Data Communication and Computer Networks

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Module 1

Introduction

DATA COMMUNICATIONS

Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable.

The effectiveness of a data communications system depends on four fundamental characteristics:

1. Delivery
2. Accuracy
3. Timeliness
4. Jitter

Introduction

COMPONENTS

A data communications system has five components:

1. Message
2. Sender
3. Receiver
4. Transmission Medium
5. Protocol

Introduction

Data Representation

1. Text
2. Numbers
3. Images
4. Audio
5. Video

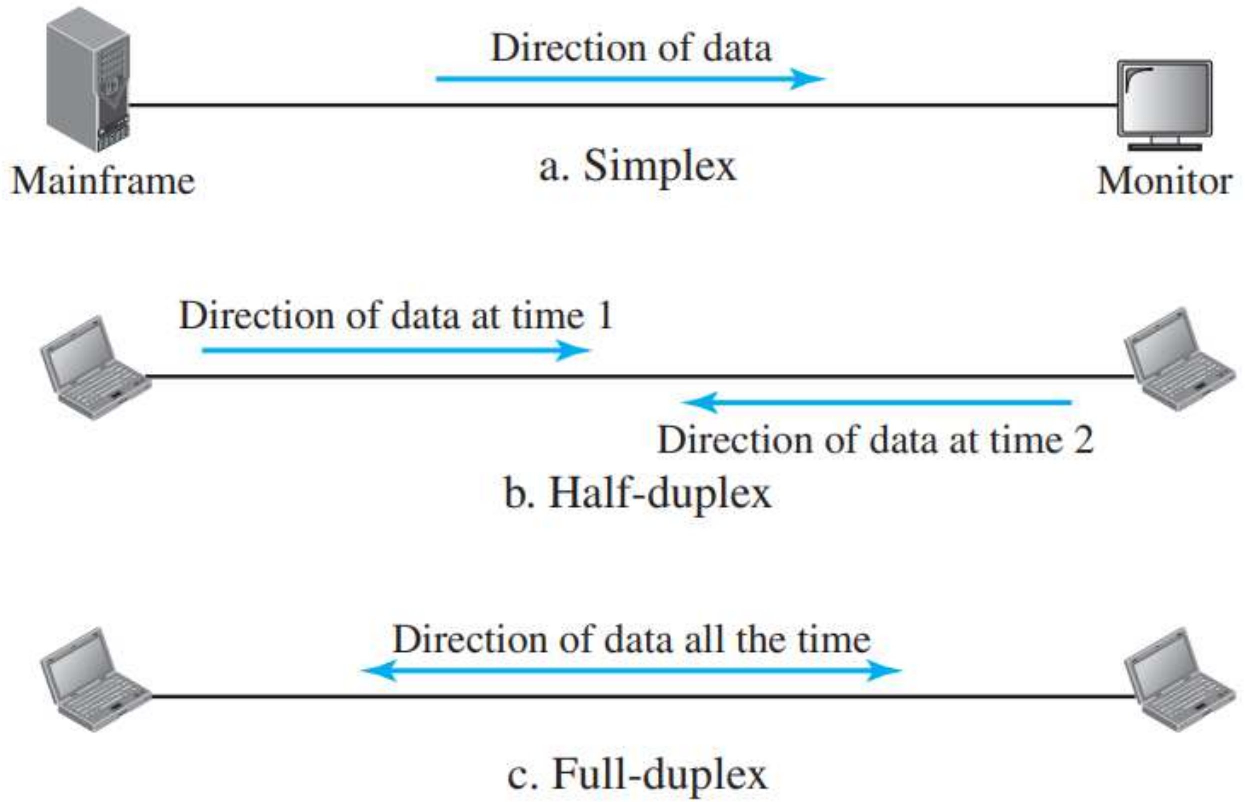
Introduction

Data Flow

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

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.

Keyboards and traditional monitors are examples of simplex devices.


Direction of data
Mainframe
a. Simplex
Monitor
Direction of data at time 1
Direction of data at time 2
b. Half-duplex
Direction of data all the time
c. Full-duplex

Introduction

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.

The half-duplex mode is like a one-lane road with traffic allowed in both directions. When cars are traveling in one direction, cars going the other way must wait.

In a half-duplex transmission, the entire capacity of a channel is taken over by whichever of the two devices is transmitting at the time.

Walkie-talkies and CB (citizens band) radios are both half-duplex systems.

Introduction

In full-duplex mode (also called duplex), both stations can transmit and receive simultaneously.

full-duplex mode is like a two-way street with traffic flowing in both directions at the same time.

In full-duplex mode, signals going in one direction share the capacity of the link with signals going in the other direction.

This sharing can occur in two ways: Either the link must contain two physically separate transmission paths, one for sending and the other for receiving; or the capacity of the channel is divided between signals traveling in both directions.

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

Introduction

NETWORKS

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

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.

Introduction

Network Criteria

1. Performance

    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.

1. 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.

Introduction

Network Criteria

3. 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.

Network Models

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.

When communication is simple, we may need only one simple protocol; when the communication is complex, we may need to divide the task between different layers, in which case we need a protocol at each layer, or protocol layering.

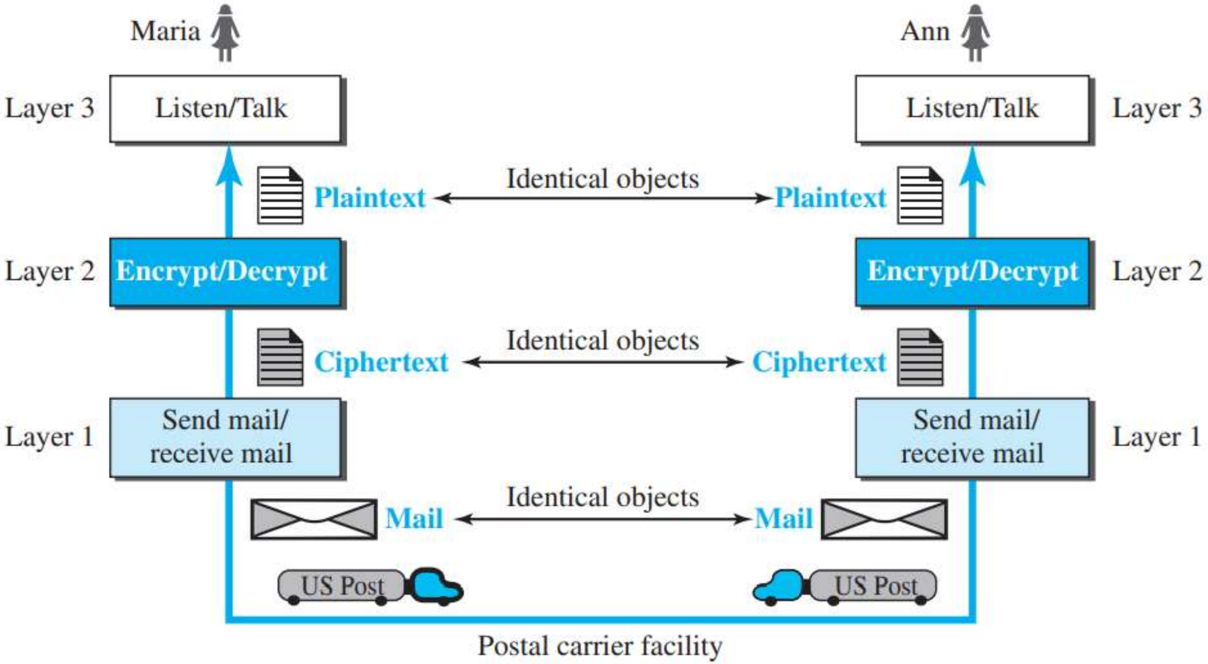
Network Models

Scenarios

In the first scenario, communication is so simple that it can occur in only one layer.

Network Models

Scenario 2:



Principles of Protocol Layering

First Principle

The first principle dictates that if we want bidirectional communication, we need to make each layer so that it is able to perform two opposite tasks, one in each direction.

For example, the third layer task is to listen (in one direction) and talk (in the other direction).

The second layer needs to be able to encrypt and decrypt. The first layer needs to send and receive mail

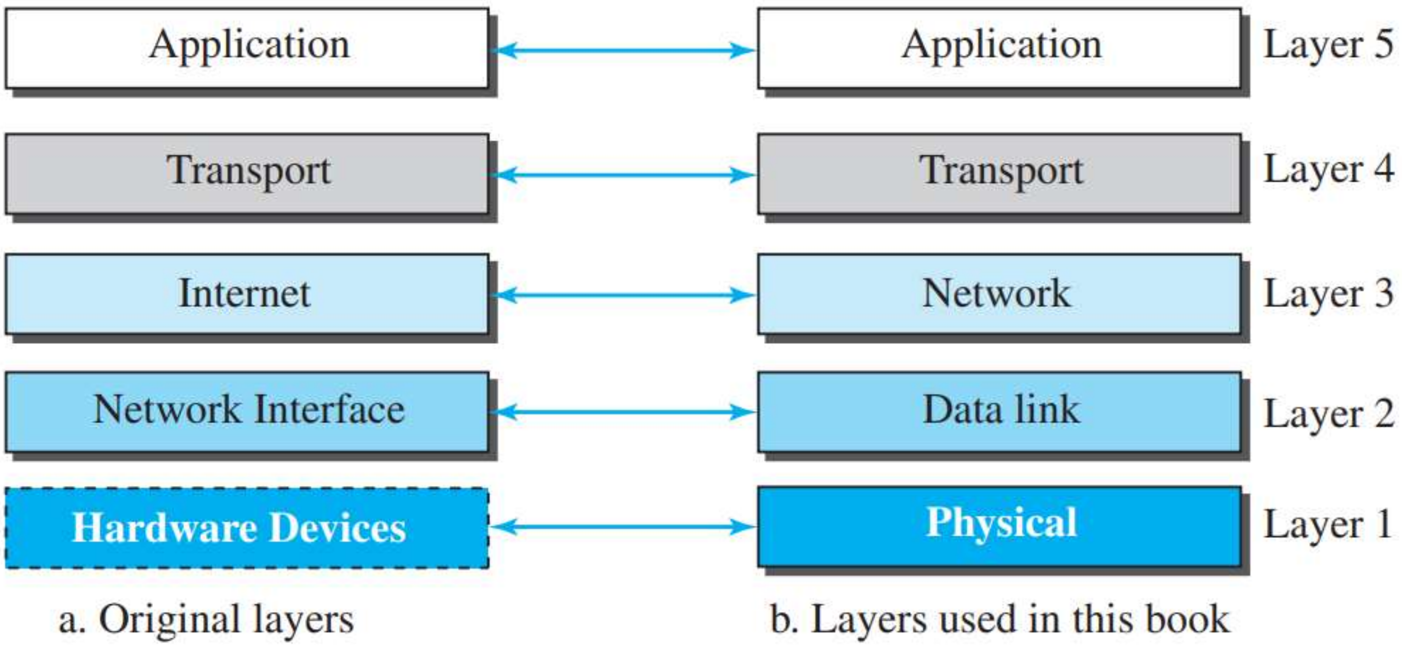
Principles of Protocol Layering

Second Principle

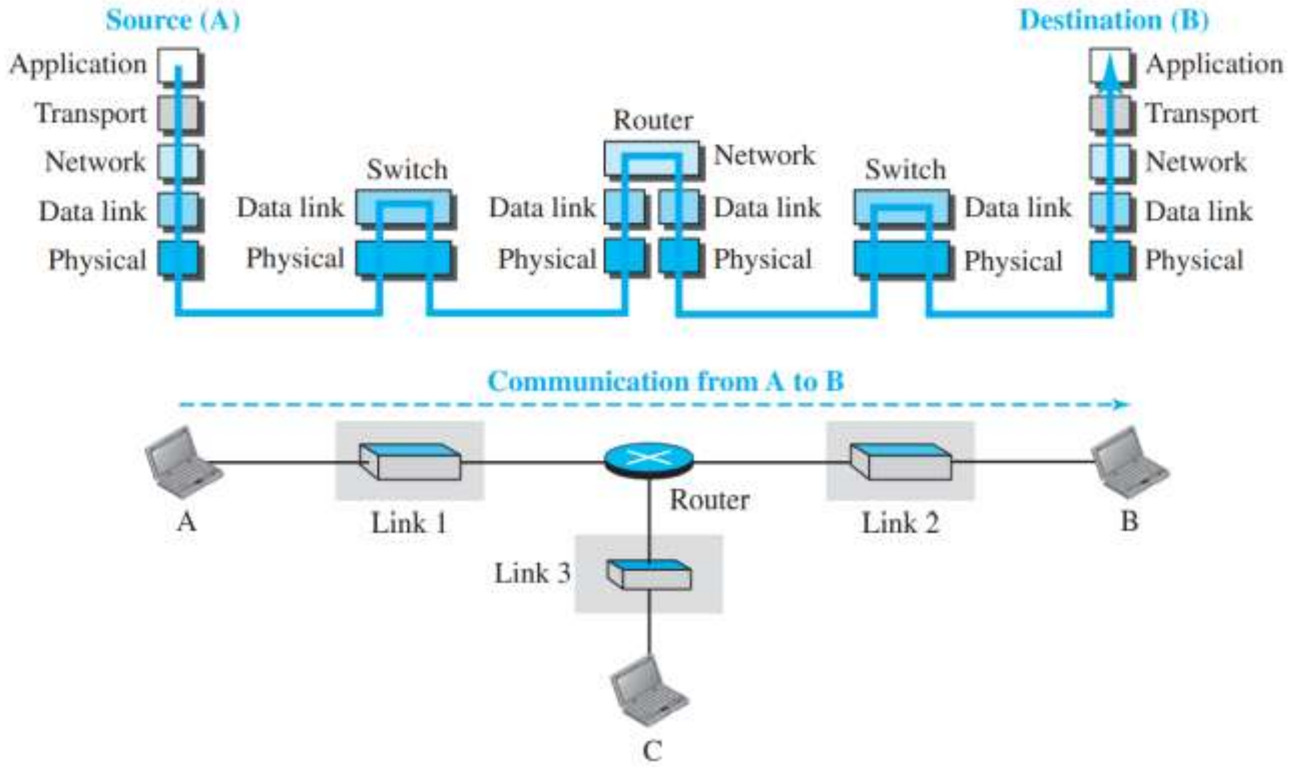
The second principle that we need to follow in protocol layering is that the two objects under each layer at both sites should be identical.

For example, the object under layer 3 at both sites should be a plaintext letter. The object under layer 2 at both sites should be a ciphertext letter. The object under layer 1 at both sites should be a piece of mail.

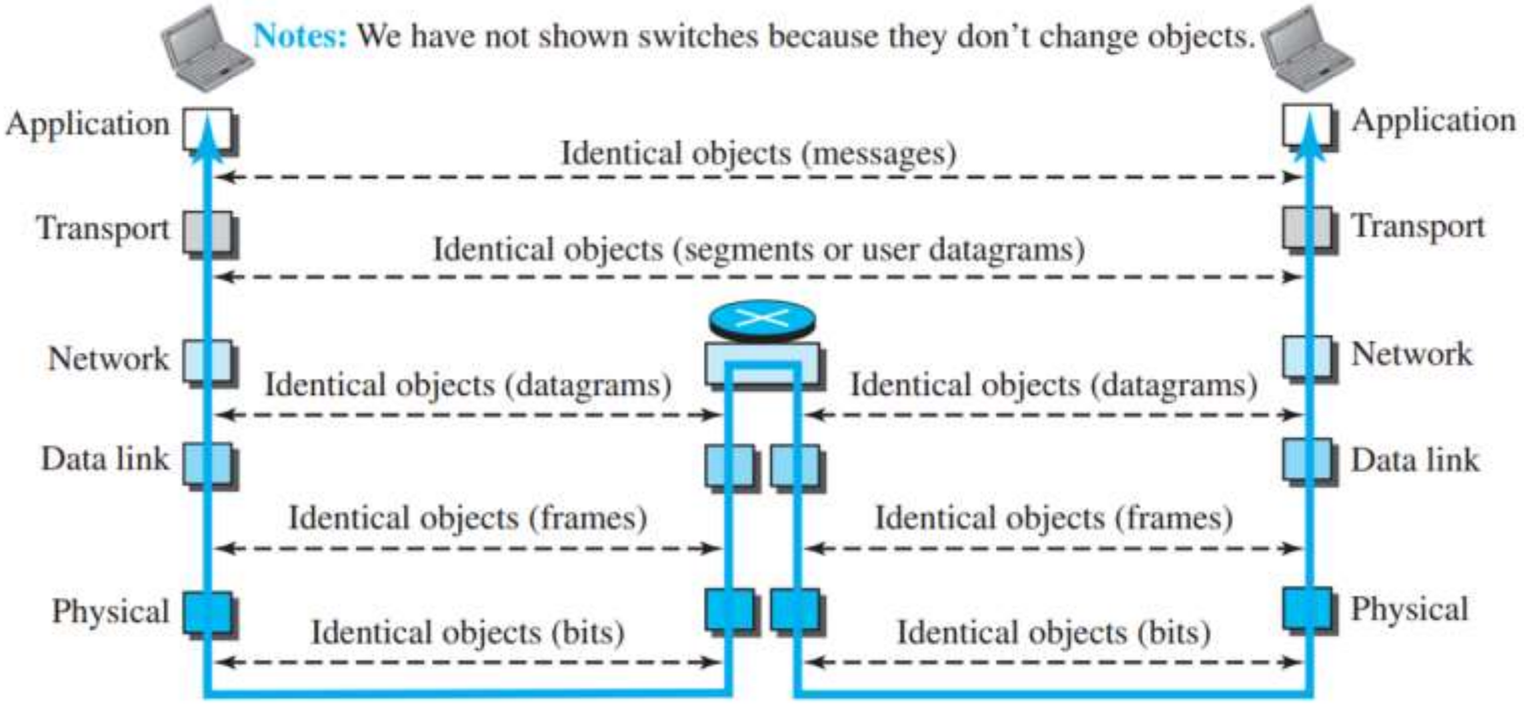
Layers in TCP/IP protocol suite



Communication through Internet



Identical Objects in the TCP/IP protocol suite



Description of each layer

Physical Layer

The physical layer is responsible for carrying individual bits in a frame across the link.

There is another, hidden layer, the transmission media, under the physical layer.

Two devices are connected by a transmission medium (cable or air).

The transmission medium does not carry bits; it carries electrical or optical signals.So the bits received in a frame from the data-link layer are transformed and sent through the transmission media, but we can think that the logical unit between two physical layers in two devices is a bit.

The protocols transforms a bit to signals

Description of each layer

Data Link Layer

An internet is made up of several links (LANs and WANs) connected by routers.

There may be several overlapping sets of links that a datagram can travel from the host to the destination. The routers are responsible for choosing the best links.

When the next link to travel is determined by the router, ***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 data-link layer takes a datagram and encapsulates it in a packet called a frame.

Description of each layer

Network Layer

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.

Since there can be several routers from the source to the destination, the routers in the path are responsible for choosing the best route for each packet.

The network layer is responsible for host-to-host communication and routing the packet through possible routes.

Description of each layer

Network Layer

The network layer in the Internet includes the main protocol, Internet Protocol (IP), that defines the format of the packet, called a datagram at the network layer.

IP also defines the format and the structure of addresses used in this layer.

IP is also responsible for routing a packet from its source to its destination, which is achieved by each router forwarding the datagram to the next router in its path.

IP is a connectionless protocol that provides no flow control, no error control, and no congestion control services. This means that if any of theses services is required for an application, the application should rely only on the transport-layer protocol.

The network layer also includes unicast (one-to-one) and multicast (one-to-many) routing protocols.

A routing protocol does not take part in routing (it is the responsibility of IP), but it creates forwarding tables for routers to help them in the routing process.

Description of each layer

Network Layer

The network layer also has some auxiliary protocols that help IP in its delivery and routing tasks.

The Internet Control Message Protocol (ICMP) helps IP to report some problems when routing a packet.

The Internet Group Management Protocol (IGMP) is another protocol that helps IP in multitasking.

The Dynamic Host Configuration Protocol (DHCP) helps IP to get the network-layer address for a host.

The Address Resolution Protocol (ARP) is a protocol that helps IP to find the link-layer address of a host or a router when its network-layer address is given.

Description of each layer

Transport Layer

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.

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.

Description of each layer

Transport Layer

The main protocol, ***Transmission Control Protocol (TCP),*** is a connection-oriented protocol that first establishes a logical connection between transport layers at two hosts before transferring data. It creates a logical pipe between two TCPs for transferring a stream of bytes.

TCP provides ***flow control*** (matching the sending data rate of the source host with the receiving data rate of the destination host to prevent overwhelming the destination),

error control (to guarantee that the segments arrive at the destination without error and resending the corrupted ones),

and ***congestion control*** to reduce the loss of segments due to congestion in the network.

Description of each layer

Transport Layer

The other common protocol, ***User Datagram Protocol (UDP)***, is a ***connectionless protocol*** that transmits user datagrams without first creating a logical connection.

In UDP, each user datagram is an independent entity without being related to the previous or the next one (the meaning of the term connectionless).

UDP is a simple protocol that does not provide flow, error, or congestion control.

Description of each layer

Application Layer

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, we should know that the communication is done through all the layers.

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

To communicate, a process sends a request to the other process and receives a response.

Process-to-process communication is the duty of the application layer.

Description of each layer

Application Layer

The Hypertext Transfer Protocol (HTTP) is a vehicle for accessing the World Wide Web (WWW).

The Simple Mail Transfer Protocol (SMTP) is the main protocol used in electronic mail (e-mail) service.

The File Transfer Protocol (FTP) is used for transferring files from one host to another.

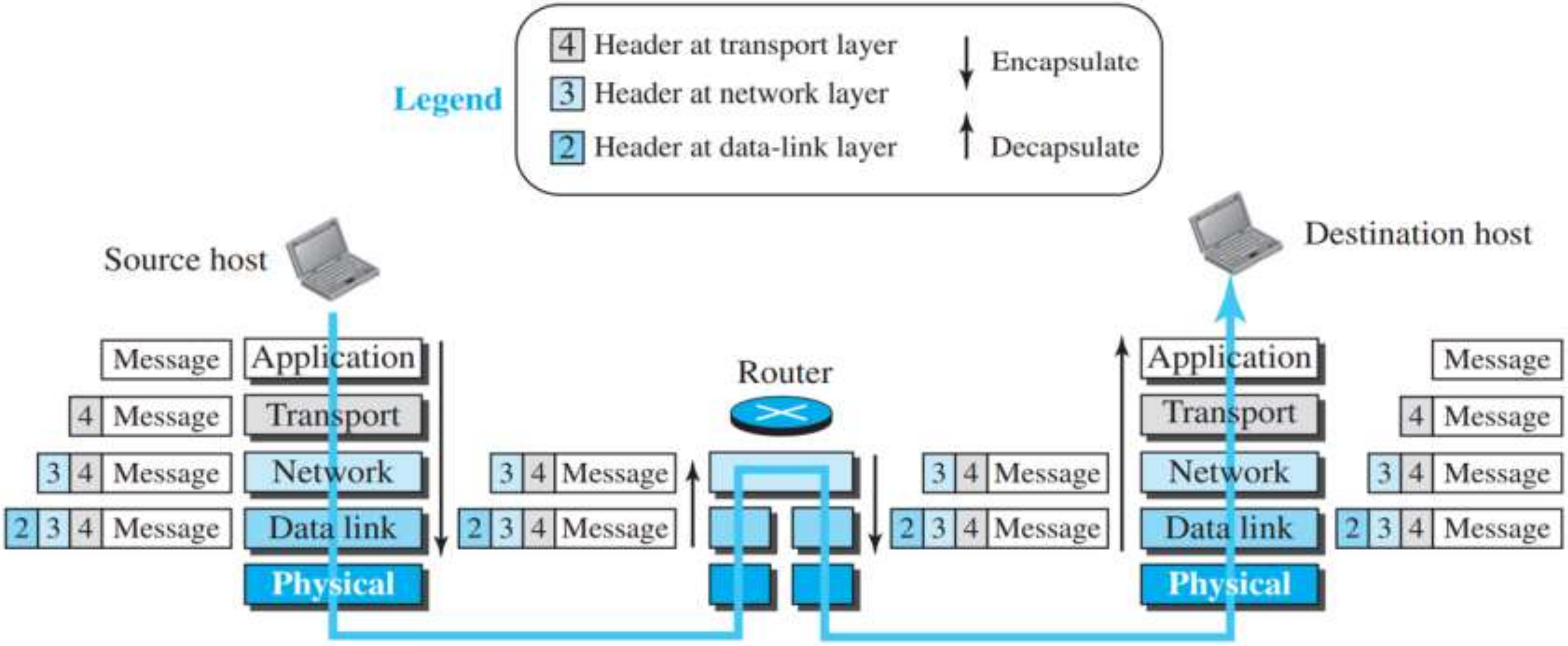
The Terminal Network (TELNET) and Secure Shell (SSH) are used for accessing a site remotely.

The Simple Network Management Protocol (SNMP) is used by an administrator to manage the Internet at global and local levels.

The Domain Name System (DNS) is used by other protocols to find the network-layer address of a computer.

The Internet Group Management Protocol (IGMP) is used to collect membership in a group.

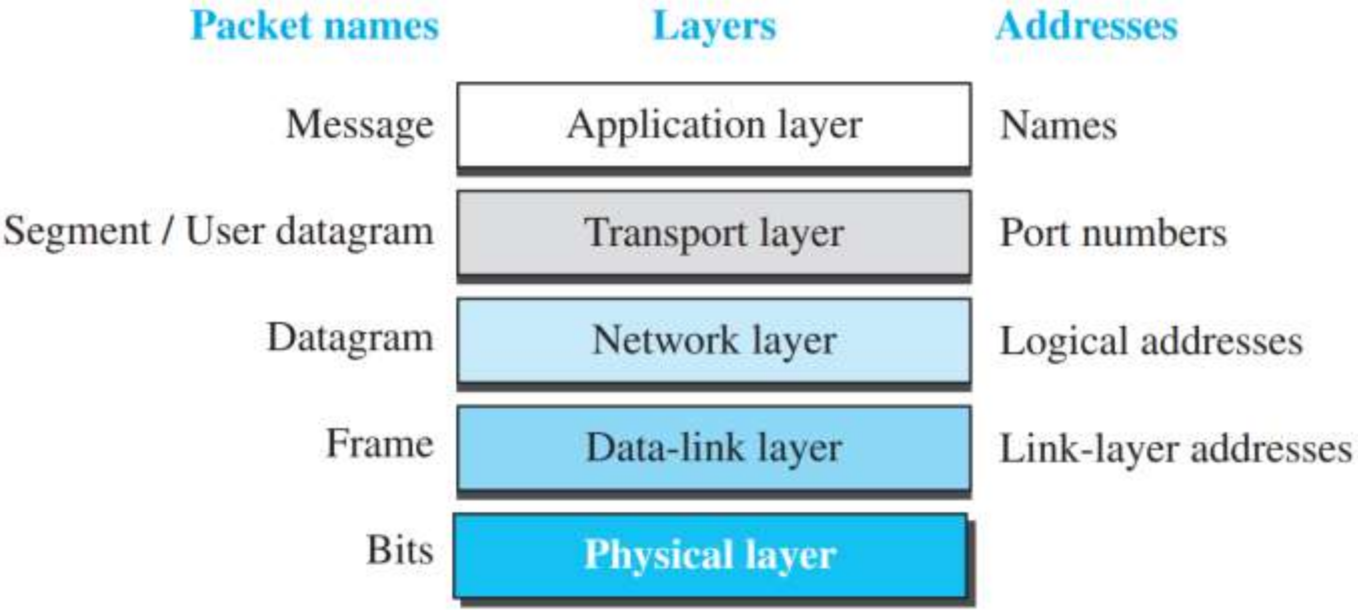
Encapsulation/Decapsulation



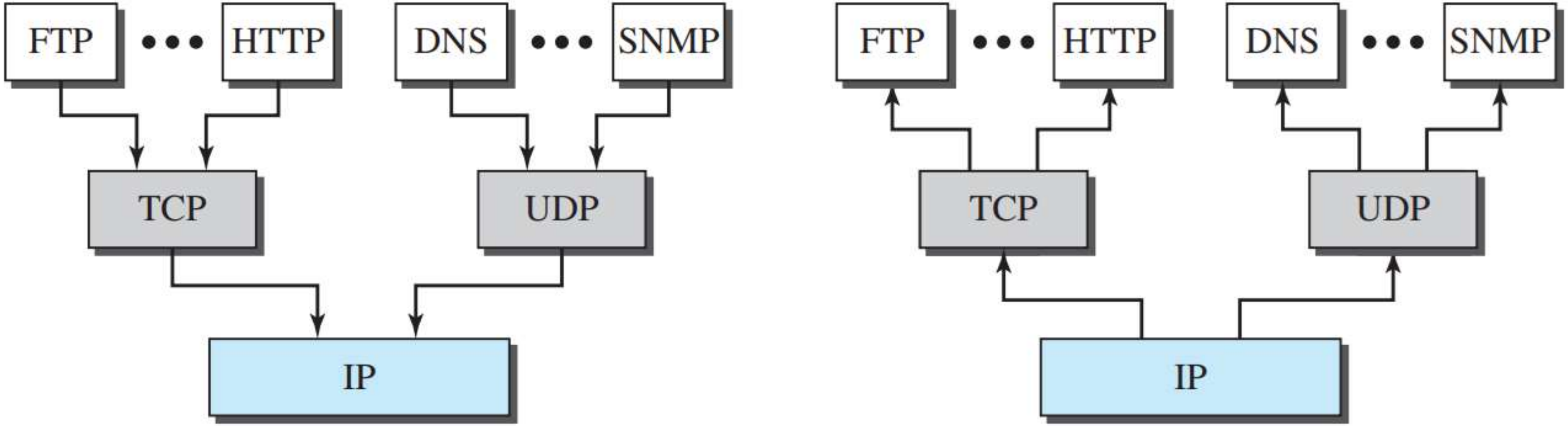
Addressing

Any communication that involves two parties needs two addresses:

Source address and Destination address.



Multiplexing and Demultiplexing



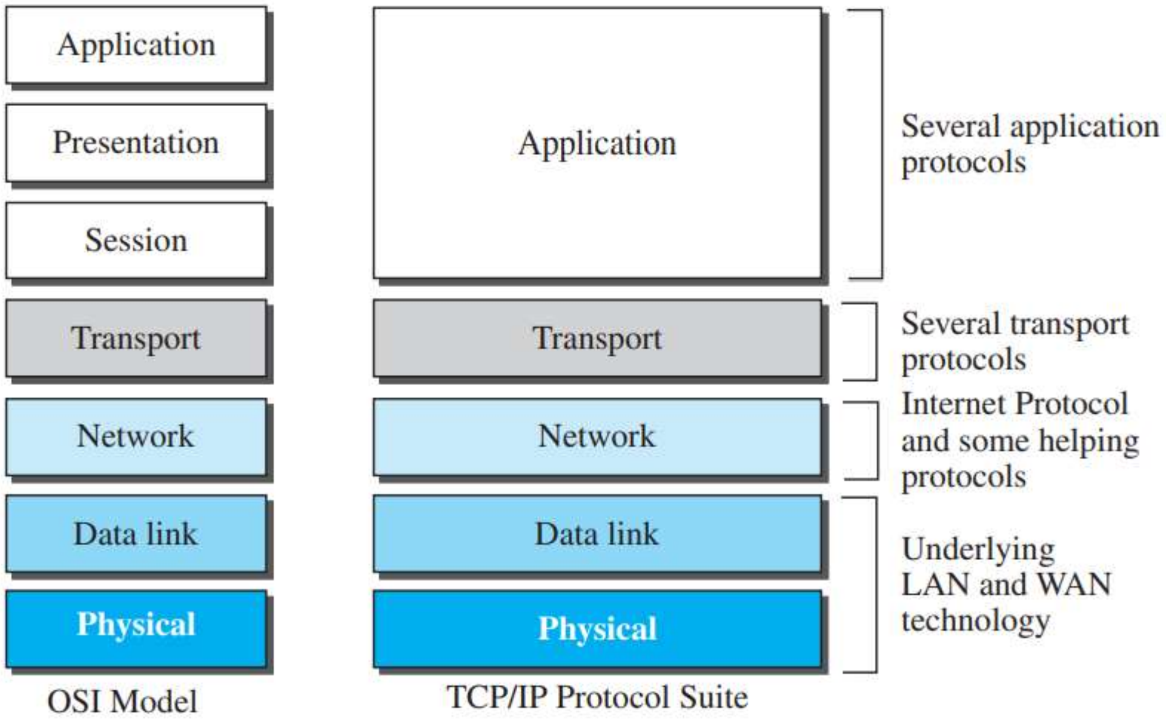
a. Multiplexing at source

b. Demultiplexing at destination

OSI Reference Model

Layer		Description	Protocols / Function
7 - Application		Software that is requesting or receiving a network communication	Web browser, e-mail client, FTP client, etc.
6 - Presentation		Responsable for translating between software encoding and human readable format	DOC, JPG, GIF, XLS, WRI, etc.
5 - Session		Establishes a logical connection between software endpoints	FTP (20/21), SSH (22), HTTP (80), HTTPS (443), NTP (123)
4 - Transport		Segments traffic for reliable or best effort transmission between hosts.	TCP, UDP, SPX
3 - Network		Configures packets for intra-subnet and inter-subnet communications	IPv4, IPv6 , IPX
2 – Data Link	LLC MAC	Applies physical addresses to the data creating a switchable frame.	MAC addresses
1 - Physical		Converts the data into the format appropriate for the associated media.	Hubs, fiber optics, copper, electricity, RF

TCP/IP vs ISO/OSI Model



TCP/IP	OSI Model	Protocols
Application Layer	Application Layer	DNS, DHCP, FTP, HTTPS, IMAP, LDAP, NTP,POP3, RTP, RTSP, SSH, SIP, SMTP, SNMP, Telnet, TFTP
	Presentation Layer	JPEG, MIDI, MPEG, PICT, TIFF
	Session Layer	NetBIOS, NFS, PAP, SCP, SQL, ZIP
Transport Layer	Transport Layer	TCP, UDP
Internet Layer	Network Layer	ICMP, IGMP, IPsec, IPv4, IPv6, IPX, RIP
Link Layer	Data Link Layer	ARP, ATM, CDP, FDDI, Frame Relay, HDLC, MPLS, PPP, STP, Token Ring
	Physical Layer	Bluetooth, Ethernet, DSL, ISDN, 802.11 Wi-Fi

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.

Analog and Digital signals

Like the data they represent, signals can be either analog or digital.

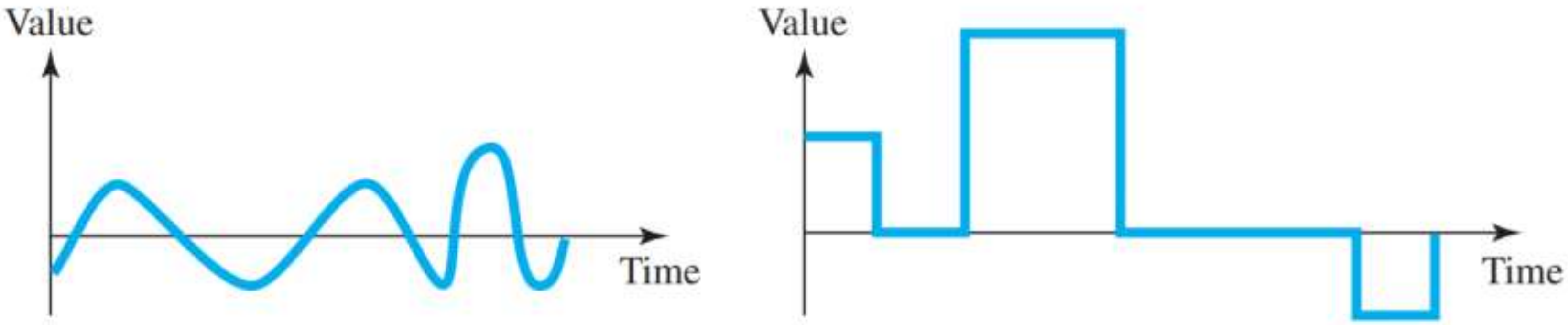
An analog signal has infinitely many levels of intensity over a period of time. As the wave moves from value A to value B, it passes through and includes an infinite number of values along its path.

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 0.

Analog and Digital signals

The simplest way to show signals is by plotting them on a pair of perpendicular axes.

The vertical axis represents the value or strength of a signal. The horizontal axis represents time.



a. Analog signal

b. Digital signal

Periodic and Non-periodic

Both analog and digital signals can take one of two forms: ***periodic or nonperiodic***

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.

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

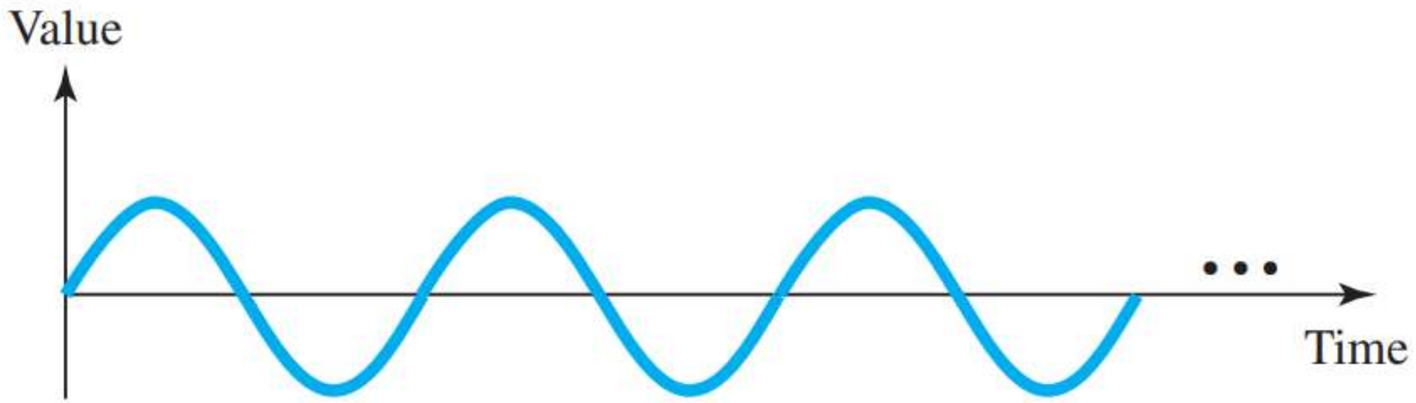
A composite periodic analog signal is composed of multiple sine waves.

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.

A Sine wave can be represented by three parameters: the peak amplitude, the frequency, and the phase. These three parameters fully describe a sine wave.



Sine Wave

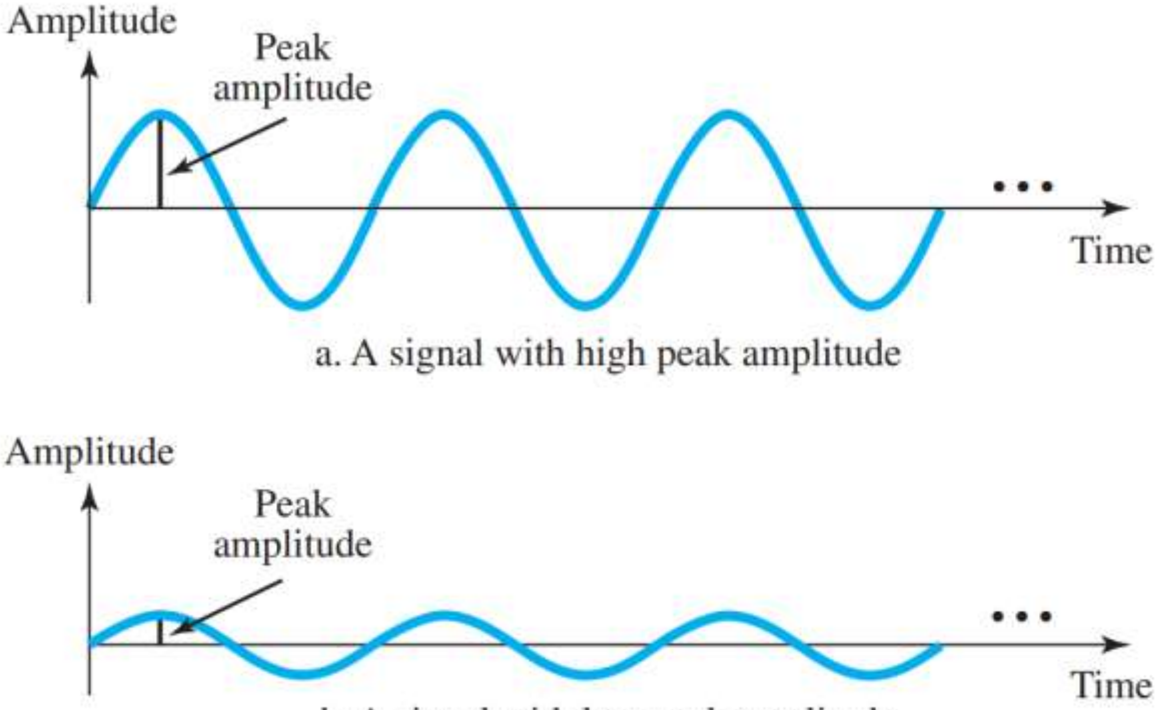
Peak Amplitude

The peak amplitude of a signal is the absolute value of its highest intensity, proportional to the energy it carries.

For electric signals, peak amplitude is normally measured in volts.

Eg; The voltage of a battery is a constant; this constant value can be considered 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

Sine Wave

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.

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

Sine Wave

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

Sine Wave

Period and frequency

The power we use at home has a frequency of 60 Hz (50 Hz in Europe). Calculate the period of this sine wave.

Sine Wave

Period and frequency

The power we use at home has a frequency of 60 Hz (50 Hz in Europe). Calculate the period of this sine wave.

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

Sine Wave

Period and frequency

Express a period of 100 ms in microseconds.

Sine Wave

Period and frequency

Express a period of 100 ms in microseconds.

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 100 \times 10^{-3} \times 10^{6} \ \mu\text{s} = 10^{2} \times 10^{-3} \times 10^{6} \ \mu\text{s} = 10^{5} \ \mu\text{s}$$

Sine Wave

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

Sine Wave

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).

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

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

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

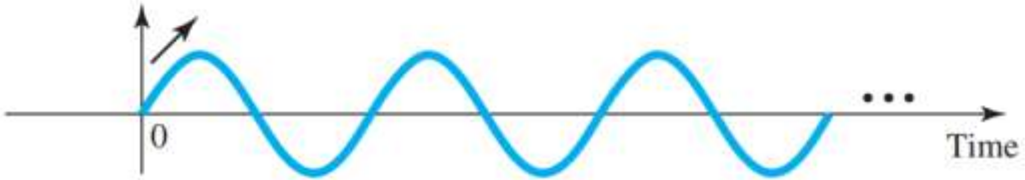
Phase is measured in degrees or radians [360° is 2π rad; 1° is 2π/360 rad, and 1 rad is 360/(2π)].

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

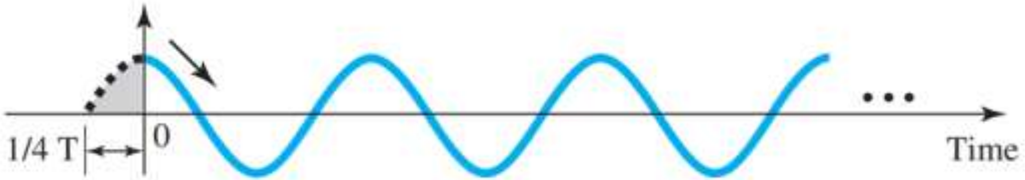
a phase shift of 180° corresponds to a shift of one-half of a period;

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

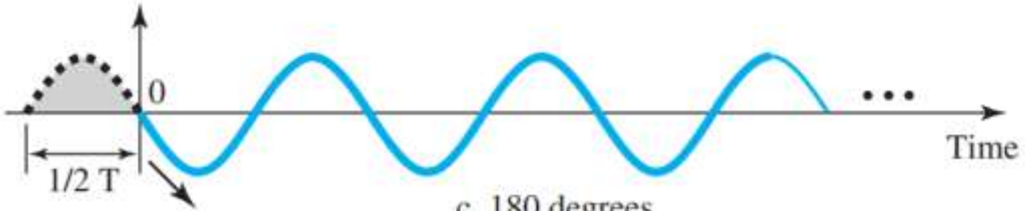
Three sine waves with the same amplitude and frequency, but different phases



a. 0 degrees



b. 90 degrees



c. 180 degrees

Phase

Looking at Figure, we can say that

1. A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.
2. A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.
3. A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.

Another way to look at the phase is in terms of shift or offset. We can say that

1. A sine wave with a phase of 0° is not shifted.
2. A sine wave with a phase of 90° is shifted to the left by cycle. However, note that the signal does not really exist before time 0.
3. A sine wave with a phase of 180° is shifted to the left by cycle. However, note that the signal does not really exist before time 0.

Phase

Example:

A sine wave is offset ⅙ cycle with respect to time 0. What is its phase in degrees and radians?

Phase

Example:

A sine wave is offset ⅙ cycle with respect to time 0. What is its phase in degrees and radians?

Solution

We know that 1 complete cycle is 360°. Therefore, $\frac{1}{6}$ cycle is

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

Wavelength

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.

While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium.

The wavelength is the distance a simple signal can travel in one period.

Wavelength

Wavelength can be calculated if one is given the propagation speed (the speed of light) and the period of the signal.

However, since period and frequency are related to each other, if we represent ***wavelength by λ***, propagation speed by ***c (speed of light)***, and ***frequency by f,*** we get

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

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

Wavelength

The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal.

For example, in a vacuum, light is propagated with a speed of 3 × 10^8 m/s. ***That speed is lower in air and even lower in cable.***

The wavelength is normally measured in micrometers (microns) instead of meters.

For example, the wavelength of red light (frequency = 4 × 1014) in air is,

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{4 \times 10^{14}} = 0.75 \times 10^{-6}\ \mathrm{m} = 0.75\ \mu\mathrm{m}$$

Bandwidth

The range of frequencies contained in a composite signal is its bandwidth.

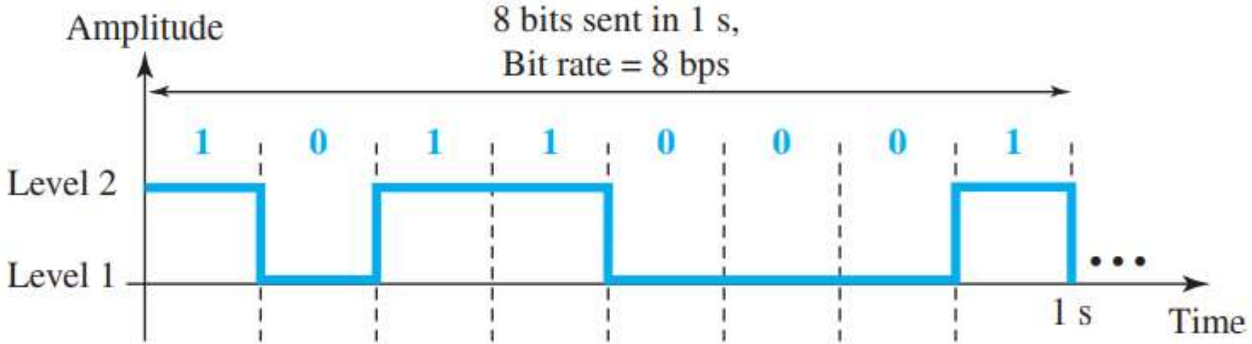
The bandwidth is normally a difference between two numbers.

For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 – 1000, or 4000.

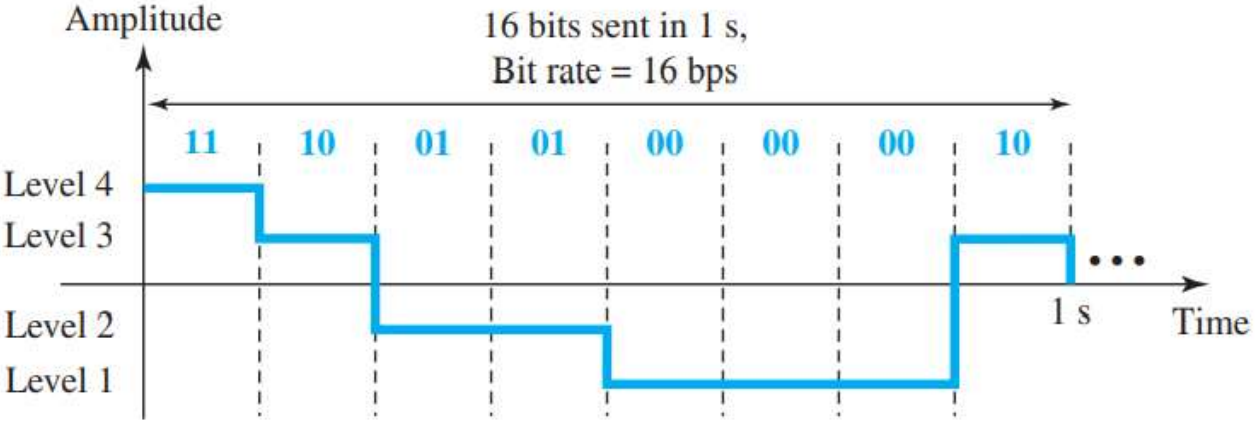
The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

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.



a. A digital signal with two levels



b. A digital signal with four levels

DIGITAL SIGNALS

In general, if a signal has L levels, each level needs log2 L bits.

For this reason, we can send log24 = 2 bits in part b.

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 1s, expressed in bits per second (bps).

Bit Length

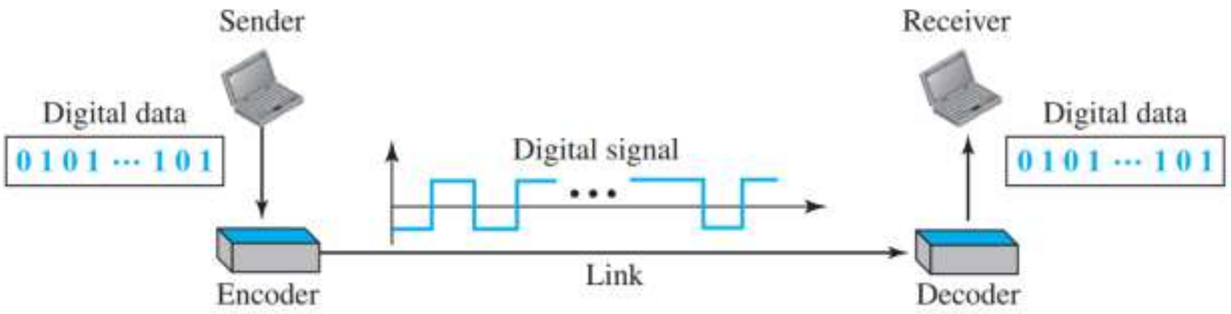
The bit length is the distance one bit occupies on the transmission medium.

$$\textbf{Bit length} = \textbf{propagation speed} \times \textbf{bit duration}$$

Digital Transmission

DIGITAL TO DIGITAL CONVERSION

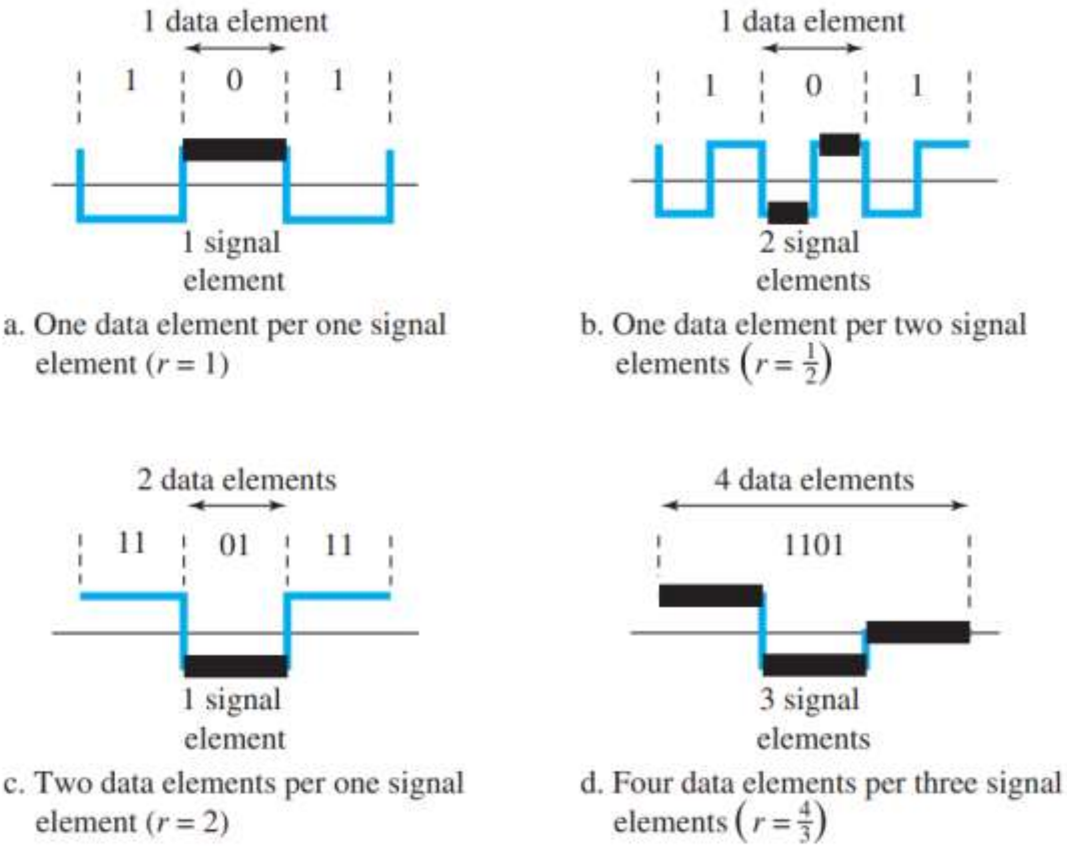
1. **Line Coding**
    a. Line coding is the process of converting digital data to digital signals.
    b. Line coding converts a sequence of bits to a digital signal.
    c. At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal.



DIGITAL TO DIGITAL CONVERSION

Characteristics:

1. Signal Element Versus Data Element
   a. In data communications, our goal is to send data elements.
   b. A data element is the smallest entity that can represent a piece of information: ***this is the bit.***
   c. In digital data communications, a signal element carries data elements.
   d. A signal element is the shortest unit (timewise) of a digital signal.
   e. 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.



a. One data element per one signal element ($r = 1$)

b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$

c. Two data elements per one signal element ($r = 2$)

d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

DIGITAL TO DIGITAL CONVERSION

- We define a ratio ***r*** which is the number of data elements carried by each signal element.
- The figure above shows several situations with different values of ***r.***
- Suppose each data element is a person who needs to be carried from one place to another. We can think of a signal element as a vehicle that can carry people.
- When r = 1, it means each person is driving a vehicle. When r > 1, it means more than one person is travelling in a vehicle (a carpool, for example). We can also have the case where one person is driving a car and a trailer (r = 1/2).

DIGITAL TO DIGITAL CONVERSION

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.
- ➢ 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***.

DIGITAL TO DIGITAL CONVERSION

- 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.
- Consider the relationship between data rate (N) and signal rate (S)

$$\mathbf{S = N/r}$$

- Here ***r*** has been previously defined.
- This relationship, of course, depends on the value of r.
- It also depends on the data pattern.

DIGITAL TO DIGITAL CONVERSION

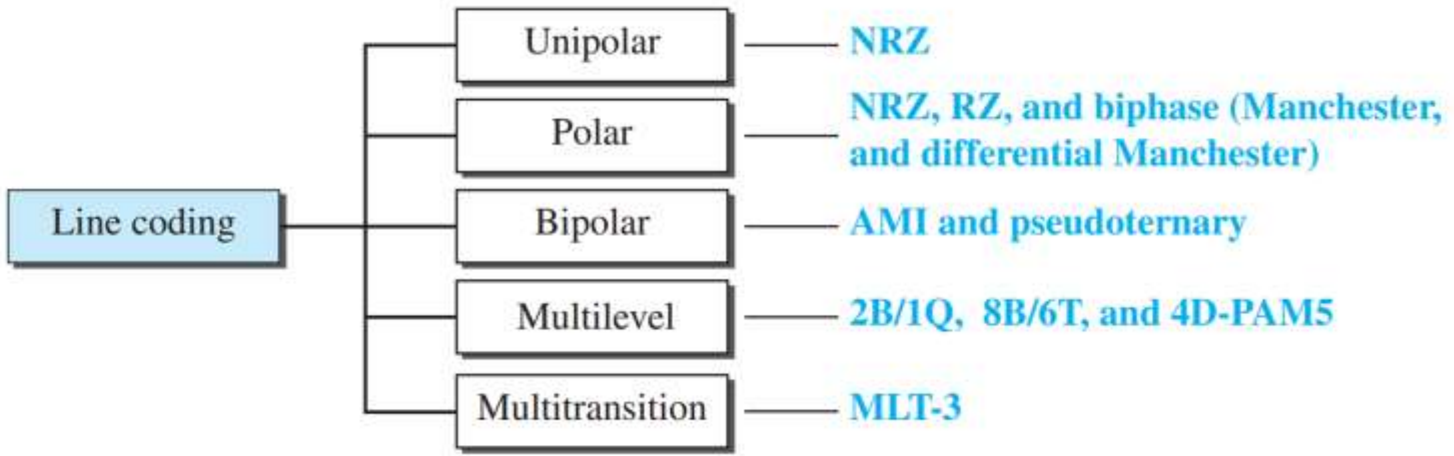
We can formulate the relationship between data rate and signal rate as

$$S_{ave} = c \times N \times (1/r) \textit{ baud}$$

- where N is the data rate (bps);
- c is the case factor, which varies for each case;
- S is the number of signal elements per second;
- and r is the previously defined factor.

Line Coding Schemes

- We can roughly divide line coding schemes into five broad categories.
- There are several schemes in each category.



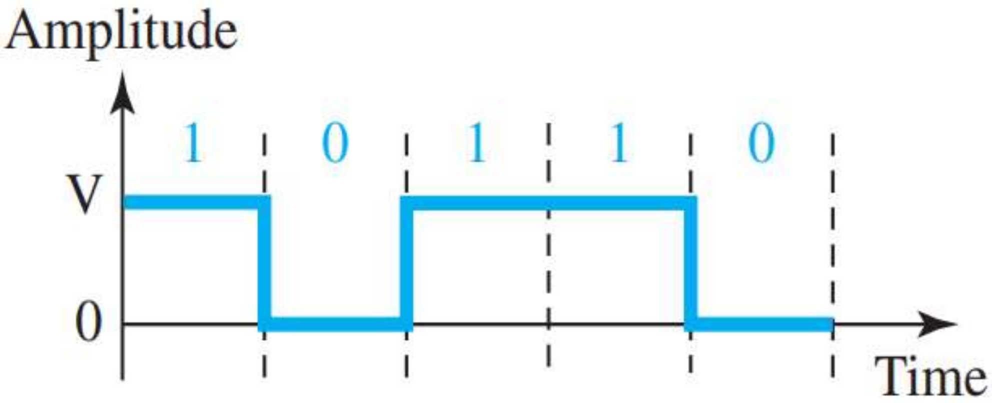
Line Coding Schemes

1. **Unipolar Scheme**

In a unipolar scheme, all the signal levels are on one side of the time axis, either above or below.

- ***NRZ (Non-Return-to-Zero)***
    - Traditionally, a unipolar scheme was designed as a non-return-to-zero (NRZ) scheme in which the ***positive voltage defines bit 1 and the zero voltage defines bit 0***.
    - It is called NRZ because the signal does not return to zero at the middle of the bit.

Line Coding Schemes



$$\frac{1}{2}V^2 + \frac{1}{2}(0)^2 = \frac{1}{2}V^2$$

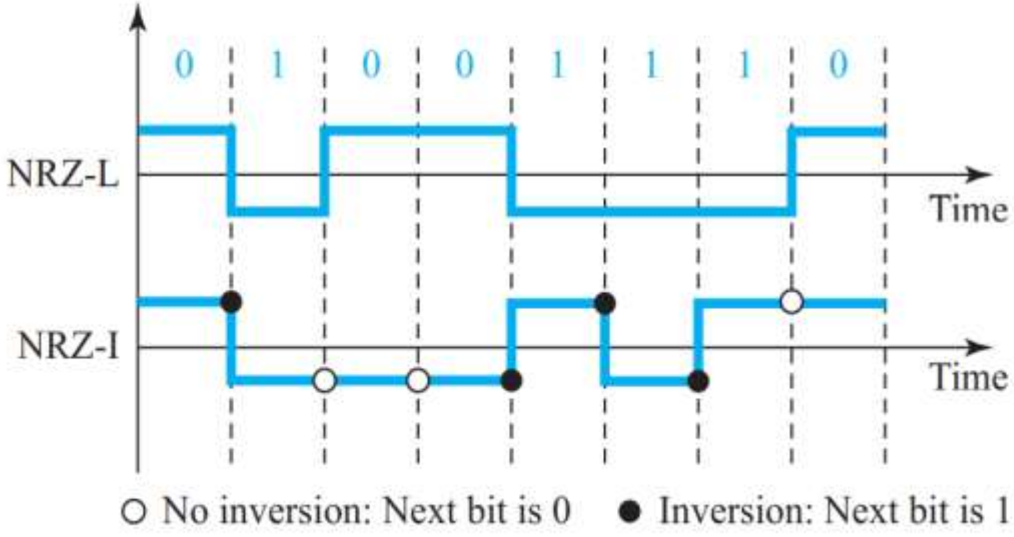
Normalized power

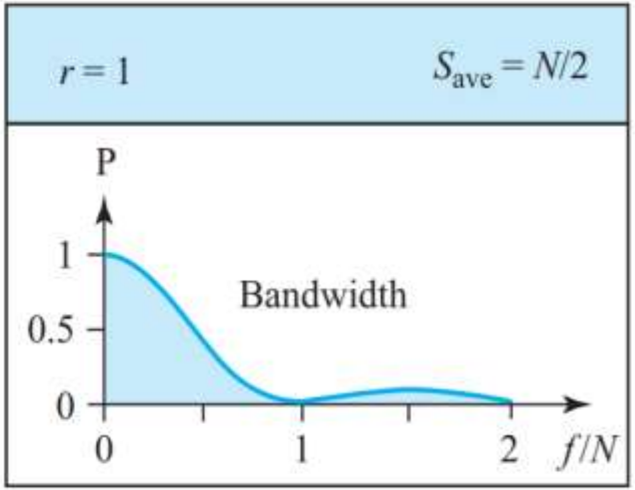
Line Coding Schemes

2. Polar Schemes

- In polar schemes, the voltages are on both sides of the time axis.
- For example, the voltage level for ***0 can be positive*** and the voltage level for ***1 can be negative***.
    - **Non-Return-to-Zero (NRZ)**
        - In polar NRZ encoding, we use two levels of voltage amplitude.
        - We can have two versions of polar NRZ: ***NRZ-L and NRZ-I***.

Line Coding Schemes





Non-Return-to-Zero (NRZ)

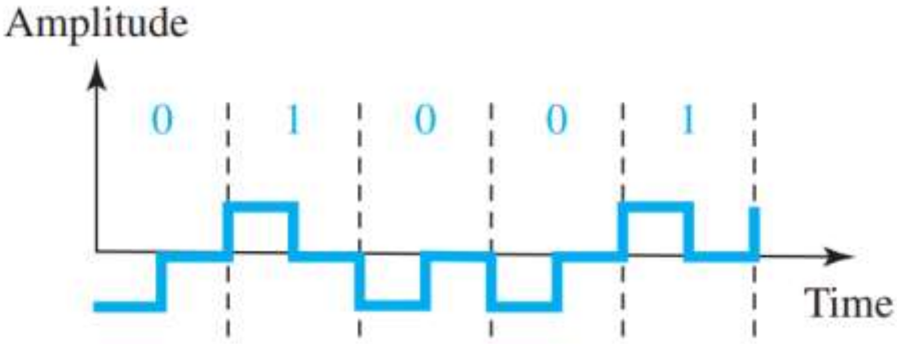
- In the first variation, NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit.
- In the second variation, NRZ-I (NRZ-Invert), the change or lack of change in the level of the voltage determines the value of the bit. If there is no change, the bit is 0; if there is a change, the bit is 1.
- Both schemes have an average signal rate of ***N/2 Bd***.

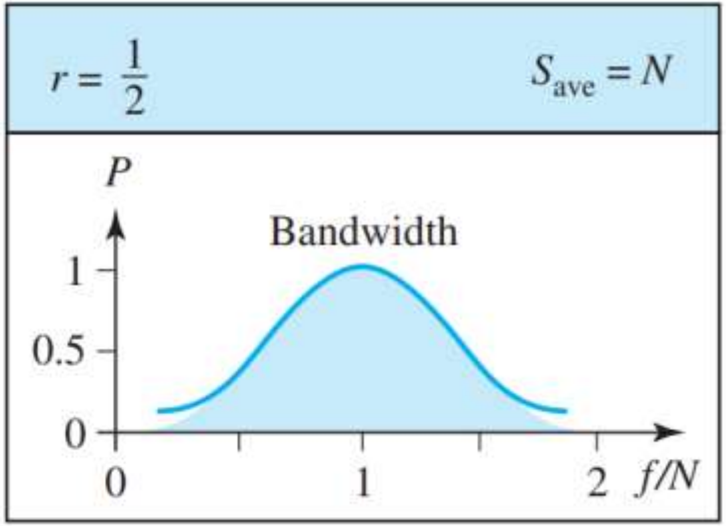
In NRZ-L the level of the voltage determines the value of the bit. In NRZ-I the inversion or the lack of inversion determines the value of the bit.

Return-to-Zero (RZ)

- ➢ The main problem with NRZ encoding occurs when the sender and receiver clocks are not synchronized.
- ➢ The receiver does not know when one bit has ended and the next bit is starting.
- ➢ One solution is the return-to-zero (RZ) scheme, which uses three values:
  - Positive,
  - Negative, and
  - Zero.
- ➢ In RZ, the signal changes not between bits but during the bit.

Return-to-Zero (RZ)





Return-to-Zero (RZ)

- ➢ Here we can see that the signal goes to 0 in the middle of each bit.
- ➢ It remains there until the beginning of the next bit.
- ➢ The main disadvantage of RZ encoding is that it requires two signal changes to encode a bit and therefore occupies greater bandwidth.

Return-to-Zero (RZ)

- ➢ The same problem we mentioned, a sudden change of polarity resulting in all 0s interpreted as 1s and all 1s interpreted as 0s, still exists here, but there is no DC component problem.
- ➢ Another problem is the complexity: RZ uses three levels of voltage, which is more complex to create and discern.
- ➢ As a result of all these deficiencies, the scheme is not used today.

Biphase: Manchester and Differential Manchester

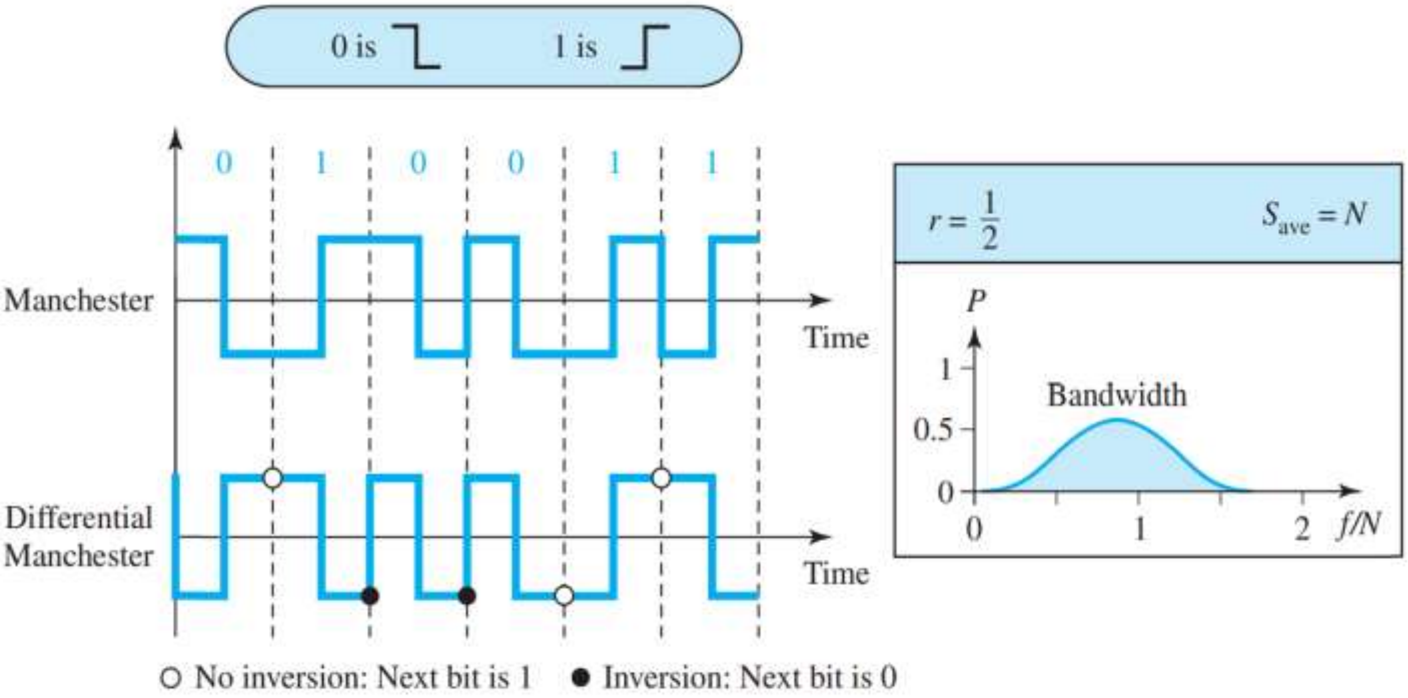
- ➢ The idea of RZ (transition at the middle of the bit) and the idea of NRZ-L are combined into the Manchester scheme.
- ➢ In Manchester encoding, the duration of the bit is divided into two halves.
- ➢ The voltage remains at one level during the first half and moves to the other level in the second half.
- ➢ The transition at the middle of the bit provides synchronization.

Biphase: Manchester and Differential Manchester

- Differential Manchester, on the other hand, combines the ideas of RZ and NRZ-I.
- There is always a transition at the middle of the bit, but the bit values are determined at the beginning of the bit.
- If the next bit is 0, there is a transition; if the next bit is 1, there is none.

The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.

Biphase: Manchester and Differential Manchester



2. Block Coding

- We need redundancy to ensure synchronization and to provide some kind of inherent error detecting.
- Block coding can give us this redundancy and improve the performance of line coding.
- In general, block coding changes a block of ***m*** bits into a block of ***n*** bits, where ***n*** is larger than ***m***.
- Block coding is referred to as an ***mB/nB*** encoding technique.

ANALOG-TO-DIGITAL CONVERSION

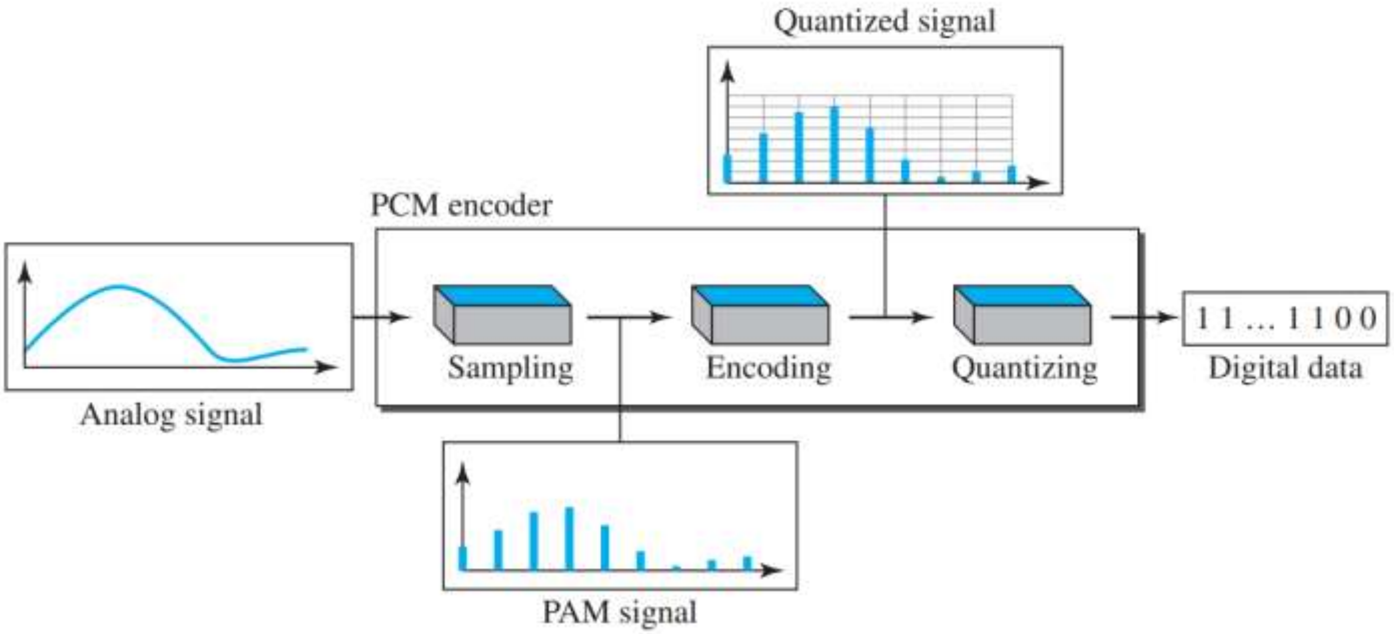
1. **Pulse Code Modulation (PCM)**
2. **Delta Modulation (DM)**

Pulse Code Modulation (PCM)

The most common technique to change an analog signal to digital data (digitization) is called pulse code modulation (PCM).

1. *The analog signal is sampled.*
2. *The sampled signal is quantized.*
3. *The quantized values are encoded as streams of bits.*

Pulse Code Modulation (PCM)



Pulse Code Modulation (PCM)

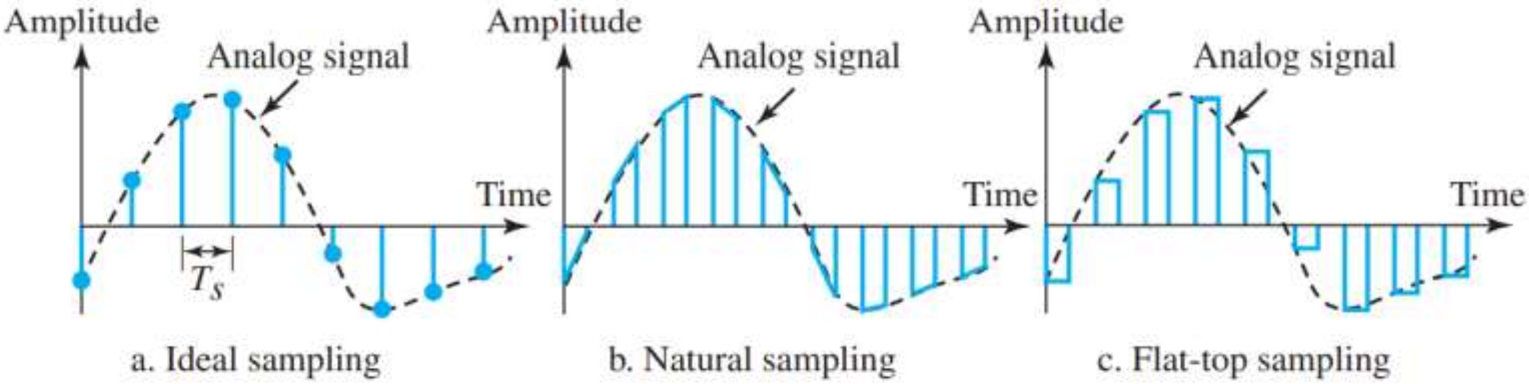
Sampling

- The first step in PCM is sampling.
- The analog signal is sampled every T_s s, where T_s is the sample interval or period.
- The inverse of the sampling interval is called the sampling rate or sampling frequency and denoted by f_s, where $f_s = 1/T_s$.
- There are three sampling methods—ideal, natural, and flat-top.

Pulse Code Modulation (PCM)

- In ideal sampling, pulses from the analog signal are sampled.
- This is an ideal sampling method and cannot be easily implemented.
- In natural sampling, a high-speed switch is turned on for only the small period of time when the sampling occurs.
- The result is a sequence of samples that retains the shape of the analog signal.
- The most common sampling method, called sample and hold, however, creates flat-top samples by using a circuit.

Pulse Code Modulation (PCM)



Pulse Code Modulation (PCM)

Quantization

- ➢ The result of sampling is a series of pulses with amplitude values between the maximum and minimum amplitudes of the signal.
- ➢ The set of amplitudes can be infinite with non integral values between the two limits.

Pulse Code Modulation (PCM)

Quantization

These values cannot be used in the encoding process. The following are the steps in quantization:

1. We assume that the original analog signal has instantaneous amplitudes between V_{min} ***and*** V_{max}.
2. We divide the range into L zones, each of height Δ (delta).

$$\Delta = \frac{V_{max} - V_{min}}{L}$$

Pulse Code Modulation (PCM)

Quantization

3. We assign quantized values of 0 to L – 1 to the midpoint of each zone.
4. We approximate the value of the sample amplitude to the quantized values.

Example, assume that we have a sampled signal and the sample amplitudes are between −20 and +20 V. We decide to have eight levels ($L = 8$). This means that $\Delta = 5$ V.

Pulse Code Modulation (PCM)

Encoding

- The last step in PCM is encoding.
- After each sample is quantized and the number of bits per sample is decided, each sample can be changed to an n_b-bit code word.
- A quantization code of 2 is encoded as 010; 5 is encoded as 101; and so on.
- If the number of quantization levels is L, the number of bits is

  $n_b = \log_2 L$. In our example L is 8 and nb is therefore 3.

Pulse Code Modulation (PCM)

The bit rate can be found from the formula

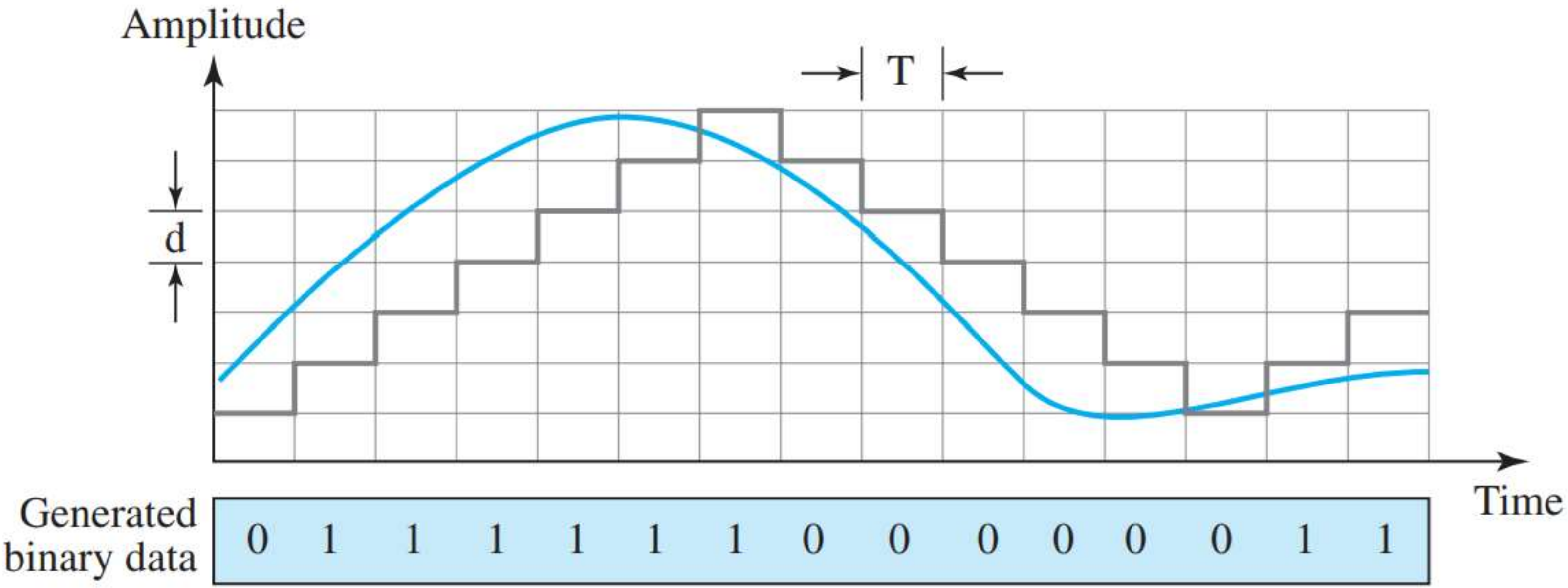
Bit rate = sampling rate* x *number of bits per sample

$$= f_s \times n_b$$

Delta Modulation (DM)

- PCM is a very complex technique.
- Other techniques have been developed to reduce the complexity of PCM.
- The simplest is delta modulation.
- PCM finds the value of the signal amplitude for each sample;
- DM finds the change from the previous sample.

Delta Modulation (DM)

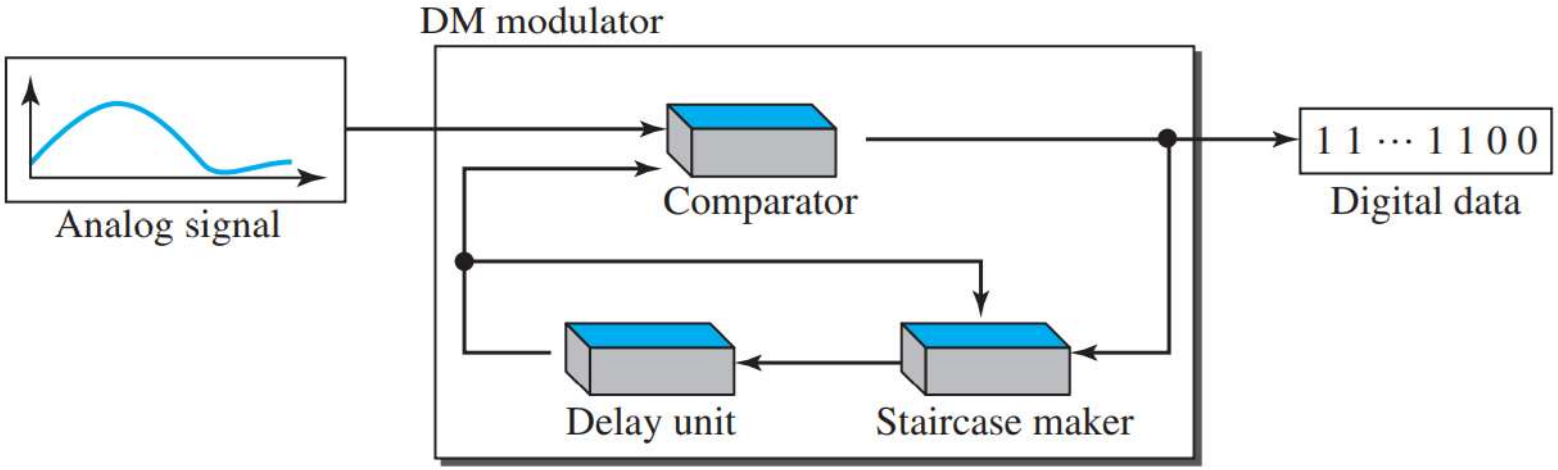


Delta Modulation (DM)

Modulator

- The modulator is used at the sender site to create a stream of bits from an analog signal.
- The process records the small positive or negative changes, called delta δ.
- If the delta is positive, the process records a 1; if it is negative, the process records a 0.
- The modulator builds a second signal that resembles a staircase.
- Finding the change is then reduced to comparing the input signal with the gradually made staircase signal.

Delta Modulation (DM)



Delta Modulation (DM)

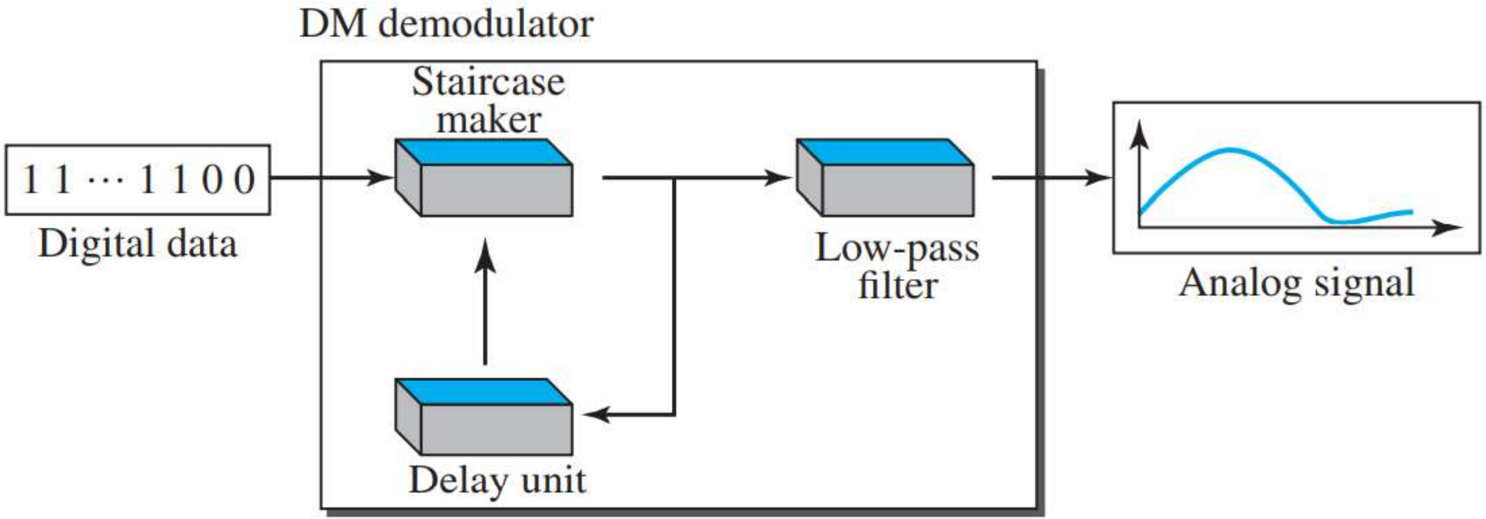
- ➢ The modulator, at each sampling interval, compares the value of the analog signal with the last value of the staircase signal.
- ➢ If the amplitude of the analog signal is larger, the next bit in the digital data is 1; otherwise, it is 0.
- ➢ The output of the comparator, however, also makes the staircase itself.
- ➢ If the next bit is 1, the staircase maker moves the last point of the staircase signal δ up;
- ➢ if the next bit is 0, it moves it δ down.

Delta Modulation (DM

Demodulator

- ➢ The demodulator takes the digital data and, using the staircase maker and the delay unit, creates the analog signal.
- ➢ The created analog signal, however, needs to pass through a low-pass filter for smoothing.

Delta Modulation (DM)



Delta Modulation (DM)

Adaptive DM

- A better performance can be achieved if the value of δ is not fixed.
- In adaptive delta modulation, the value of δ changes according to the amplitude of the analog signal.

Delta Modulation (DM)

Quantization Error

- It is obvious that DM is not perfect. Quantization error is always introduced in the process.
- The quantization error of DM, however, is much less than that of PCM.

DIGITAL-TO-ANALOG CONVERSION

Digital-to-analog conversion is the process of changing one of the characteristics of an analog signal based on the information in digital data.