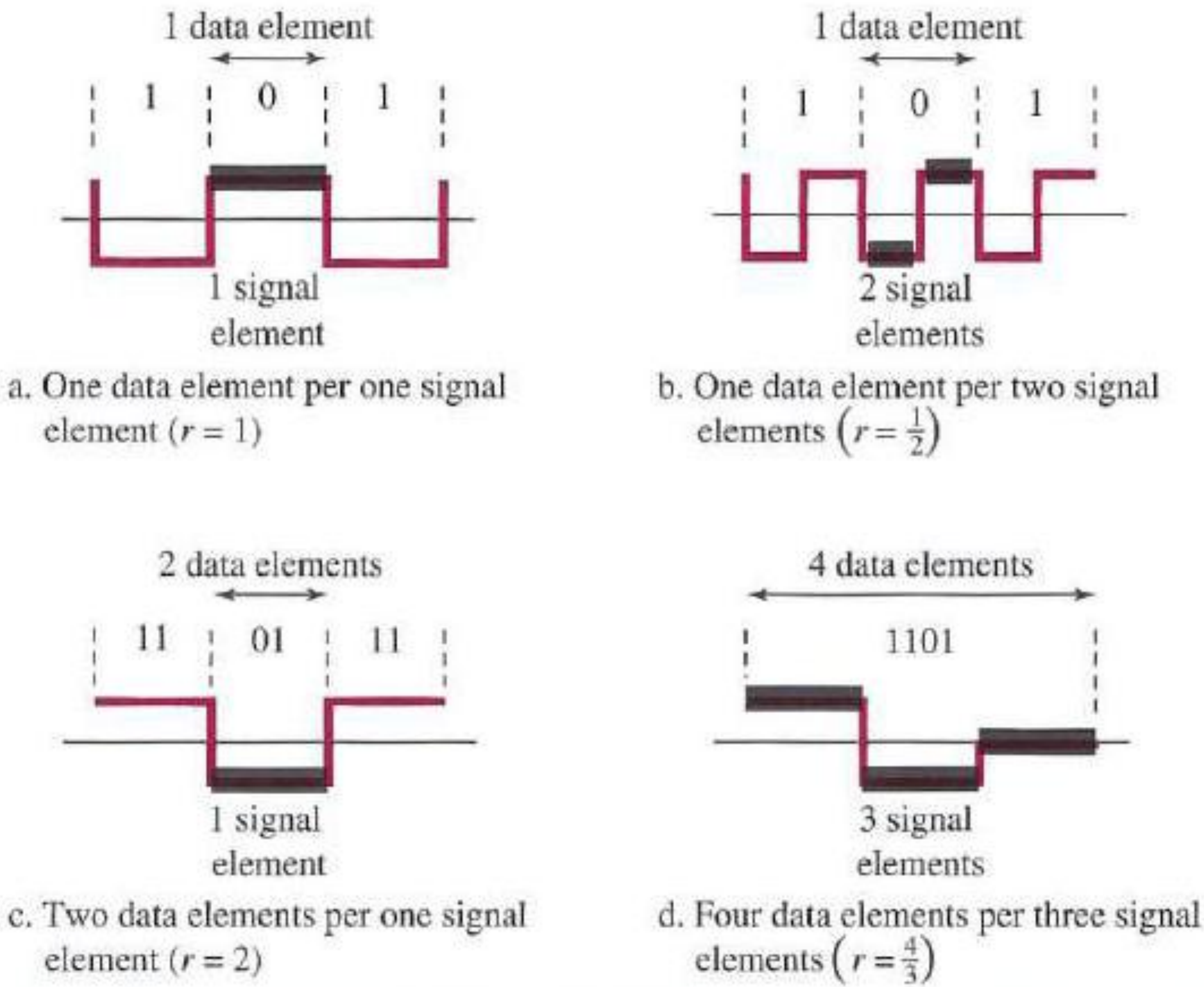


Signal Element versus Data Element

Signal Element Versus Data Element

Let us distinguish between a **data element** and a **signal element.** In data communications, our goal is to send data elements. A data element is the smallest entity that can represent a piece of information: this is the bit. In digital data communications, a signal element carries data elements. A signal element is the shortest unit (timewise) of a digital signal. In other words, data elements are what we need to send; signal elements are what we can send. Data elements are being carried; signal elements are the carriers.

.2 *Signal element versus data element*



Data Rate Versus Signal Rate

The **data rate** defines the number of data elements (bits) sent in 1s. The unit is bits per second (bps). The **signal rate** is the number of signal elements sent in 1s. The unit is the baud. There are several common terminologies used in the literature. The data rate is sometimes called the **bit rate;** the signal rate is sometimes called the **pulse rate,** the **modulation rate,** or the **baud rate.**

One goal in data communications is to increase the data rate while decreasing the signal rate. Increasing the data rate increases the speed of transmission; decreasing the signal rate decreases the bandwidth requirement.

the relationship between data rate (N) and signal rate (S)

$$S = N / r$$

one data element is carried by one signal element ($r = 1$).