DATA COMMUNICATION

[As per Choice Based Credit System (CBCS) scheme]

Course objectives:

This course will enable students to

- Comprehend the transmission technique of digital data between two or more computers and a computer network that allows computers to exchange data.
- Explain with the basics of data communication and various types of computer networks;
- Illustrate TCP/IP protocol suite and switching criteria.
- Demonstrate Medium Access Control protocols for reliable and noisy channels.
- Expose wireless and wired LANs along with IP version.

Question paper pattern:

- The question paper will have ten questions.
- Each full Question consisting of 16 marks
- There will be 2 full questions (with a maximum of four sub questions) from each module.
- Each full question will have sub questions covering all the topics under a module.
- The students will have to answer 5 full questions, selecting one full question from each module.

Course Outcomes: After studying this course, students will be able to

- Illustrate basic computer network technology.
- Identify the different types of network topologies and protocols.
- Enumerate the layers of the OSI model and TCP/IP functions of each layer.
- Make out the different types of network devices and their functions within a network
- Demonstrate the skills of sub-netting and routing mechanisms.

MODULE 1

DATA COMMUNICATION

Module 1 Teaching Hours: 10

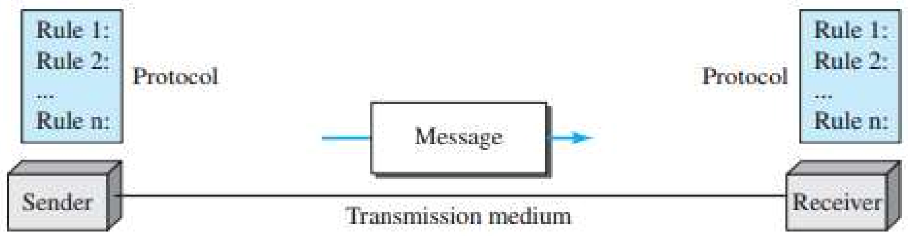
Introduction: Data Communications, Networks, Network Types, Internet History, Standards and Administration, Networks Models: Protocol Layering, TCP/IP Protocol suite, The OSI model, Introduction to Physical Layer-1: Data and Signals, Digital Signals, Transmission Impairment, Data Rate limits, Performance, Digital Transmission: Digital to digital conversion (Only Line coding: Polar, Bipolar and Manchester coding).

Module 1 Chapter 1
Data Communications

1.1.1 Components

A data communications system has five components

Figure 1.1 *Five components of data communication*



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

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

1.1.2 Data Representation

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

Text

In data communications, text is represented as a bit pattern, a sequence of bits (0s or 1s).

Numbers

Numbers are also represented by bit patterns.

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.

Audio

Audio refers to the recording or broadcasting of sound or music.

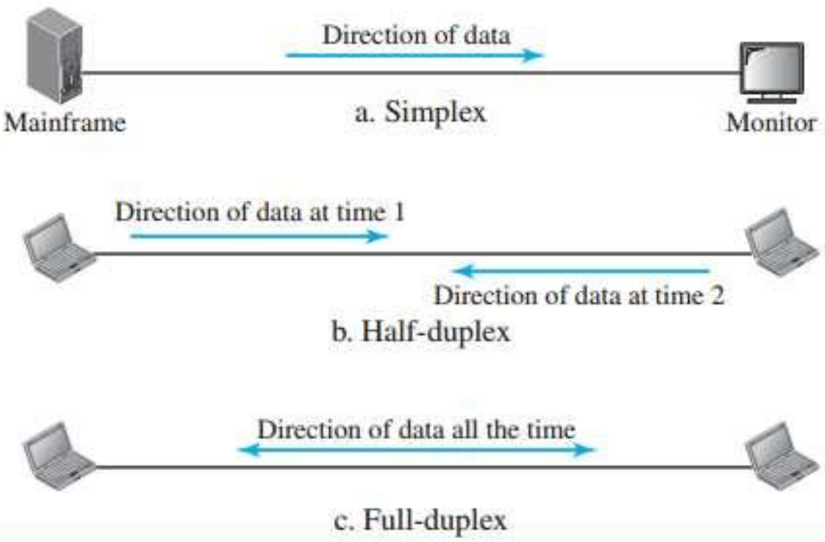
Video

Video refers to the recording or broadcasting of a picture or movie. Video can either be produced as a continuous entity (e.g., by a TV camera), or it can be a combination of images, each a discrete entity, arranged to convey the idea of motion.

1.1.3 Data Flow

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

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



1.2 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.

1.2.1 Network Criteria

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

Performance

Performance can be measured in many ways, including transit time and response time. Transit time is the amount of time required for a message to travel from one device to another. Response time is the elapsed time between an inquiry and a response. Performance is often evaluated by two networking metrics: throughput and delay.

Reliability

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.

1.2.2 Physical Structures

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

Type of Connection

A network is two or more devices connected through links. There are two possible types of connections: point-to-point and multipoint.

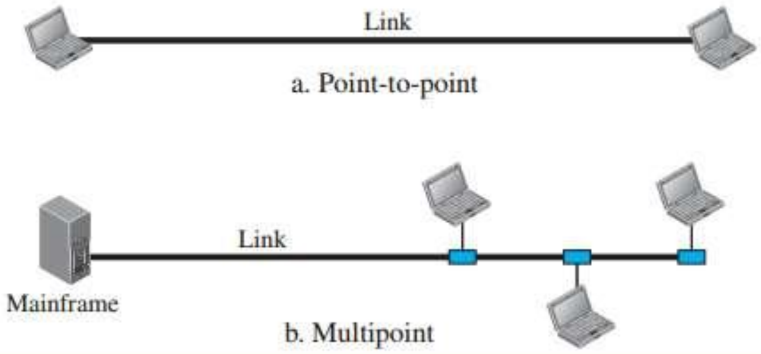
Point-to-Point

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

Multipoint

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

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



Physical Topology

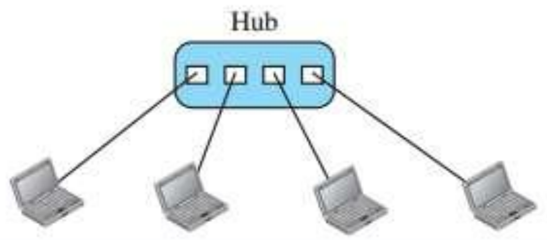
Mesh Topology

In a mesh topology, every device has a dedicated point-to-point link to every other device. in a mesh topology, we need n (n – 1) / 2 duplex-mode links. To accommodate that many links, every device on the network must have n – 1 input/output (I/O) ports (see Figure 1.4) to be connected to the other n – 1 stations.

- Pros:
  - Dedicated links
  - Robustness
  - Privacy
  - Easy to identify fault
- Cons:
  - A lot of cabling
  - I/O ports
  - Difficult to move

Star Topology
In a star topology, each device has a dedicated point-to-point link only to a central controller, usually called a hub.

Figure 1.5 *A star topology connecting four stations*

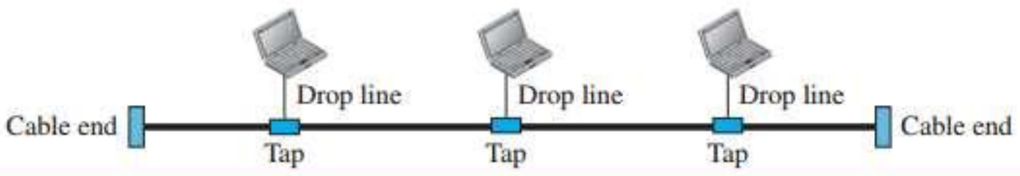


- <u>Pros:</u>
  - One I/O port per device
  - Little cabling
  - Easy to install
  - Robustness
  - Easy to identify fault
- <u>Cons:</u>
  - Single point of failure
  - More cabling still required

Bus Topology

The preceding examples all describe point-to-point connections. A bus topology, on the other hand, is multipoint. One long cable acts as a backbone to link all the devices in a network (see Figure 1.6).

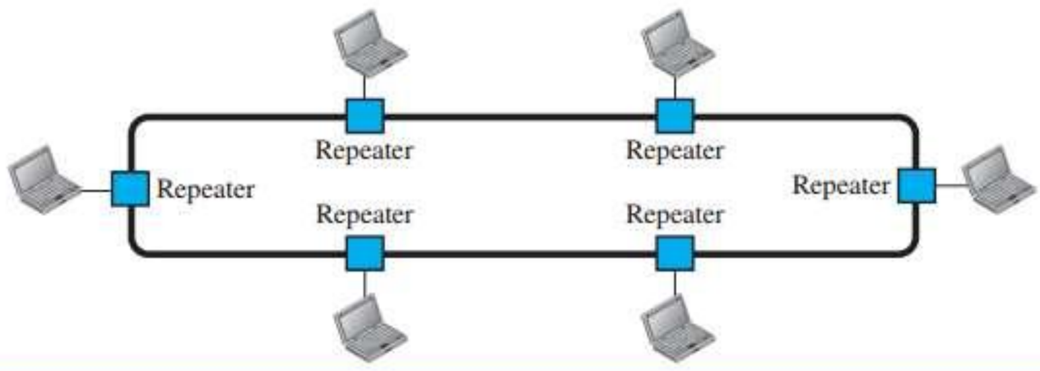
Figure 1.6 *A bus topology connecting three stations*



- <u>Pros:</u>
  - Little cabling
  - Easy to install
- <u>Cons:</u>
  - Difficult to modify
  - Difficult to isolate fault
  - Break in the bus cable stops all transmission

Ring Topology
In a ring topology, each device has a dedicated point-to-point connection with only the two devices on either side of it. A signal is passed along the ring in one direction, from device to device, until it reaches its destination.

Figure 1.7 *A ring topology connecting six stations*



- Pros:
  - Easy to install
  - Easy to identify fault
- Cons:
  - Delay in large ring
  - Break in the ring stops all transmission

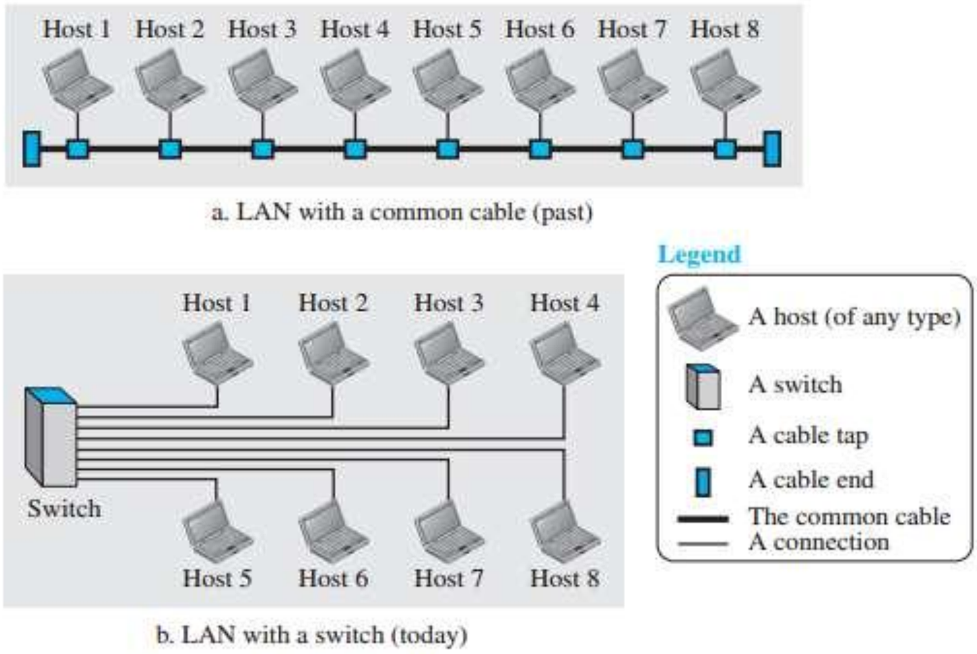
1.3 NETWORK TYPES

- Local Area Network (LAN)
- Wide Area Network (WAN)
- Metropolitan Area Network (MAN)

1.3.1 Local Area Network

A local area network (LAN) is usually privately owned and connects some hosts in a single office, building, or campus.

Figure 1.8 *An isolated LAN in the past and today*



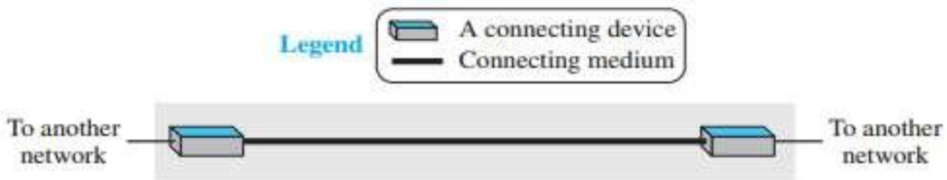
1.3.2 Wide Area Network

A wide area network (WAN) is also an interconnection of devices capable of communication. Network providing long-distance communication over a country, a continent, or the whole world We see 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).

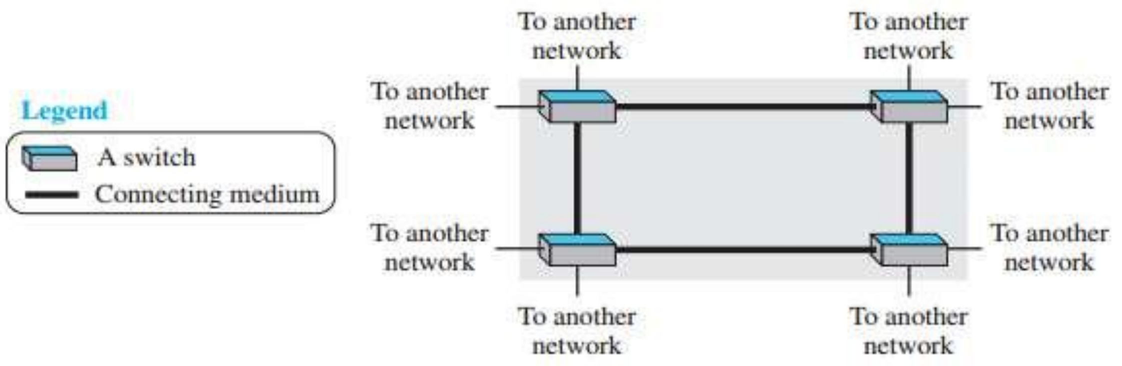
Figure 1.9 *A point-to-point WAN*



Switched WAN

A switched WAN is a network with more than two ends. A switched WAN, as we will see shortly, is used in the backbone of global communication today.

Figure 1.10 *A switched WAN*



Internetwork

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

Figure 1.11 *An internetwork made of two LANs and one point-to-point WAN*

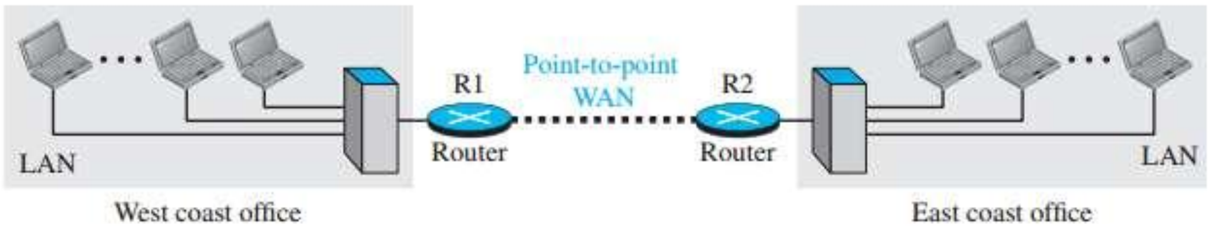
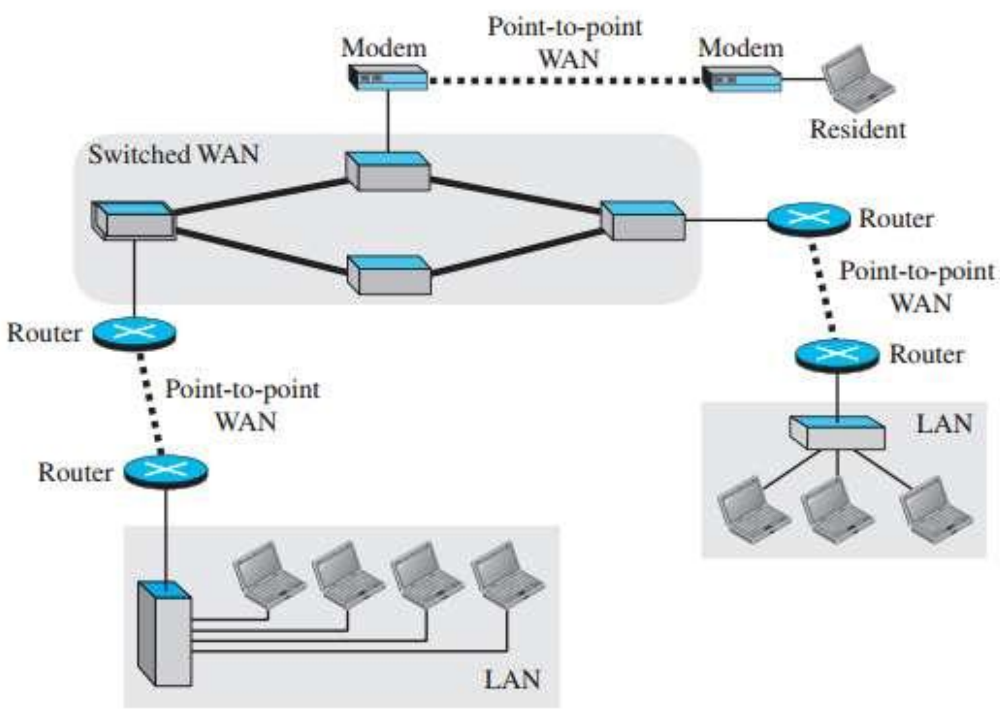


Figure 1.12 shows another internet with several LANs and WANs connected. One of the WANs is a switched WAN with four switches.

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



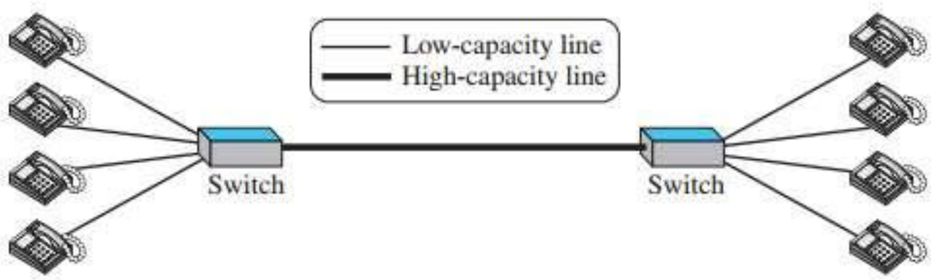
1.3.3 Switching

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.

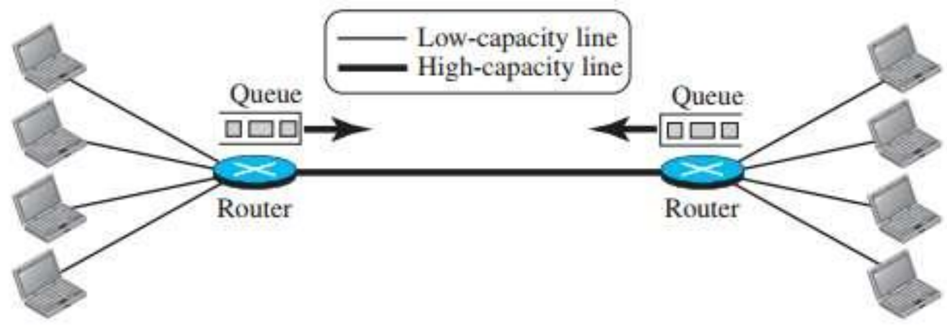
Figure 1.13 *A circuit-switched network*



Packet-Switched Network

In a computer network, the communication between the two ends is done in blocks of data called packets.

Figure 1.14 *A packet-switched network*

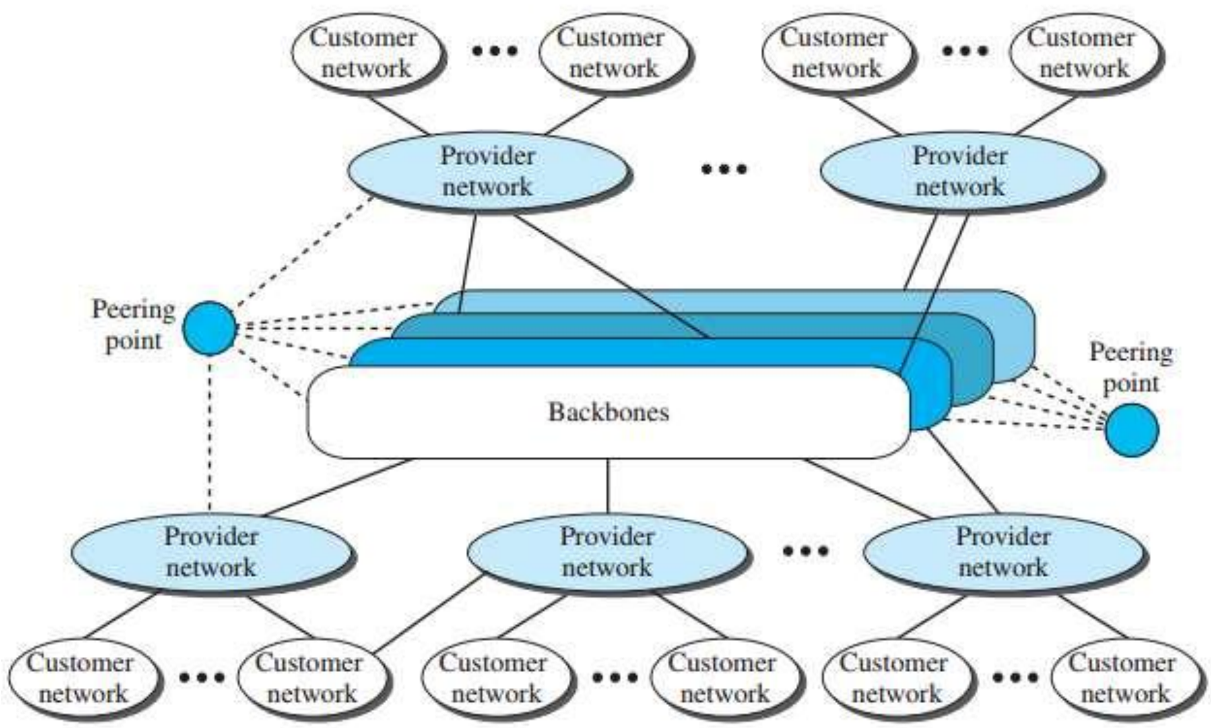


A router in a packet-switched network has a queue that can store and forward the packet.

1.3.4 The Internet

An internet (note the lowercase i) is two or more networks that can communicate with each other. The most notable internet is called the Internet (uppercase I), and is composed of thousands of interconnected networks. Figure 1.15 shows a conceptual (not geographical) view of the Internet.

Figure 1.15 *The Internet today*



Backbones and provider networks are also called Internet Service Providers (ISPs). The backbones are often referred to as international ISPs; the provider networks are often referred to as national or regional ISPs.

1.3.5 Accessing the Internet

Connecting to the internet is done using any of the following techniques

Using Telephone Networks

- Dial-up service.
- DSL Service.

Using Cable Networks

Using Wireless Networks

Direct Connection to the Internet

1.5 PROTOCOLS AND STANDARDS

Protocols

A protocol is a set of rules that govern data communications. A protocol defines what is communicated, how it is communicated, and when it is communicated. The key elements of a protocol are syntax, semantics, and timing.

o Syntax. The term syntax refers to the structure or format of the data, meaning the order in which they are presented.

o Semantics. The word semantics refers to the meaning of each section of bits.

o Timing. The term timing refers to two characteristics: when data should be sent and how fast they can be sent.

Standards

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

o De facto. Standards that have not been approved by an organized body but have been adopted as standards through widespread use are de facto standards.

o De jure. Those standards that have been legislated by an officially recognized body are de jure standards.

Standards Organizations

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

o International Organization for Standardization (ISO).

o International Telecommunication Union-Telecommunication Standards Sector (ITU-T).

o American National Standards Institute (ANSI).

o Institute of Electrical and Electronics Engineers (IEEE).

o Electronic Industries Association (EIA).

Module 1 Chapter 2
Network Models

2.1 PROTOCOL LAYERING

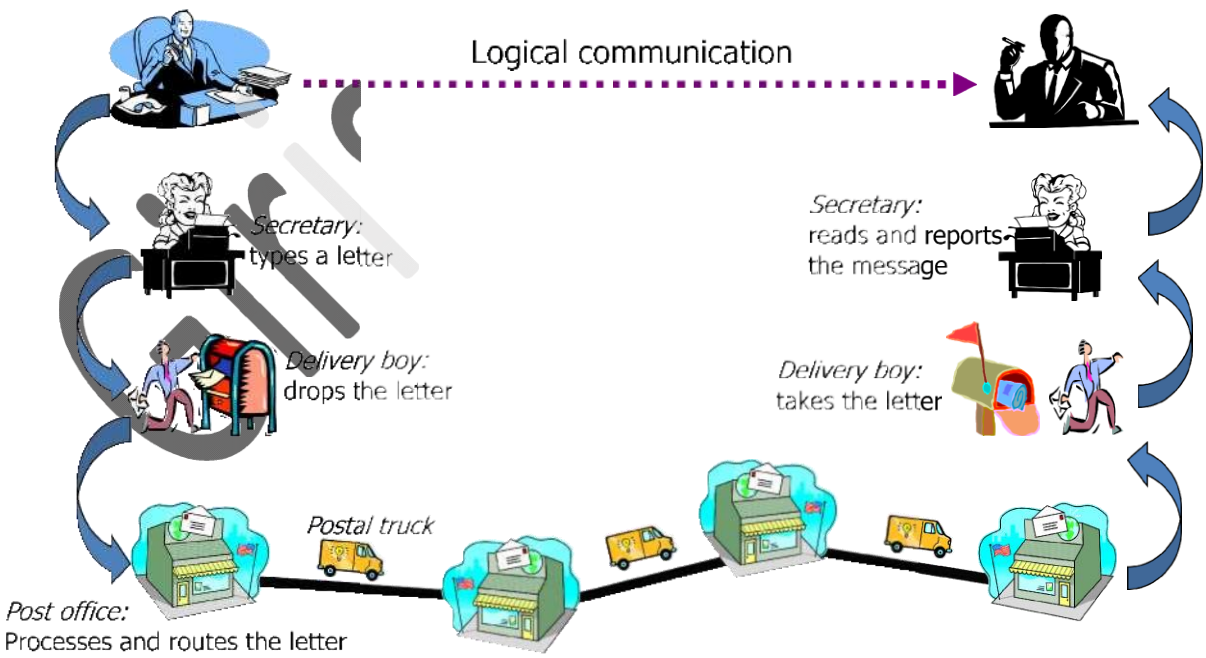
In data communication and networking, a protocol defines the rules that both the sender and receiver and all intermediate devices need to follow to be able to communicate effectively. when the communication is complex, we may need to divide the task between different layers, in which case we need a protocol at each layer, or protocol layering.

2.1.1 Scenarios

Need for protocol layering. ?

Simple form of communication

What actually happens is communication takes place thru many layers.



Advantages of protocol layering

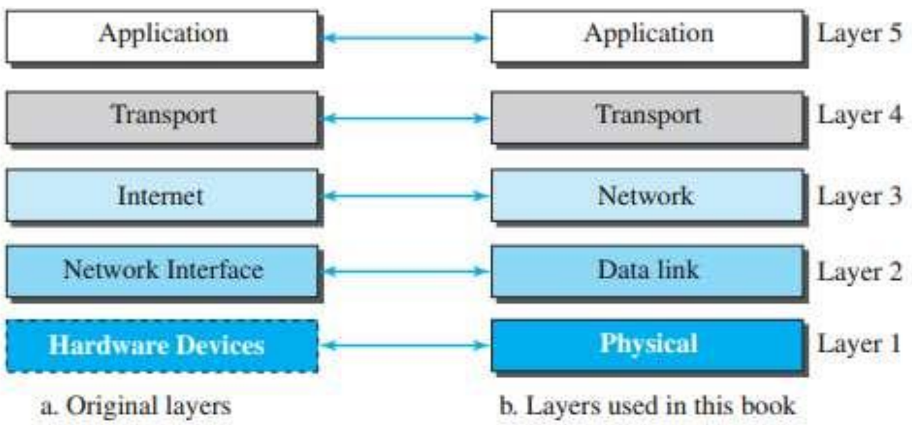
1. It allows us to separate the services from the implementation. A layer needs to be able to receive a set of services from the lower layer and to give the services to the upper layer; we don't care about how the layer is implemented.
2. Communication does not always use only two end systems; there are intermediate systems that
need only some layers, but not all layers. If we did not use protocol layering, we would have to make each intermediate system as complex as the end systems, which makes the whole system more expensive.

2.2 TCP/IP PROTOCOL SUITE

TCP/IP (Transmission Control Protocol/Internet Protocol). TCP/IP is a protocol suite (a set of protocols organized in different layers) used in the Internet today. It is a hierarchical protocol made up of interactive modules, each of which provides a specific functionality. The term hierarchical means that each upper level protocol is supported by the services provided by one or more lower level protocols.

2.2.1 Layered Architecture

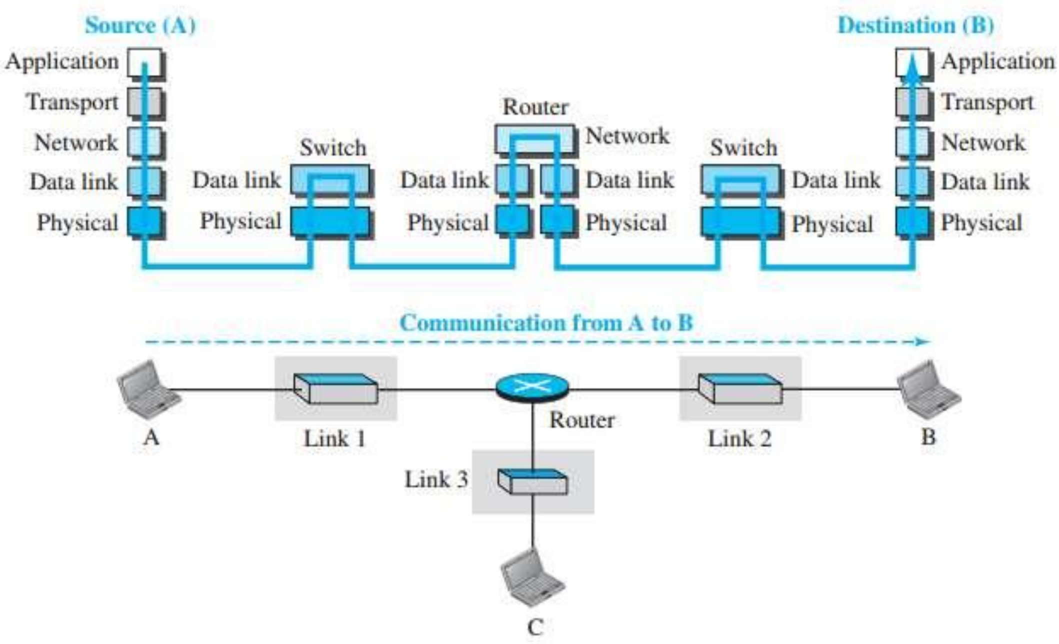
Figure 2.4 *Layers in the TCP/IP protocol suite*



AS in fig 2.5 Let us assume that computer A communicates with computer B. As the figure shows, we have five communicating devices in this communication: source host (computer A), the link-layer switch in link 1, the router, the link-layer switch in link 2, and the destination host (computer B). Each device is involved with a set of layers depending on the role of the device in the internet. The two hosts are involved in all five layers; the source host needs to create a message in the application layer and send it down the layers so that it is physically sent to the destination host. The destination host needs to receive the communication at the physical layer and then deliver it through the other layers to the application layer.

The router is involved in only three layers; there is no transport or application layer in a router as long as the router is used only for routing. Although a router is always involved in one network layer, it is involved in n combinations of link and physical layers in which n is the number of links the router is connected to.

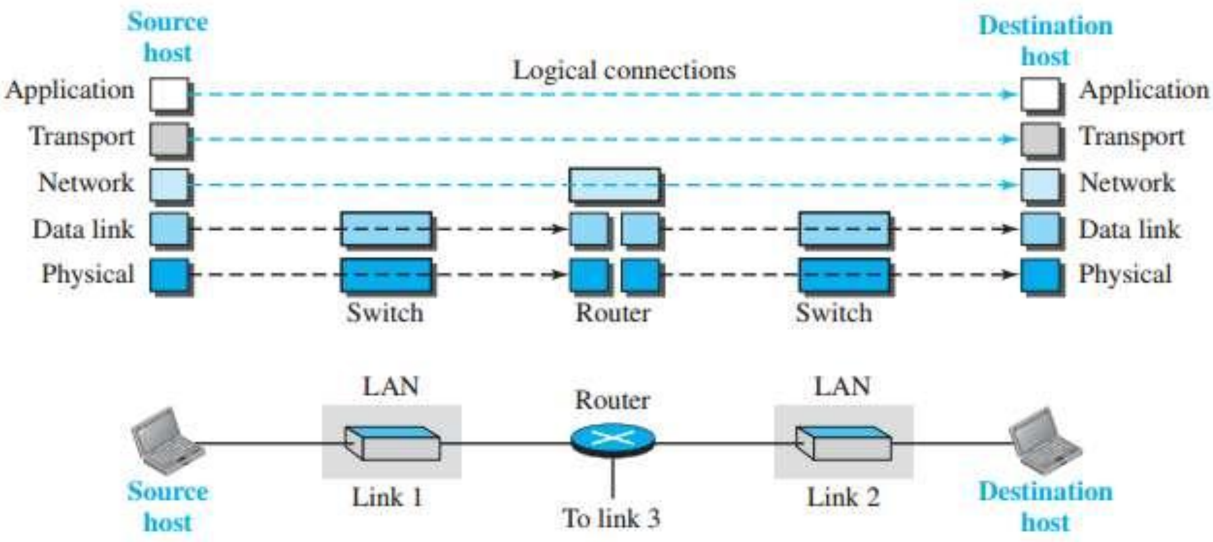
Figure 2.5 *Communication through an internet*



2.2.2 Layers in the TCP/IP Protocol Suite

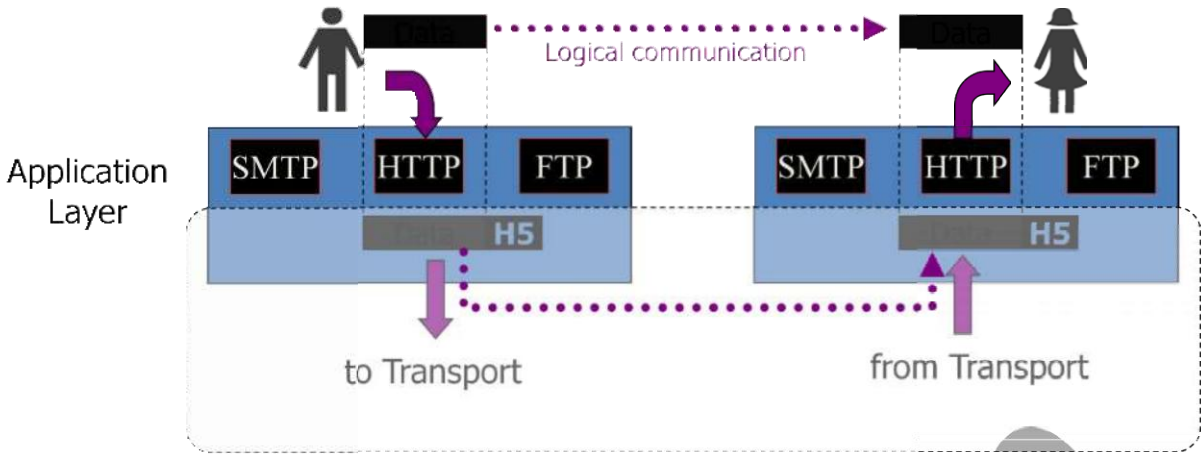
This section briefly discusses the functions and duties of layers in the TCP/IP protocol suite.

Figure 2.6 *Logical connections between layers of the TCP/IP protocol suite*



Application Layer

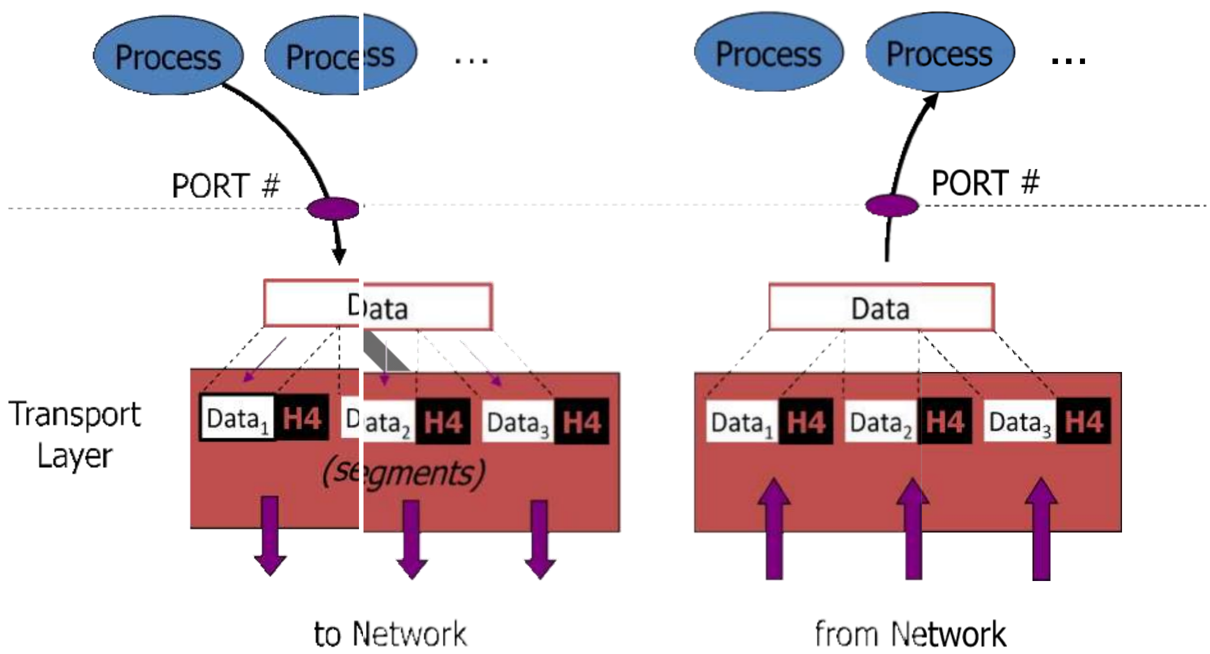
Responsible for providing service to the users. Only layer to interact with user.



Transport Layer

Responsible for delivery of a message from one process to another

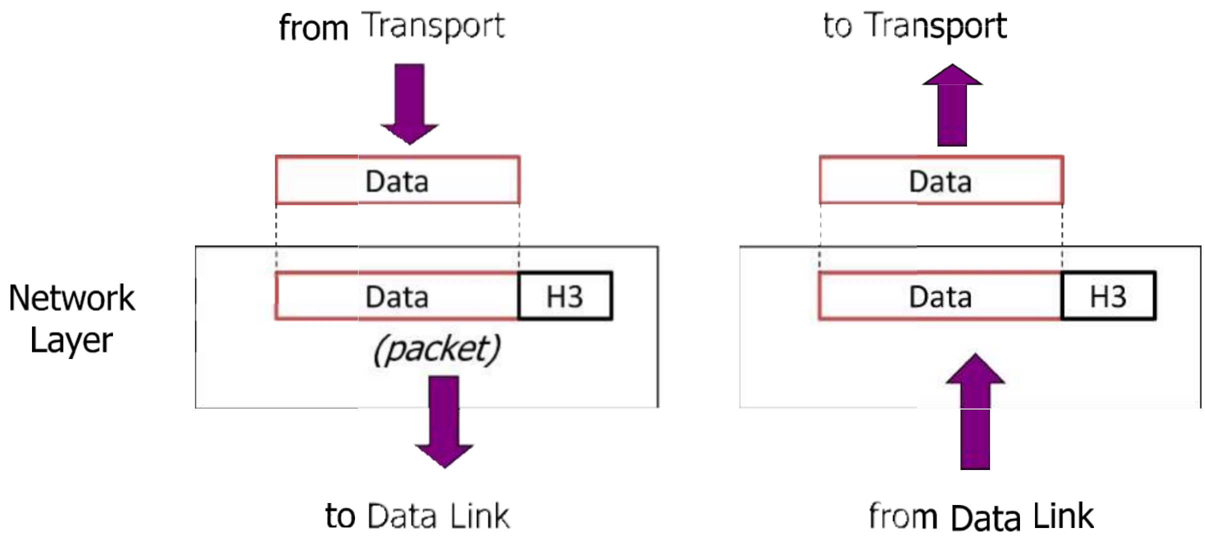
- Duties/services
  - Port addressing
  - Segmentation and reassembly
  - Connection control
  - Flow control (end-to-end)
  - Error control (end-to-end)



Network Layer

Responsible for the delivery of packets from the original source to the destination

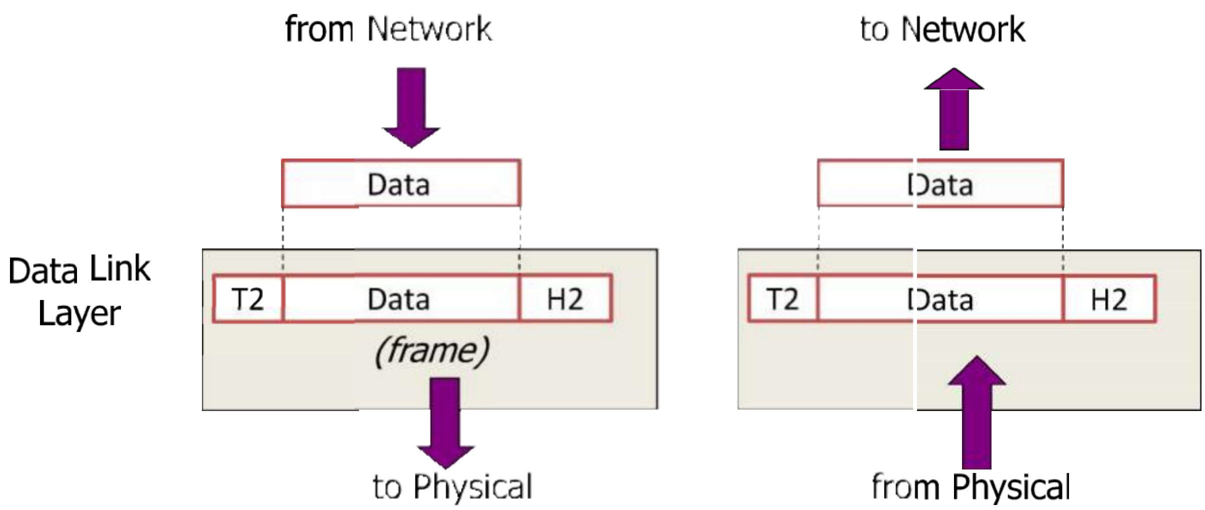
- Duties/services
  - Logical addressing
  - Routing



Data Link layer

Responsible for transmitting frames from one node to the next

- Duties/services
  - Framing
  - Physical addressing
  - Flow control (hop-to-hop)
  - Error control (hop-to-hop)
  - Access control

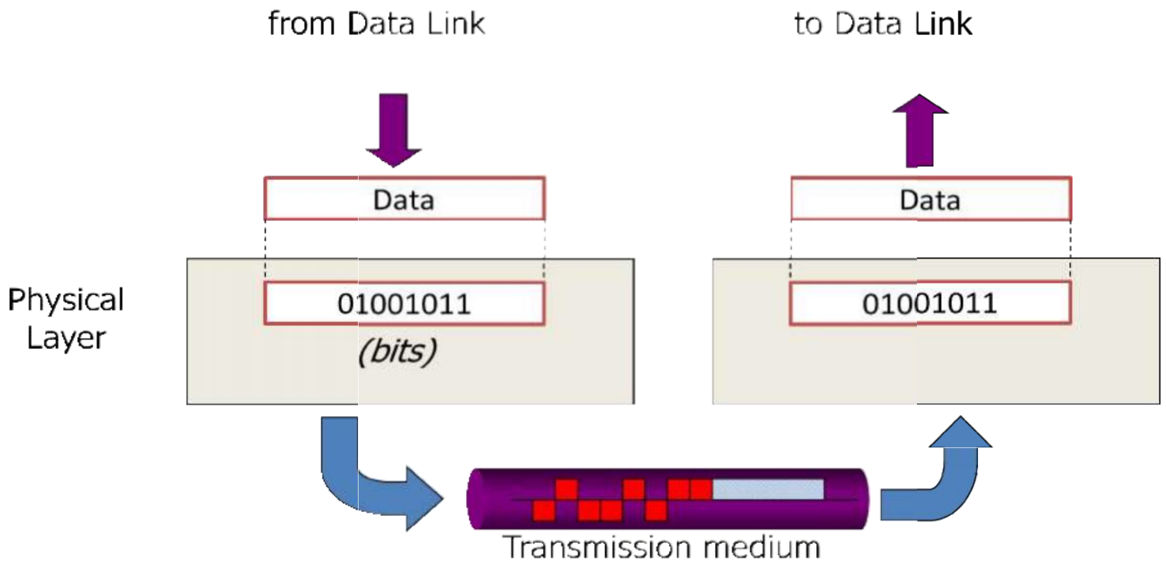


Physical Layer

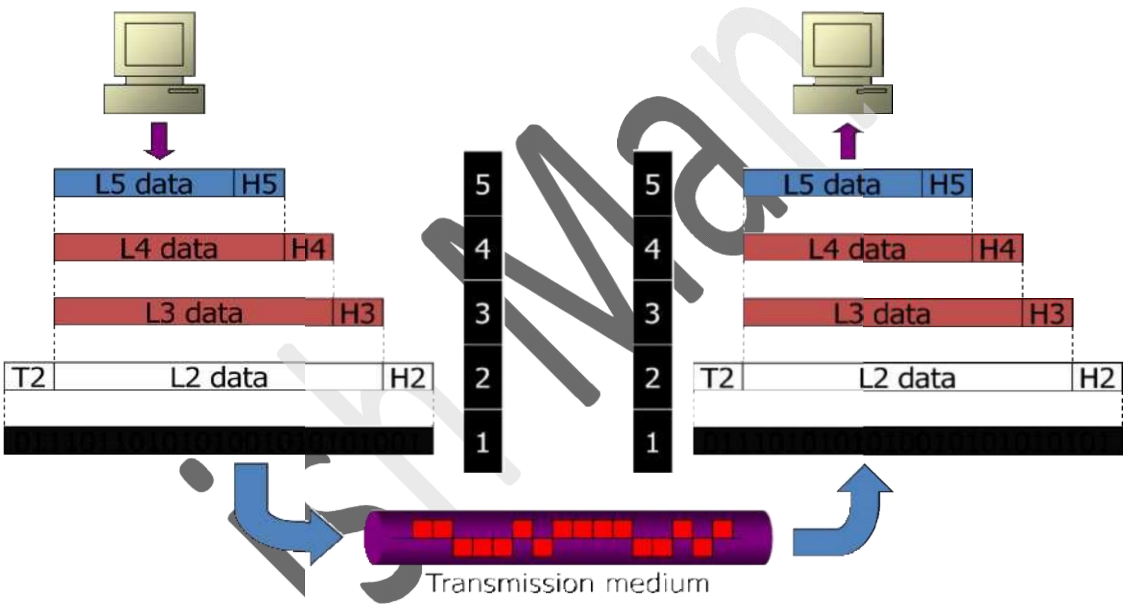
Responsible for transmitting individual bits from one node to the next

- Duties/services
  - Physical characteristics of interfaces and media
  - Representation of bits
  - Data rate (transmission rate)

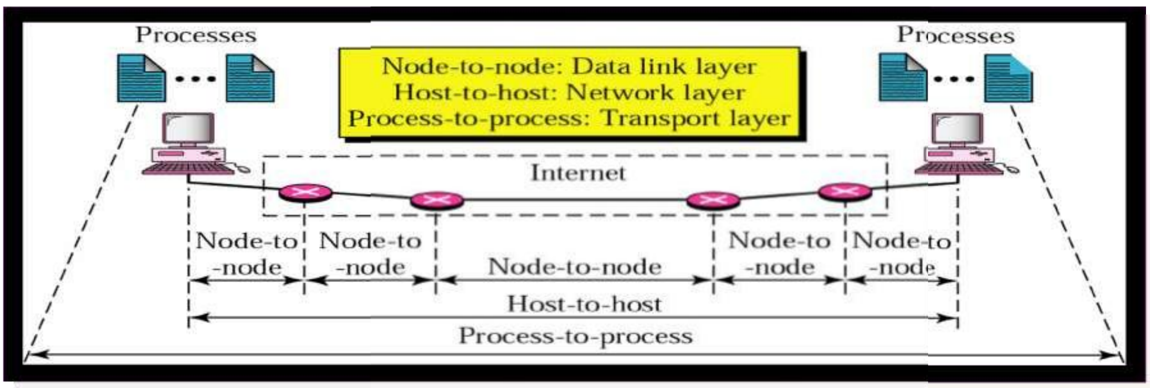
– Synchronization of bits



The Big Picture



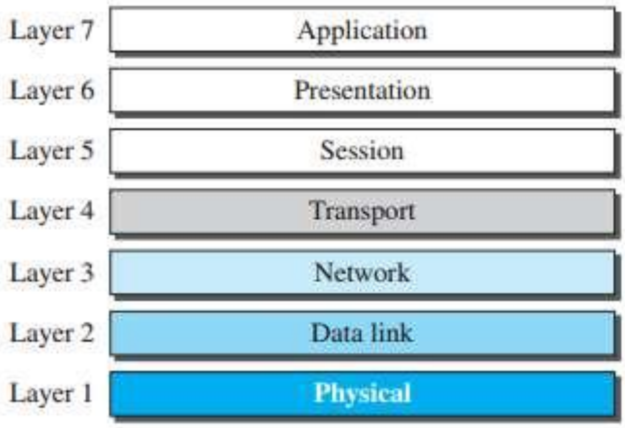
Summary of TCP/IP Protocol suite



2.3 THE OSI MODEL

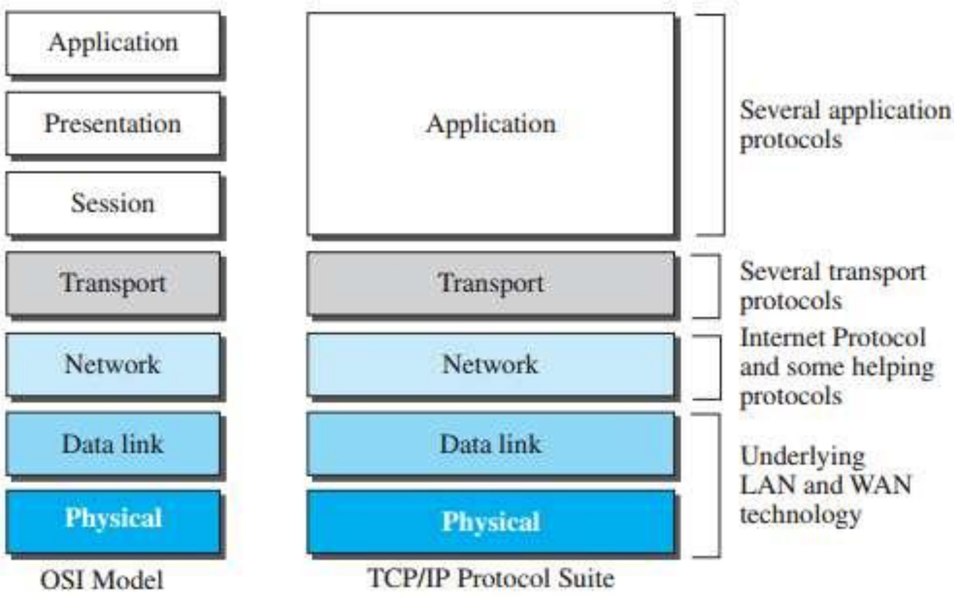
Open Systems Interconnection (OSI) model. The OSI model is a layered framework for the design of network systems that allows communication between all types of computer systems. It consists of seven separate but related layers, each of which defines a part of the process of moving information across a network (see Figure 2.11).

Figure 2.11 *The OSI model*



2.3.1 OSI versus TCP/IP

Figure 2.12 *TCP/IP and OSI model*



When we compare the two models, we find that two layers, session and presentation, are missing from the TCP/IP protocol suite.

Presentation layer

Responsible for handling differences in data representation to applications

- Duties/services
  - Data translation
  - Encryption
  - Decryption
  - Compression

Session Layer

Responsible for establishing, managing and terminating connections between applications

- Duties/services
  - Interaction management
    ⇨ Simplex, half-duplex, full-duplex
  - Session recovery

Module 1 Chapter 3
Introduction to Physical Layer-1

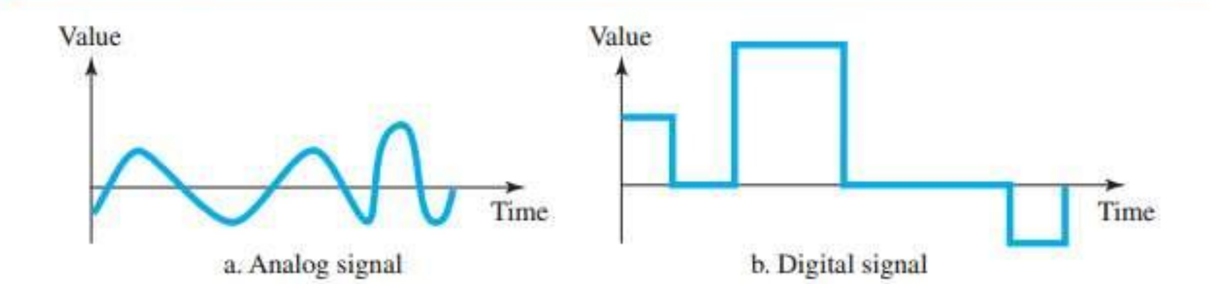
3.1 DATA AND SIGNALS

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 Analog data, such as the sounds made by a human voice, take on continuous values. Digital data take on discrete values. For example data are stored in computer memory in the form of 0s and 1s. Both analog and digital data will be converted to either analog or digital signals and transmitted across network.

3.1.2 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.

Figure 3.2 *Comparison of analog and digital signals*



In figure 3.2 the vertical axis represents the value or strength of a signal. The horizontal axis represents time. 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.

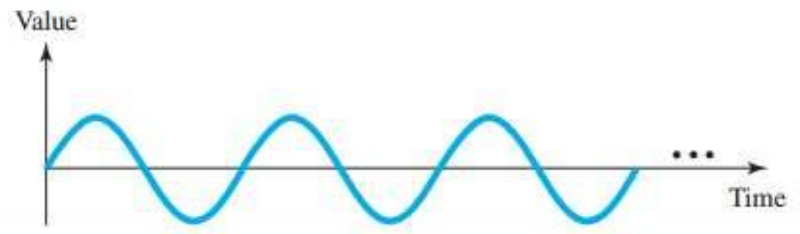
3.2 PERIODIC ANALOG SIGNALS

A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.

3.2.1 Sine Wave

Figure 3.3 shows a sine wave. Each cycle consists of a single arc above the time axis followed by a single arc below it.

Figure 3.3 *A sine wave*

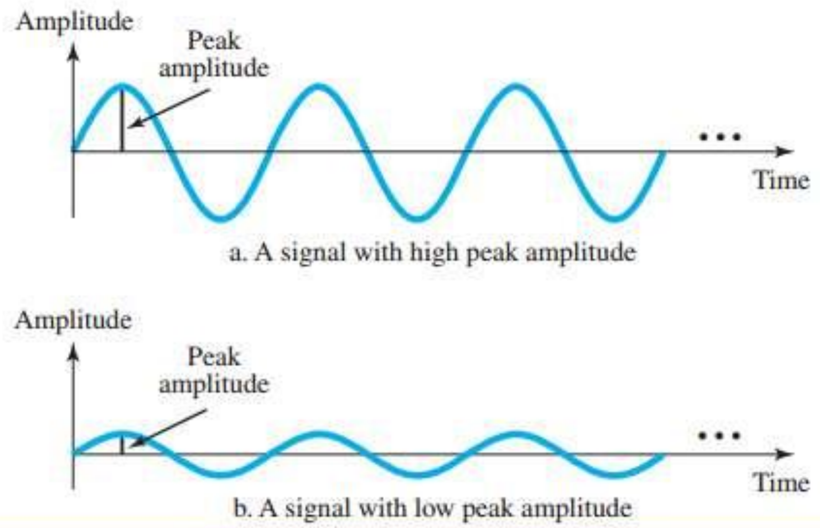


A sine wave can be represented by three parameters: the peak amplitude, the frequency, and the phase.

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. Figure 3.4 shows two signals and their peak amplitudes.

Figure 3.4 *Two signals with the same phase and frequency, but different amplitudes*



Period and Frequency

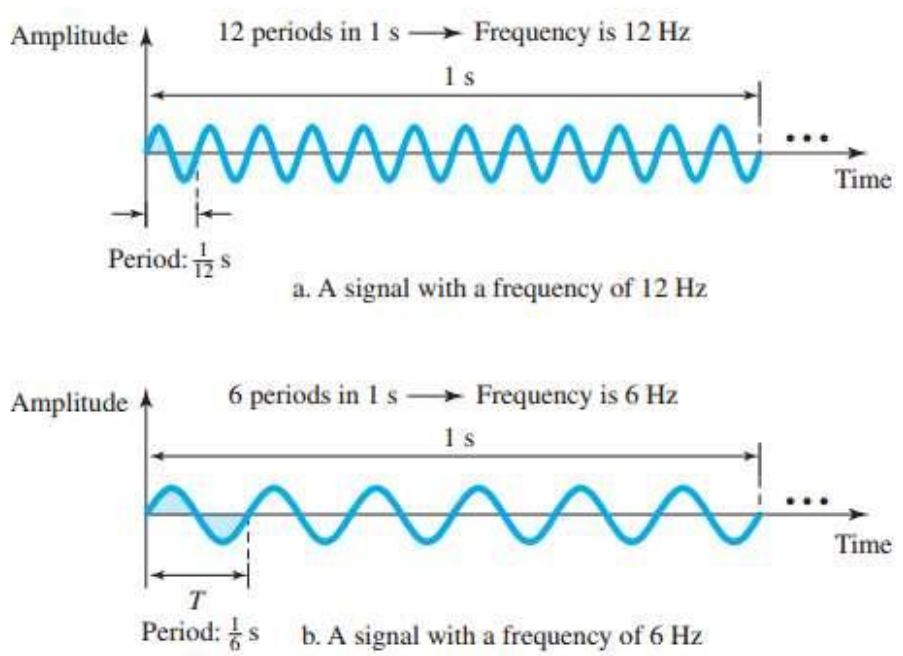
Period refers to the amount of time, in seconds, a signal needs to complete 1 cycle. Frequency refers to the number of periods in 1 s.

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

Frequency and period are the inverse of each other.

Frequency is formally expressed in Hertz (Hz), which is cycle per second.

Figure 3.5 *Two signals with the same amplitude and phase, but different frequencies*



Example :

The power we use at home has a frequency of 60 Hz (50 Hz in Europe). The period of this sine wave can be determined as follows:

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

Example :

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

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

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

NOTE :

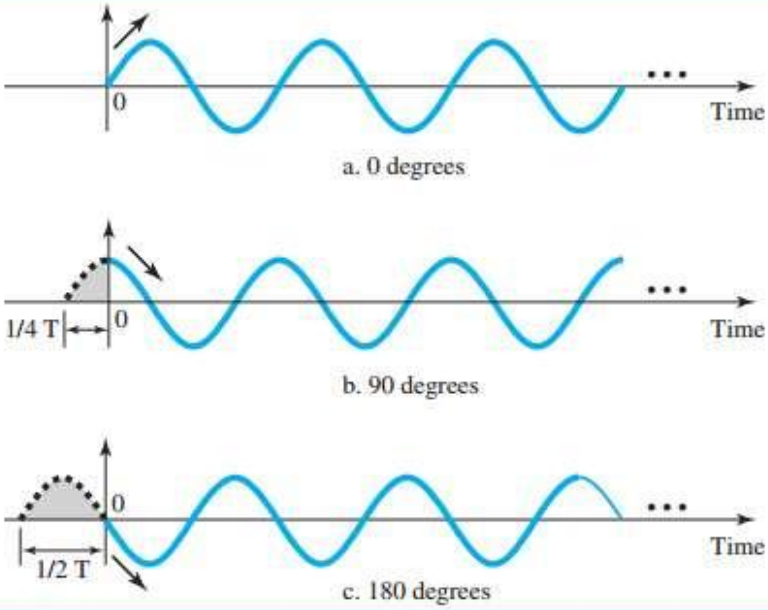
1. Frequency is the rate of change with respect to time. Change in a short span of time means high frequency. Change over a long span of time means low frequency.

2. 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. It indicates the status of the first cycle. i.e Phase describes the position of the waveform relative to time 0.

Figure 3.6 *Three sine waves with the same amplitude and frequency, but different phases*

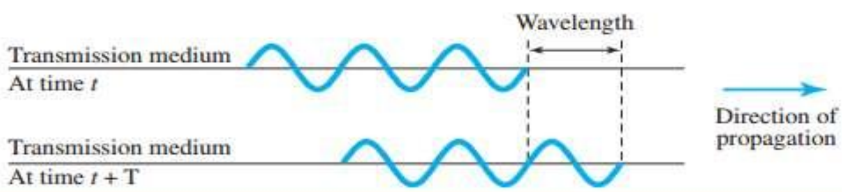


a. A sine wave with a phase of 0° is not shifted.
b. A sine wave with a phase of 90° is shifted to the left by ¼ cycle. However, note that the signal does not really exist before time 0.
c. A sine wave with a phase of 180° is shifted to the left by ½ cycle. However, note that the signal does not really exist before time 0.

3.2.3 Wavelength

Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium

Figure 3.7 *Wavelength and period*



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

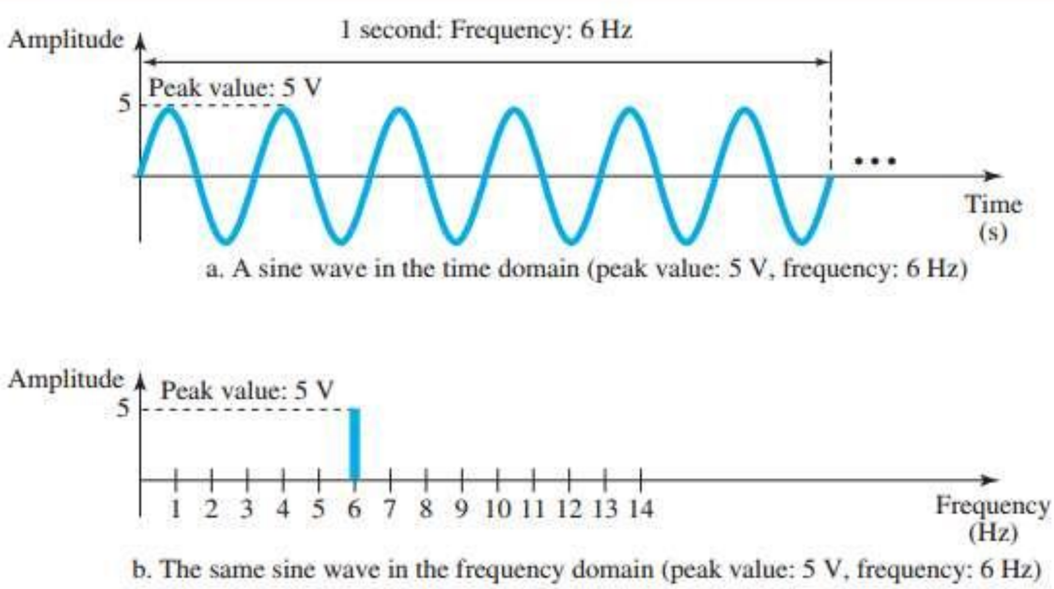
$$\textbf{Wavelength} = (\textbf{propagation speed}) \times \textbf{period} = \frac{\textbf{propagation speed}}{\textbf{frequency}}$$

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

3.2.4 Time and Frequency Domains

The time-domain plot shows changes in signal amplitude with respect to time. To show the relationship between amplitude and frequency, we can use what is called a frequency-domain plot. A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

Figure 3.8 *The time-domain and frequency-domain plots of a sine wave*



3.2.5 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.

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

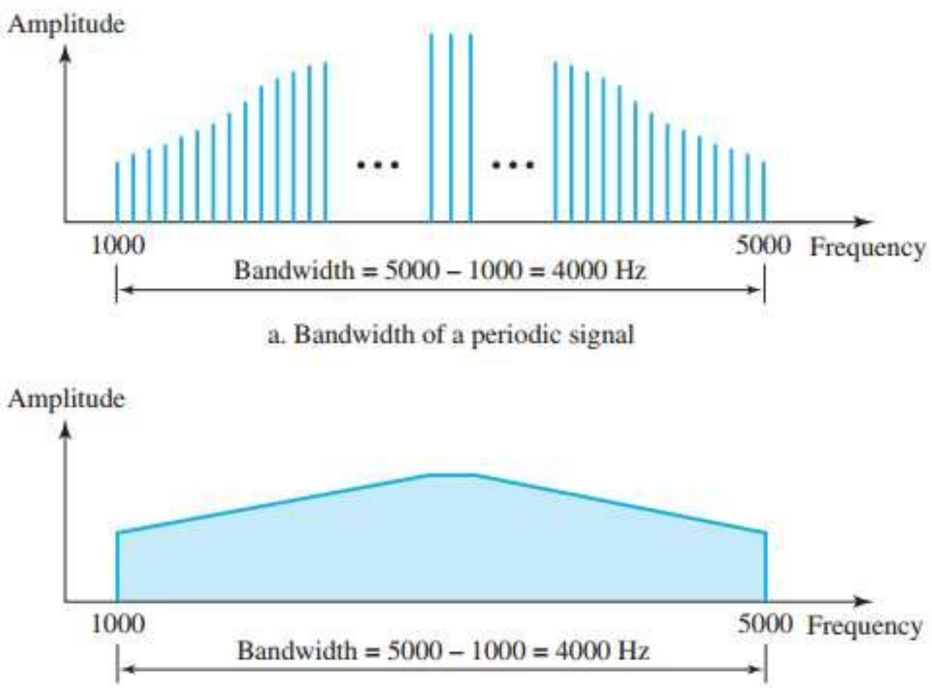
If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies; if the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

3.2.6 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.

Figure 3.13 *The bandwidth of periodic and nonperiodic composite signals*



a. Bandwidth of a periodic signal

b. Bandwidth of a nonperiodic signal

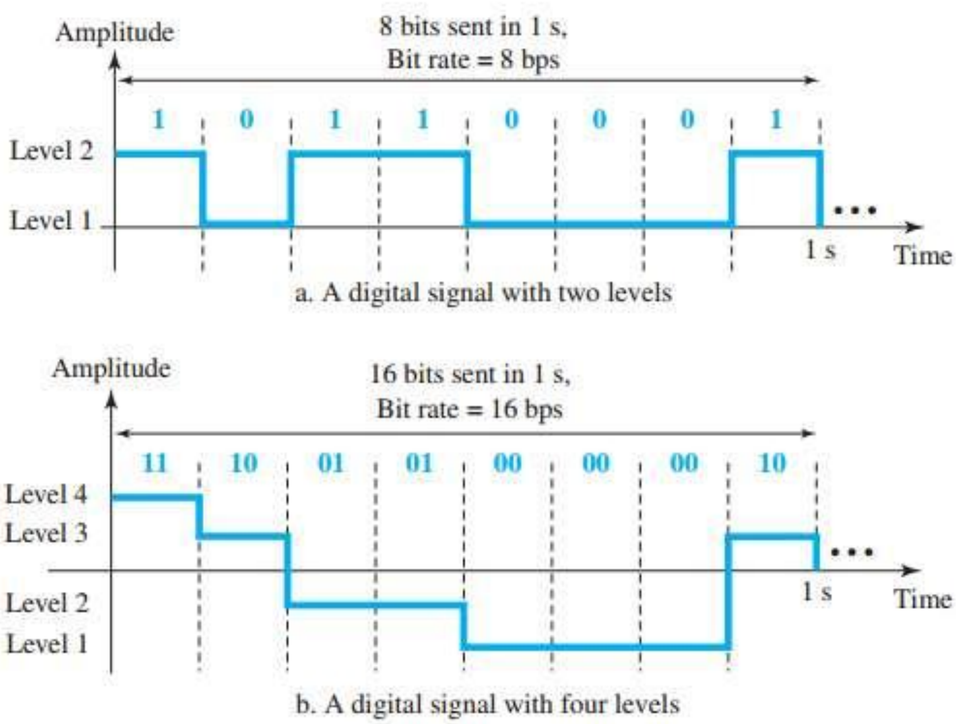
3.3 DIGITAL SIGNALS

Digital Signal is a data stored with some discrete values. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage.

We calculate the number of bits from the following formula. Each signal level is represented by 3 bits.

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

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



3.3.1 Bit Rate

The bit rate is the number of bits sent in 1s, expressed in bits per second (bps). Figure 3.17 shows the bit rate for two signals.

Example 3.18

Assume we need to download text documents at the rate of 100 pages per second. 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, the bit rate is

$$100 \times 24 \times 80 \times 8 = 1{,}536{,}000 \text{ bps} = 1.536 \text{ Mbps}$$

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 (in contrast to 4 : 3 for regular TV), which means the screen is wider. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second. Twenty-four bits represents one color pixel. We can calculate the bit rate as

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

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

3.3.2 Bit Length

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

Bit length = propagation speed x bit duration

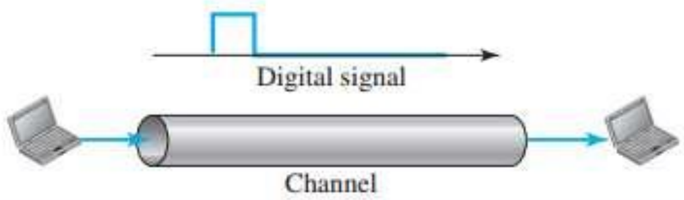
3.3.4 Transmission of Digital Signals

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

Baseband Transmission

Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal. Figure 3.19 shows baseband transmission.

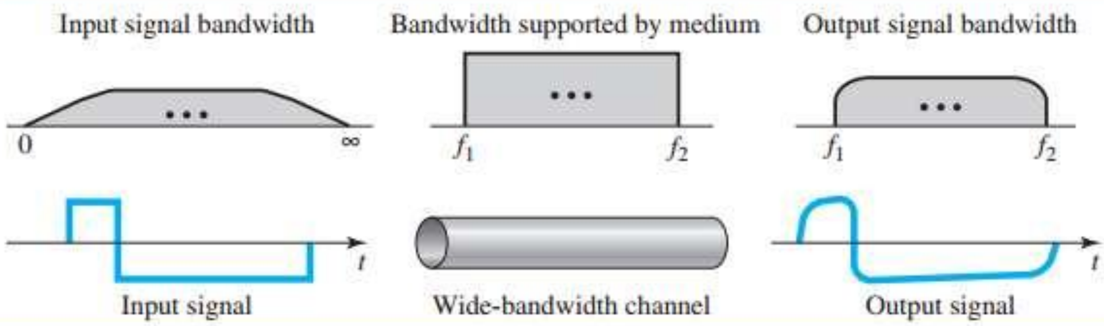
Figure 3.19 *Baseband transmission*



Baseband transmission requires that we have a low-pass channel, a channel with a bandwidth that starts from zero.

Case 1: Low-Pass Channel with Wide Bandwidth

Figure 3.21 *Baseband transmission using a dedicated medium*



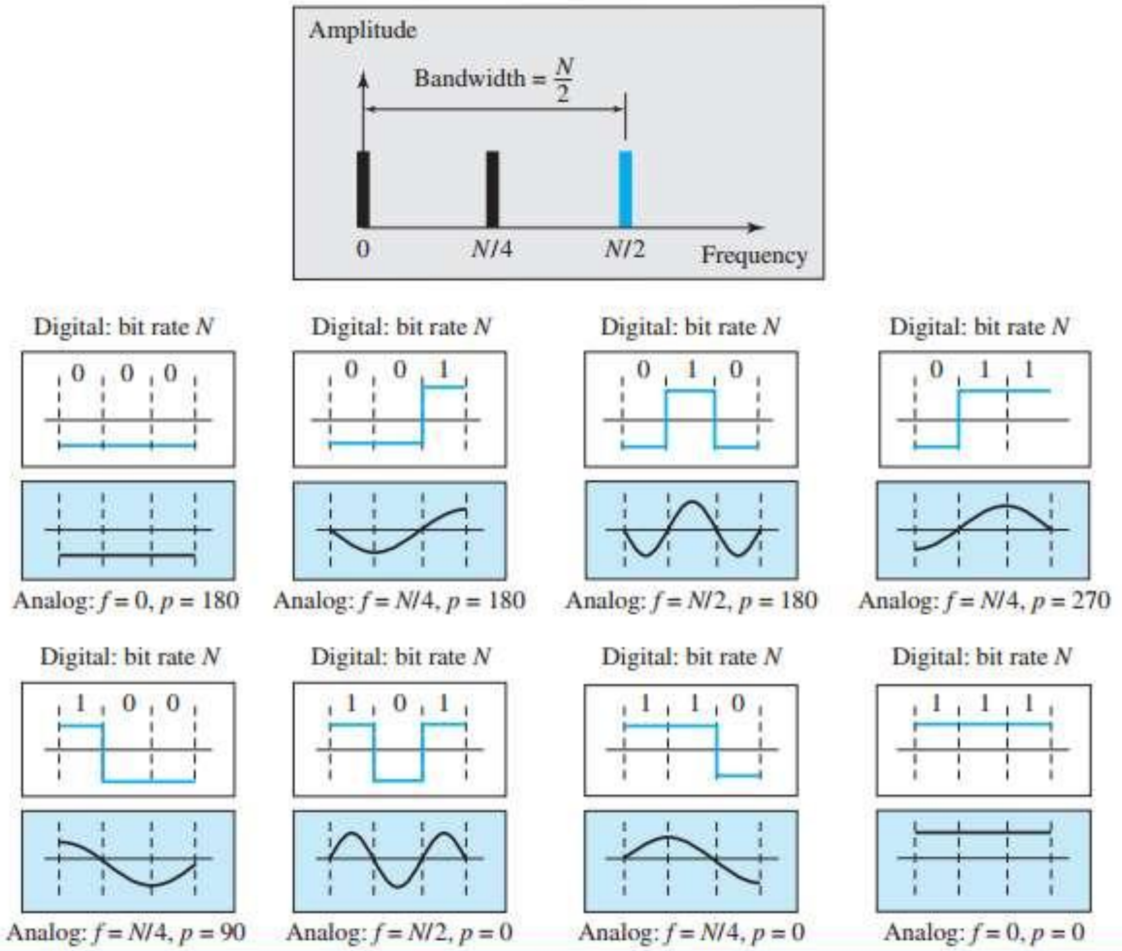
Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.

Case 2: Low-Pass Channel with Limited Bandwidth

In a low-pass channel with limited bandwidth, we approximate the digital signal with an analog signal. The level of approximation depends on the bandwidth available.

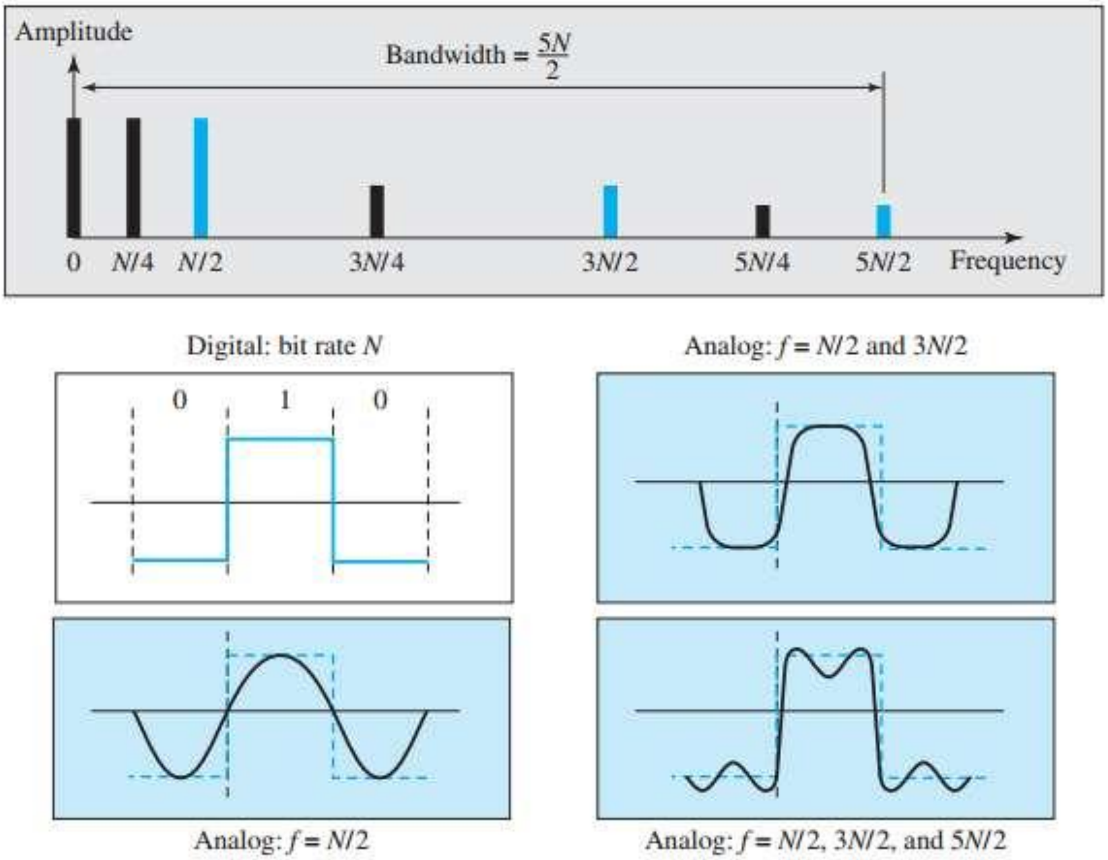
Rough Approximation

Figure 3.22 *Rough approximation of a digital signal using the first harmonic for worst case*



Better Approximation

Figure 3.23 *Simulating a digital signal with first three harmonics*

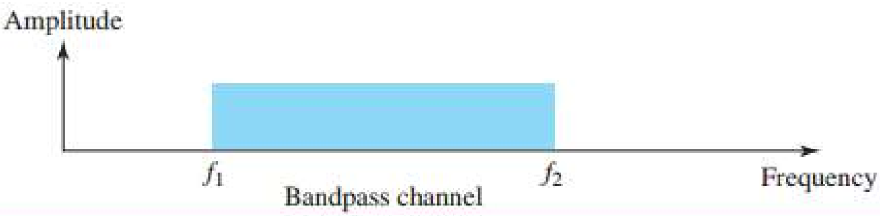


In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth.

Broadband Transmission (Using Modulation)

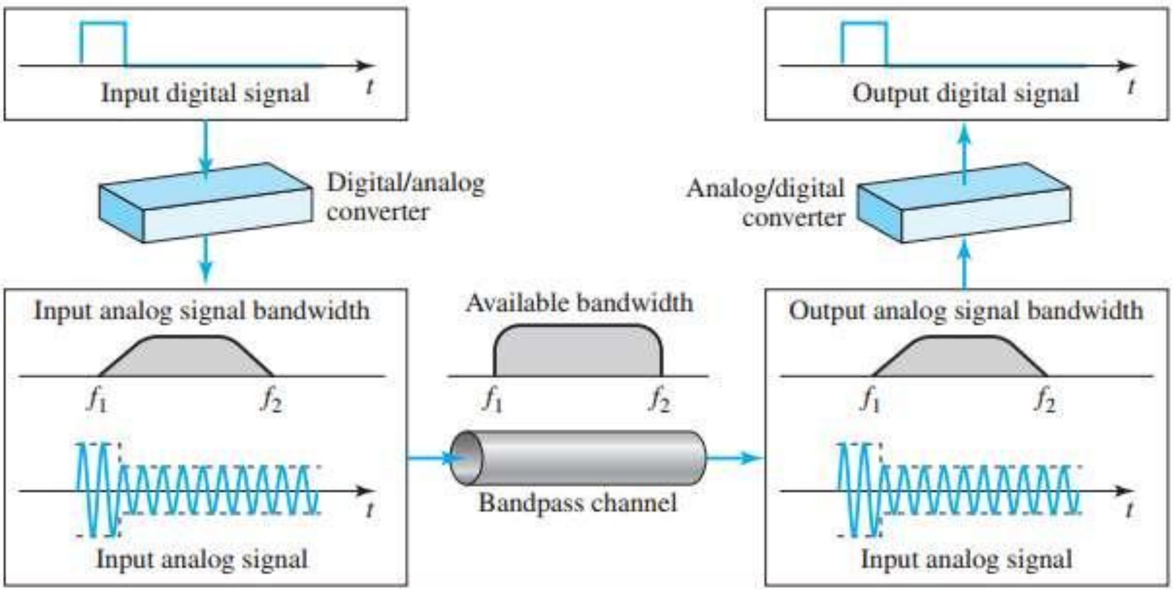
Broadband transmission or modulation means changing the digital signal to an analog signal for transmission. Modulation allows us to use a bandpass channel—a channel with a bandwidth that does not start from zero.

Figure 3.24 *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 3.25 *Modulation of a digital signal for transmission on a bandpass channel*

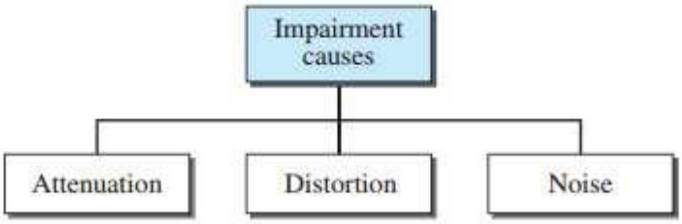


If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

3.4 TRANSMISSION IMPAIRMENT

Changes in the signal while it is transmitted via media are called impairment. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise

Figure 3.26 *Causes of impairment*

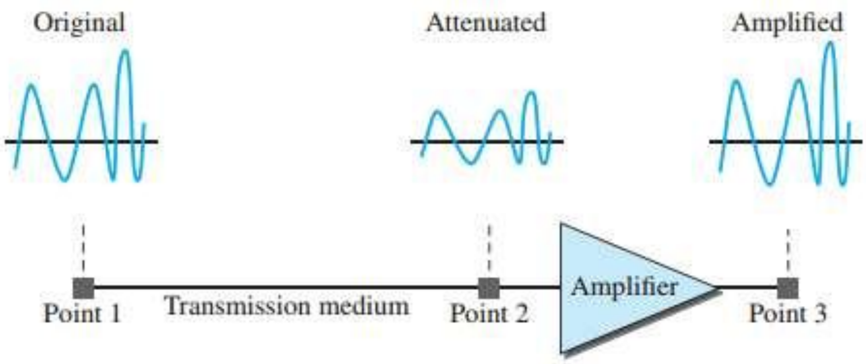


3.4.1 Attenuation

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.

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.

Figure 3.27 *Attenuation*



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

Note : Variables P1 and P2 are the powers of a signal at points 1 and 2, respectively.

Example :

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 = ½ P1. In this case, the attenuation (loss of power) can be calculated as

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

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

Example 3.27

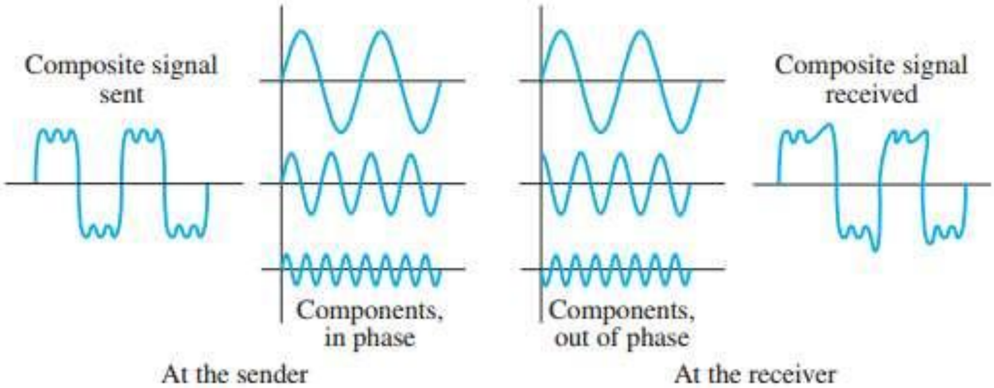
A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1. In this case, the amplification (gain of power) can be calculated as

$$10\log_{10}\frac{P_2}{P_1} = 10\log_{10}\frac{10P_1}{P_1} = 10\log_{10}10 = 10(1) = 10\text{ dB}$$

3.4.2 Distortion

Distortion means that the signal changes its form or shape. Distortion can occur in a composite signal made of different frequencies.

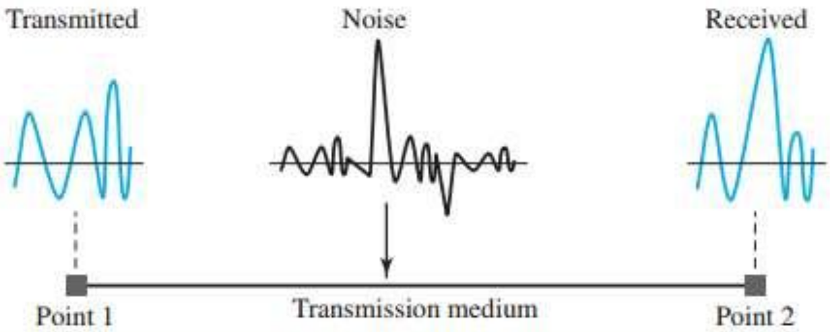
Figure 3.29 *Distortion*



3.4.3 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.

Figure 3.30 *Noise*



Signal-to-Noise Ratio (SNR)

The signal-to-noise ratio is defined as

$$\mathbf{SNR} = \frac{\textbf{average signal power}}{\textbf{average noise power}}$$

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, SNR dB, defined as

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

Example :

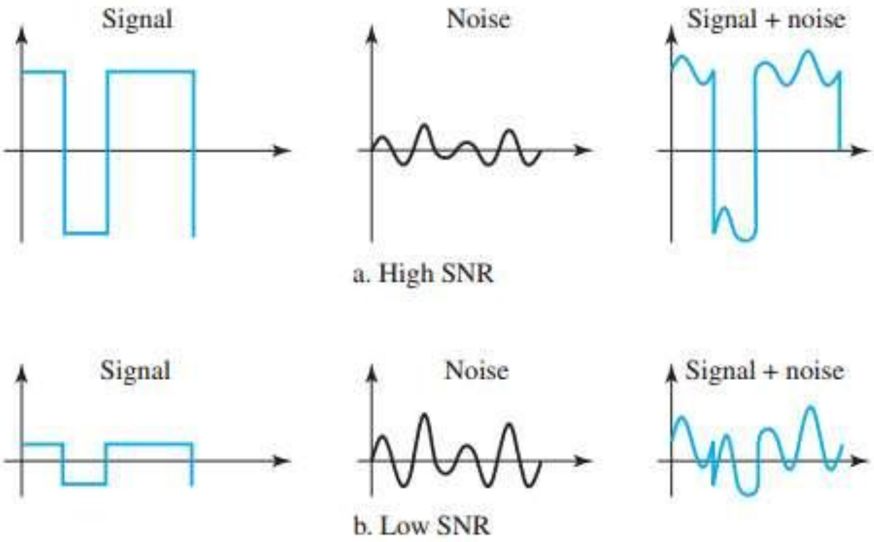
The power of a signal is 10 mW and the power of the noise is 1 mW; what are the values of SNR and SNR dB?

Solution

The values of SNR and SNR dB can be calculated as follows:

SNR = (10,000 μw) / (1 μw) = 10,000 $\quad SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$

Figure 3.31 *Two cases of SNR: a high SNR and a low SNR*



Is a measure of 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.

3.5.1 Noiseless Channel: Nyquist Bit Rate

For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate

$$\text{BitRate} = 2 \times \text{bandwidth} \times \log_2 L$$

In this formula, 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(bps).

Note: Increasing the levels of a signal may reduce the reliability of the system.

Example: Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

$$\textbf{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}$$

Example: Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\textbf{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

3.5.2 Noisy Channel: Shannon Capacity

In reality, we cannot have a noiseless channel; the channel is always noisy. Shannon capacity is to determine the theoretical highest data rate for a noisy channel:

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

Capacity: bits per second
Bandwidth: Hz
SNR: Signal to Noise ratio.

Example:

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$C = B \log_2 (1 + \text{SNR}) = B \log_2(1 + 0) = B \log_2 1 = B \times 0 = 0$$

Example:

We can calculate the theoretical highest bit rate of a regular telephone line of bandwidth 3000Hz and The signal-to-noise ratio is usually 3162.

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2(1 + 3162) = 3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps.

3.6 PERFORMANCE

Performance of the network—how good is it? Performance is discussed wrto Bandwidth, Throughput, Latency (Delay), Bandwidth-delay product and Jitter.

3.6.1 Bandwidth

Bandwidth can be used in two different contexts with two different measuring values: bandwidth in hertz and 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.

3.6.2 Throughput

The throughput is a measure of how fast we can actually send data through a network. A link may have a bandwidth of B bps, but we can only send T bps through this link with T always less than B.

Imagine a highway designed to transmit 1000 cars per minute from one point to another. However, if there is congestion on the road, this figure may be reduced to 100 cars per minute. The bandwidth is 1000 cars per minute; the throughput is 100 cars per minute.

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

Where

Propagation time = Distance / (Propagation Speed) , it is the time taken by a bit to reach destination.

Transmission time = (Message size) / Bandwidth

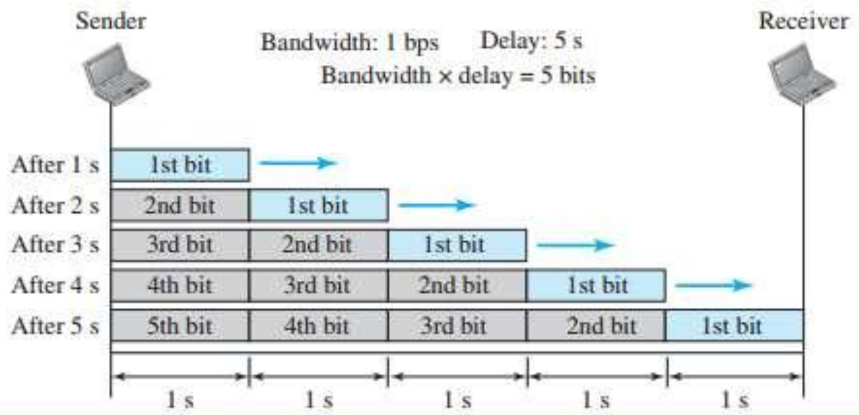
Queuing Time = time needed for each intermediate or end device to hold the message before it can be processed. The queuing time is not a fixed factor; it changes with the load imposed on the network.

3.6.4 Bandwidth-Delay Product

Bandwidth and delay are two performance metrics of a link.

- Case 1. Figure 3.32 shows case 1.

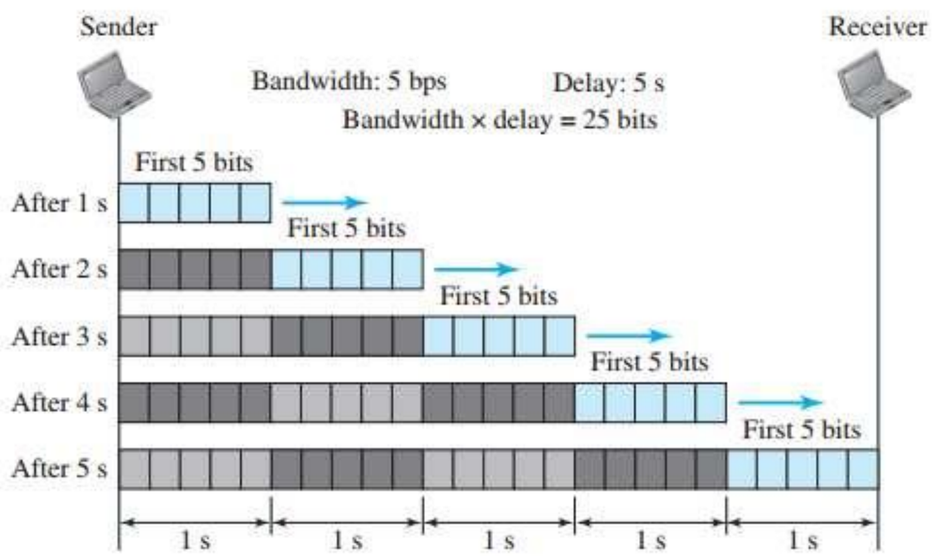
Figure 3.32 *Filling the link with bits for case 1*



There can be no more than 5 bits at any time on the link.

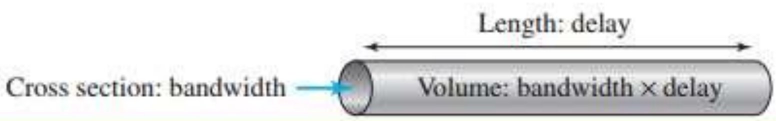
- Case 2. Now assume we have a bandwidth of 5 bps. Figure 3.33 shows that there can be maximum 5 × 5 = 25 bits on the line. The reason is that, at each second, there are 5 bits on the line; the duration of each bit is 0.20 s.

Figure 3.33 *Filling the link with bits in case 2*



Note : The bandwidth-delay product defines the number of bits that can fill the link.

Figure 3.34 *Concept of bandwidth-delay product*



3.6.5 Jitter

Jitter is a problem of different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for example).

Module 1 Chapter 4
Digital Transmission

Digital data which will be in the format of 0 or 1, will transmitted either converting into digital or analog signal.

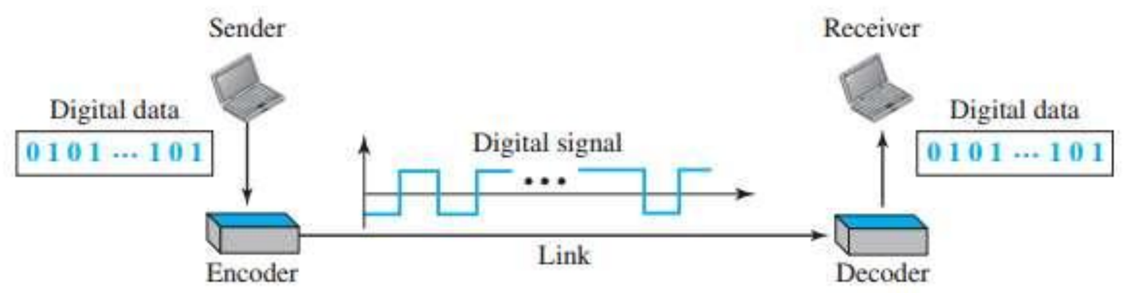
4.1 DIGITAL-TO-DIGITAL CONVERSION

This section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: line coding, block coding, and scrambling. Line coding is always needed; block coding and scrambling may or may not be needed.

4.1.1 Line Coding

Line coding is the process of converting digital data to digital signals. At the sender, digital data are encoded into a digital signal; at the receiver, the digital data are recreated by decoding the digital signal. Figure 4.1 shows the process.

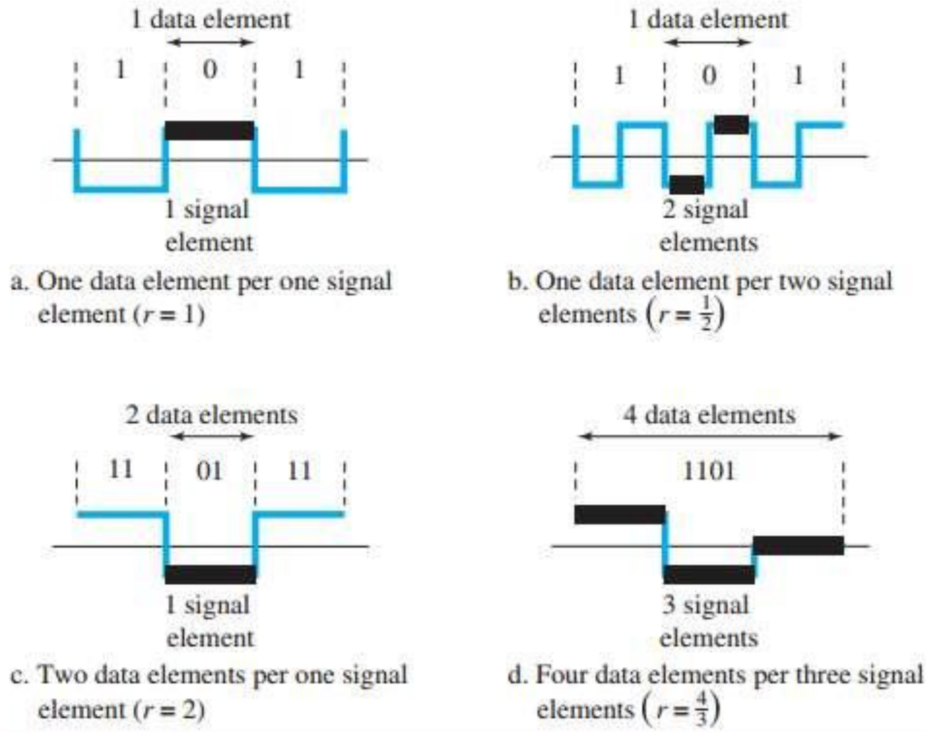
Figure 4.1 *Line coding and decoding*



Characteristics

Signal Element versus Data Element

Figure 4.2 *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 or pulse rate.

$$S = N/r$$

Where: S is Signal Rate (No of signals per second)
N is data rate (bps)

Bandwidth: Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.

The minimum bandwidth can be given as

$$B_{min} = c \times N \times (1 / r)$$

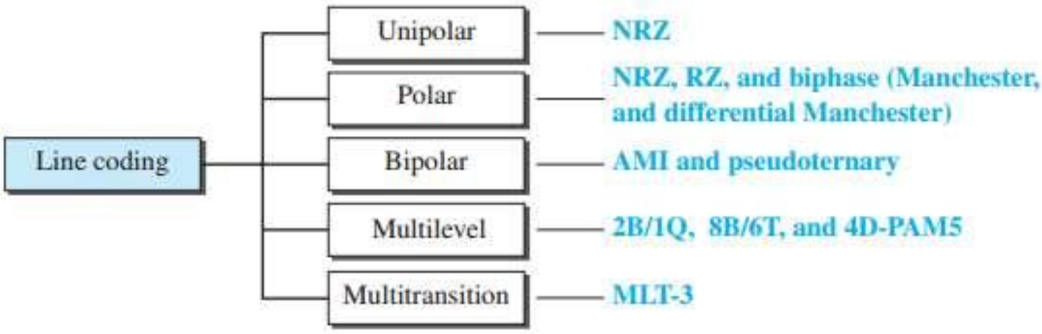
where N is the data rate (bps); c is the case factor, which varies for each case; S is the number of signal elements per second; and r is the previously defined factor.

Note: Although the actual bandwidth of a digital signal is infinite, the effective bandwidth is finite.

4.1.2 Line Coding Schemes

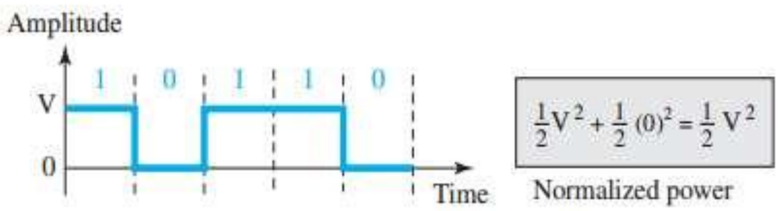
(For syllabus Line Coding: Polar, Bipolar and Manchester coding)

Figure 4.4 *Line coding schemes*



NRZ (Non-Return-to-Zero)

Figure 4.5 *Unipolar NRZ scheme*

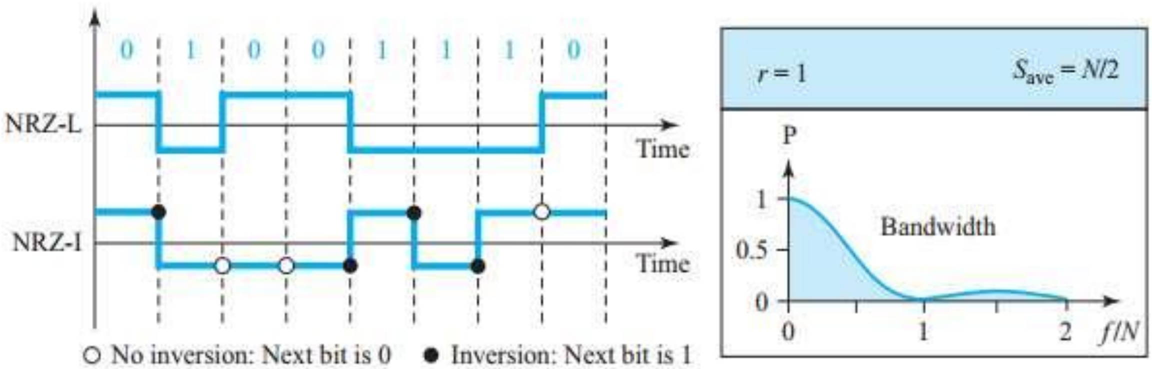


It is called NRZ because the signal does not return to zero at the middle of the bit.

Polar NRZ-L and NRZ-I schemes

In NRZ-L (NRZ-Level), the level of the voltage determines the value of the bit. In 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.

Figure 4.6 *Polar NRZ-L and NRZ-I schemes*

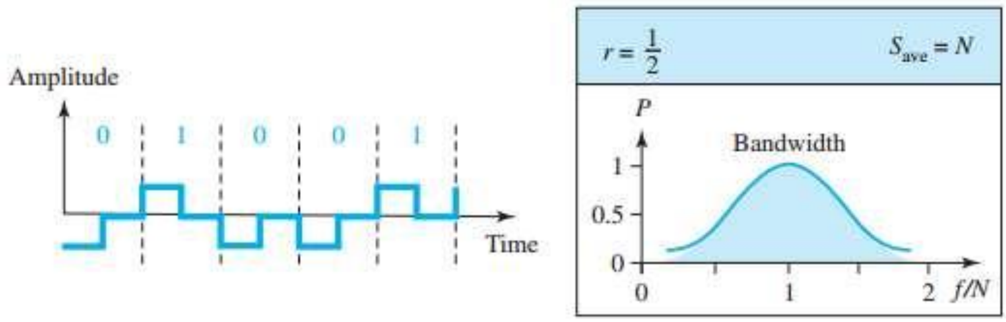


In NRZ-L the level of the voltage determines the value of the bit. In NRZ-I the inversion or the lack of inversion determines the value of the bit.

Return-to-Zero (RZ)

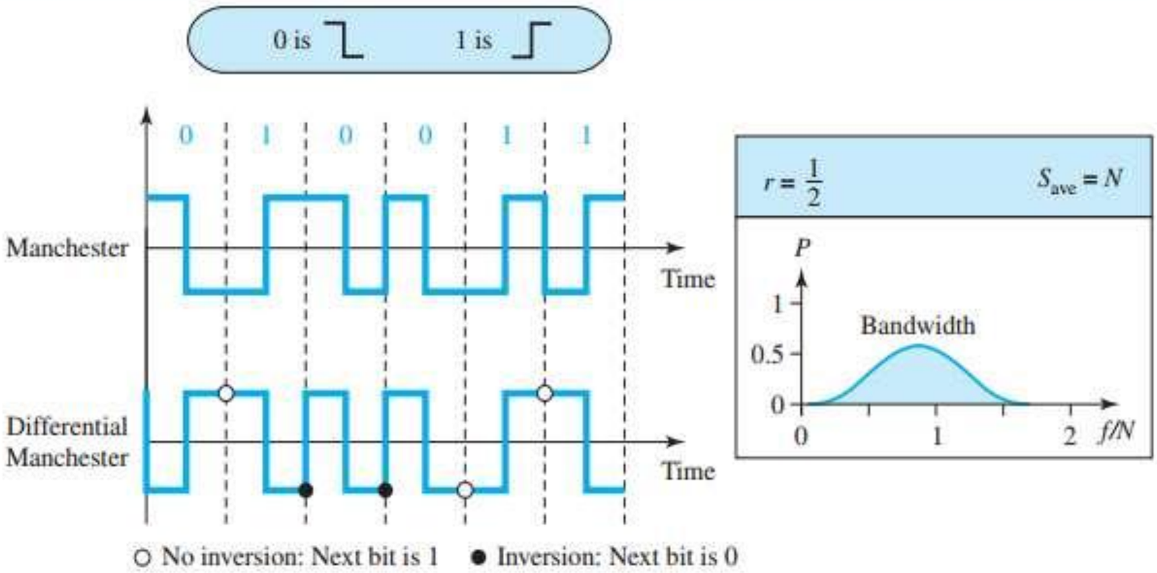
Return-to-zero (RZ) scheme uses three values: positive, negative, and zero. In RZ, the signal changes not between bits but during the bit.

Figure 4.7 *Polar RZ scheme*



Biphase: Manchester and Differential Manchester

Figure 4.8 *Polar biphase: Manchester and differential Manchester schemes*



In Manchester zero and 1 most visit voltage zero in the middle of the signal. Which are shown in fig 4.8

In Differential Manchester if the next bit is 0, there is a transition; if the next bit is 1, there is none.

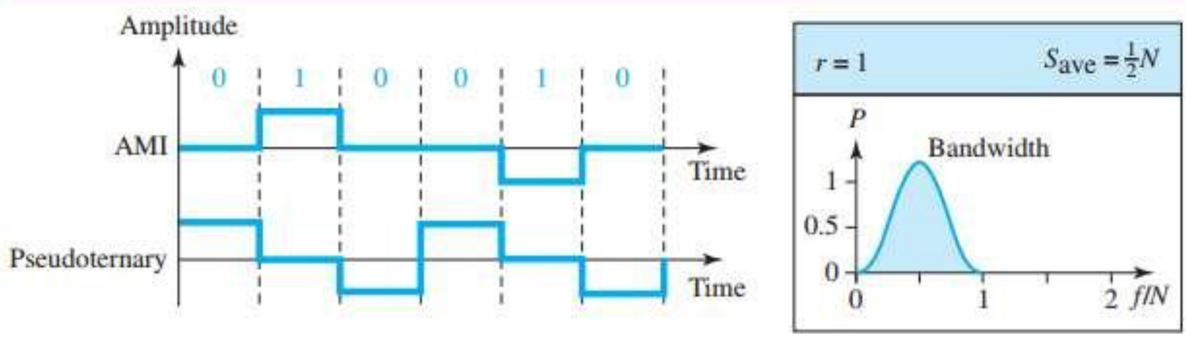
Bipolar Schemes

In bipolar encoding (sometimes called multilevel binary), there are three voltage levels: positive, negative, and zero. The voltage level for one data element is at zero, while the voltage level for the other element alternates between positive and negative.

In bipolar encoding, three levels are used: positive, zero, and negative.

AMI and Pseudoternary

Figure 4.9 *Bipolar schemes: AMI and pseudoternary*



A common bipolar encoding scheme is called bipolar alternate mark inversion (AMI). In the term alternate mark inversion, the word mark comes from telegraphy and means 1. So AMI means alternate 1 inversion. A neutral zero voltage represents binary 0. Binary 1s are represented by alternating positive and negative voltages. A variation of AMI encoding is called pseudoternary in which the 1 bit is encoded as a zero voltage and the 0 bit is encoded as alternating positive and negative voltages.

--- END MODULE 1 ---