# Data Communication and Computer Networks

**Module – I**

**Overview of Data Communications and Networking:**

**Introduction:**

Data communications and networking are changing the way we do business and the way we live. Business decisions have to be made ever more quickly, and the decision makers require immediate access to accurate information.

A revolution is occurring in data communications and networking. Technological advances are making it possible for communications links to carry more and faster signals. As a result, services are evolving to allow use of this expanded capacity.

**Data Communications:**

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 combination of hardware and software.

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.
4. **Jitter:** Jitter refers to the variation in the packet arrival time.

**Components:**

A data communications system has five components as follows;

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.

**Data Representation:**

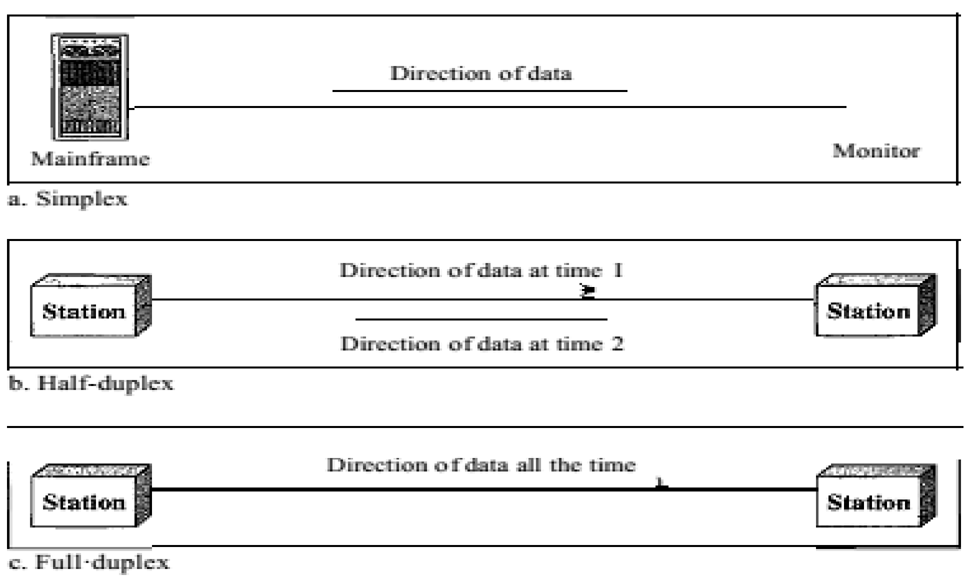
Information today comes in different forms such as text, numbers, images, audio, and video.

1. **Text:** In data communications, text is represented as a bit pattern, a sequence of bits (0s or Is).
2. **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.
3. **Images:** Images are also represented by bit patterns. In its simplest form, an image is composed of matrix of pixels (picture elements), where each pixel is a small dot.
4. **Audio:** Audio refers to the recording or broadcasting of sound or music.
5. **Video:** Video refers to the recording or broadcasting of a picture or movie.

**Data Flow**

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

- **Simplex:** In simplex mode, the communication is unidirectional, as on a one-way street.
- **Half-Duplex:** In half-duplex mode, each station can both transmit and receive, but not at the same time.




- **Full-Duplex**: In full-duplex mode both stations can transmit and receive simultaneously. The full-duplex mode is like a two way street with traffic flowing in both directions at the same time.

**NETWORKS:**

A network is a set of devices connected by communication links. A node can be a computer, printer, or any other device capable of sending and/or receiving data generated by other nodes on the network.

**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.
- **Reliability:** In addition to accuracy of delivery, network reliability is measured by the frequency of failure, the time it takes a link to recover from a failure, and the network's robustness in a catastrophe.
- **Security:** Network security issues include protecting data from unauthorized access, protecting data from damage and development, and implementing policies and procedures for recovery from breaches and data losses.

**Physical Structures**

**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. There are two possible types of connections: point-to-point and multipoint.

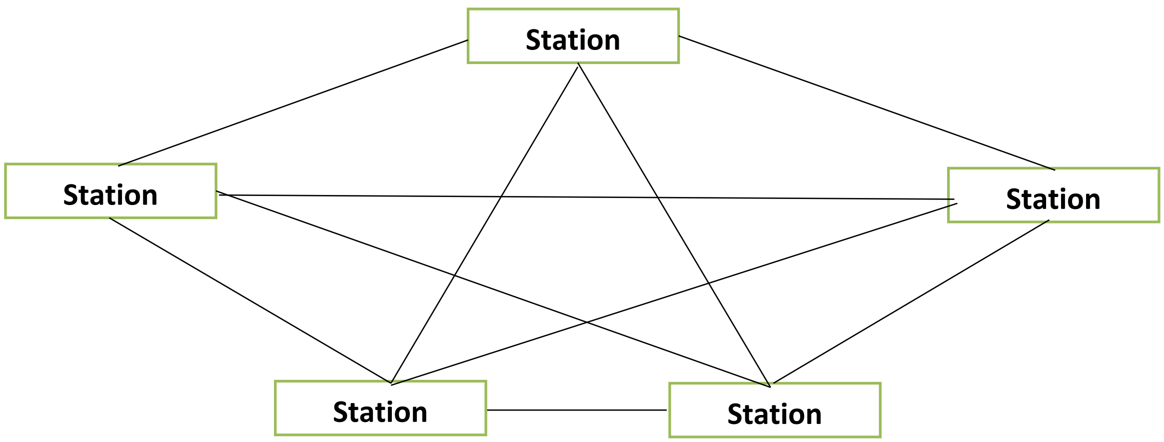
1. **Point-to-Point:** A point-to-point connection provides a dedicated link between two devices.
2. **Multipoint:** A multipoint (also called multi-drop) connection is one in which more than two specific devices share a single link.

**Physical Topology**

- The term physical topology refers to the way in which a network is laid out physically.
- In a network 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 to one another. There are four basic topologies possible: mesh, star, bus, and ring.

**Mesh:**

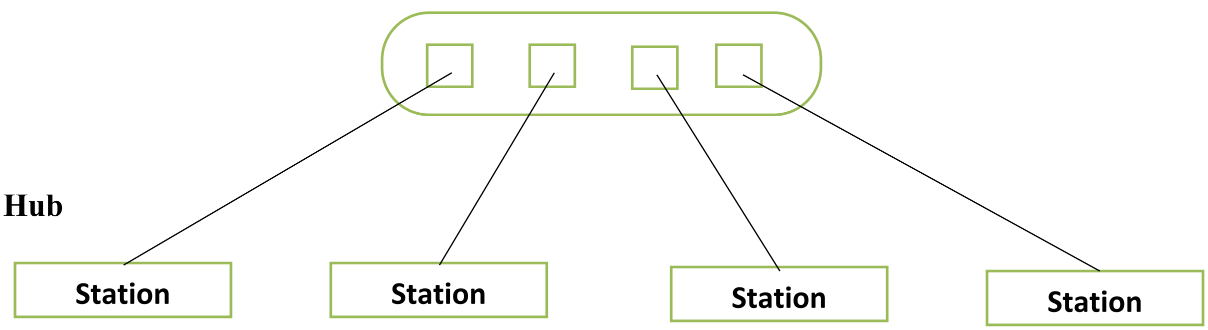
- In a mesh topology, every device has a dedicated point-to-point link to every other device.
- The term *dedicated* means that the link carries traffic only between the two devices it connects.
- To find the number of physical links in a fully connected mesh network with n nodes, we first consider that each node must be connected to every other node. We need n*(n - 1) physical links. However, if each physical link allows communication in both directions (duplex mode), we can divide the number of links by 2. In other words, we can say that in a mesh topology, we need n(n -1) /2.




- **Advantages**
  - The use of dedicated links guarantees that each connection can carry its own data load, thus eliminating the traffic problems that can occur when links must be shared by multiple devices.
  - A mesh topology is robust. If one link becomes unusable, it does not incapacitate the entire system. Third, there is the advantage of privacy or security. Traffic can be routed to avoid links with suspected problems. This facility enables the network manager to discover the precise location of the fault and aids in finding its cause and solution.
- **Disadvantages**
  - The main of a mesh are related to the amount of cabling and the number of I/O ports required. First, because every device must be connected to every other device, installation and reconnection are difficult.
  - The sheer bulk of the wiring can be greater than the available space can accommodate. Finally, the hardware required to connect each link can be prohibitively expensive. For these reasons a mesh topology is usually implemented in a limited fashion.

**Star Topology:**

- In a star topology, each device has a dedicated point-to-point link only to a central controller, usually called a hub. The devices are not directly linked to one another.
- Unlike a mesh topology, a star topology does not allow direct traffic between devices. The controller acts as an exchange: If one device wants to send data to another, it sends the data to the controller, which then relays the data to the other connected device.
- **Advantages**
  - A star topology is less expensive than a mesh topology.
  - In a star, each device needs only one link and one I/O port to connect it to any number of others. This factor also makes it easy to install and reconfigure. Far less cabling needs to be housed, and additions, moves, and deletions involve only one connection: between that device and the hub.
  - Robustness. If one link fails, only that link is affected. All other links remain active. This factor also lends itself to easy fault identification and fault isolation. As long as the hub is working, it can be used to monitor link problems and bypass defective links.



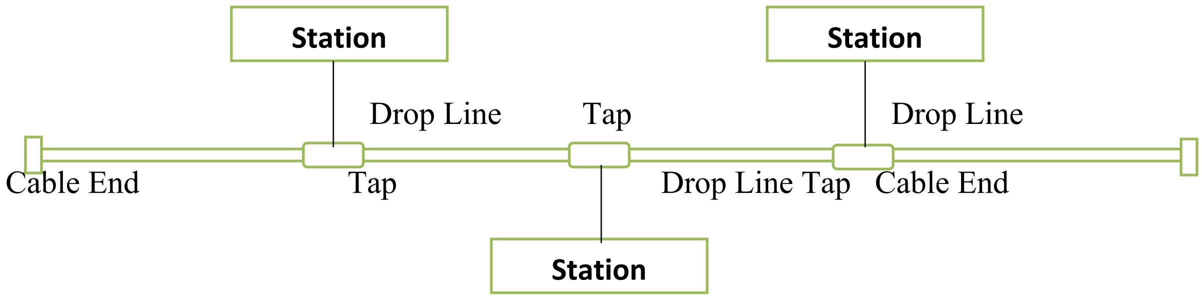

**Hub**

- **Disadvantage: T**he whole topology is dependent on one single point, the hub. If the hub goes down, the whole system is dead. Although a star requires far less cable than a mesh, each node must be linked to a central hub. For this reason, often more cabling is required in a star than in some other topologies.

**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.
- Nodes are connected to the bus cable by drop lines and taps. A drop line is a connection running between the device and the main cable.

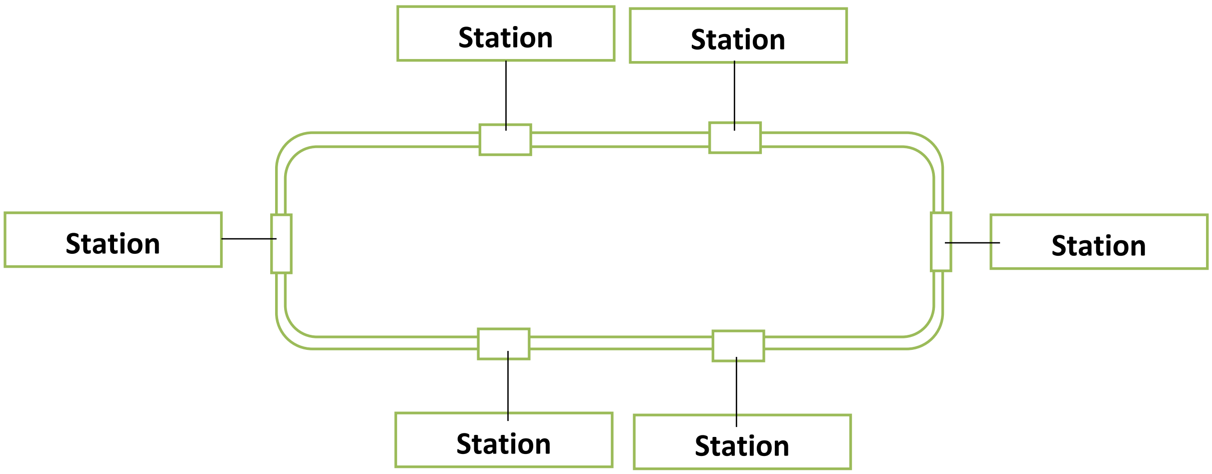
- A tap is a connector that either splices into the main cable or punctures the sheathing of a cable to create a contact with the metallic core.
- As a signal travels along the backbone, some of its energy is transformed into heat. Therefore, it becomes weaker and weaker as it travels farther and farther. For this reason there is a limit on the number of taps a bus can support and on the distance between those taps.




- **Advantages :** A bus topology include ease of installation. Backbone cable can be laid along the most efficient path, then connected to the nodes by drop lines of various lengths. In this way, a bus uses less cabling than mesh or star topologies. In a star, for example, four network devices in the same room require four lengths of cable reaching all the way to the hub. In a bus, this redundancy is eliminated. Only the backbone cable stretches through the entire facility. Each drop line has to reach only as far as the nearest point on the backbone.
- **Disadvantages**:
  - Include difficult reconnection and fault isolation. A bus is usually designed to be optimally efficient at installation. It can therefore be difficult to add new devices. Signal reflection at the taps can cause degradation in quality. This degradation can be controlled by limiting the number and spacing of devices connected to a given length of cable. Adding new devices may therefore require modification or replacement of the backbone.
  - In addition, a fault or break in the bus cable stops all transmission, even between devices on the same side of the problem. The damaged area reflects signals back in the direction of origin, creating noise in both directions.

**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. Each device in the ring incorporates a repeater. When a device receives a signal intended for another device, its repeater regenerates the bits and passes them along.




- A ring is relatively easy to install and reconfigure. Each device is linked to only its immediate neighbors.

- To add or delete a device requires changing only two connections. The only constraints are media and traffic considerations. In addition, fault isolation is simplified. Generally in a ring, a signal is circulating at all times. If one device does not receive a signal within a specified period, it can issue an alarm. The alarm alerts the network operator to the problem and its location.
- However, unidirectional traffic can be a disadvantage. In a simple ring, a break in the ring can disable the entire network. This weakness can be solved by using a dual ring or a switch capable of closing off the break.

1. **Hardware or Network device:**

- **Hub:**
    - It is uses to connect systems or nodes or networks.
    - It has direct connection to a node (point to point connection).
    - It suffers from high collision of data, results to data loss.
    - A hub takes data from input port and retransmits the input data on output port.

- **Repeater:**
    - A repeater is a device which regenerates or amplifies the data or signal so that it can be travel to the other segment of cable.
    - It is use to connect two networks that uses same technology and protocol.
    - It does not filter or translate any data.
    - Work in physical layer.

- **Bridge:**
    - **I**t is used to connect two networks.
    - It divides the collision domain based on number of ports or interface present in a bridge.
    - It uses the packet switches that forward and filter the frames using LAN destination address.
    - Bridge examines the destination address of frame and forwards it to the interface or port which leads to the destination.
    - It uses the routing table for routing frame from one node to other using MAC address.
    - It works in Data Link Layer.

- **Switch :**
    - It is similar to bridge. It has more number of interfaces as compared to bridge.
    - It allows direct communication between the nodes.
    - It work in Data Link Layer.

    - It uses MAC address for data transfer in a network.

- **Router:**
    - It is used to connect different types of network (types- architecture/ Protocol).
    - It work similar to bridge but it uses IP address for routing data.
    - Router can't be used for connecting Systems.
    - It work in Network Layer.

- **Gateways:** Gateways make communication possible between systems that use different communication protocols, data formatting structures, languages and architectures. Gateways repackage data going from one system to another. Gateways are usually dedicated servers on a network and are task-specific.

**Categories of Networks:**

Today when we speak of networks, we are generally referring to two primary categories: local-area networks and wide-area networks. The category into which a network falls is determined by its size. A LAN normally covers an area less than 2 mi; a WAN can be worldwide. Networks of a size in between are normally referred to as metropolitan area networks and span tens of miles.

**Local Area Network:**

- A local area network (LAN) is usually privately owned and links the devices in a single office, building, or campus. Depending on the needs of an organization and the type of technology used, a LAN can be as simple as two PCs and a printer in someone's home office; or it can extend throughout a company and include audio and video peripherals. Currently, LAN size is limited to a few kilometers.
- LANs are designed to allow resources to be shared between personal computers or workstations. In addition to size, LANs are distinguished from other types of networks by their transmission media and topology. In general, a given LAN will use only one type of transmission medium. The most common LAN topologies are bus, ring, and star.

**Wide Area Network:**

- A wide area network (WAN) provides long-distance transmission of data, image, audio, and video information over large geographic areas that may comprise a country, a continent, or even the whole world.

- A WAN can be as complex as the backbones that connect the Internet or as simple as a dial-up line that connects a home computer to the Internet. We normally refer to the first as a switched WAN and to the second as a point-to-point WAN.
- The point-to-point WAN is normally a line leased from a telephone or cable TV provider that connects a home computer or a small LAN to an Internet service provider. This type of WAN is often used to provide Internet access.

**Metropolitan Area Networks:**

A metropolitan area network (MAN) is a network with a size between a LAN and a WAN. It normally covers the area inside a town or a city. It is designed for customers who need a high-speed connectivity, normally to the Internet, and have endpoints spread over a city or part of city. A good example of a MAN is the part of the telephone company network that can provide a high-speed DSL line to the customer.

**THE INTERNET**

The Internet has revolutionized many aspects of our daily lives. It has affected the way we do business as well as the way we spend our leisure time. The Internet is a communication system that has brought a wealth of information to our fingertips and organized it for our use. The Internet is a structured, organized system. We begin with a brief history of the Internet. We follow with a description of the Internet today.

**PROTOCOLS AND STANDARDS:**

In this section, we define two widely used terms: protocols and standards. First, we define protocol, which is synonymous with rule. Then we discuss standards, which are agreed-upon rules.

**Protocols:** 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.

- **Syntax:** It refers to the structure or format of the data. This refers the order in which the data are presented.

**Example :**

- The first 8 bits of data to be the address of the sender.
- The second 8 bits to be the address of the receiver.
- The rest of the stream may be the message itself

- **Semantics:** It refers to the meaning of each section of bits. How a particular pattern to be interpreted. What action is to be taken based on that interpretation

**Example**

An address specifies the route to be taken or the final destination of the message.

- **Timing:** It refers to two characteristics. When data should be sent and how fast they can be sent.

  **Example**

  If a sender produces data at 100 Mbps and the receiver process data at only 1 Mbps, it will overload the receiver and data will be lost.

**Standards:**

Why do we need standards?

- To create and maintain an open and competitive market for equipment manufacturers
- To guarantee national and international interoperability of data, telecommunication technology and process
- To give a fixed quality and product to the customer
- To allow the same product to be re used again elsewhere
- To aid the design and implementation of ideas
- To provide guidelines to manufacturers, vendors, government agencies and other service providers to ensure kind of interconnectivity.

Data communication standards are divided into two categories

**De facto (from the fact):**

- Standards that have not been approved by an organized body.
- It has been adopted as standards through widespread use.
- This is often established originally by manufacturers to define the functionality of a new product or technology.

**De jure (by law):**

- Those that have been legislated by an officially recognized body.

**Standards organizations**

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

**Standards Creation Committees**

**ITU, International Telecommunications Union formerly the (CCITT):**

- It a standard for telecommunication in general and data systems in particular.

**ISO, International Standards Organization** :

- It is active in developing cooperation in the realms of scientific, technological and economic activity.

**ANSI, American National Standards Institute:**

- It is a private nonprofit corporation and affiliated with the U.S federal government.

**IEEE, Institute of Electrical and Electronics Engineers**:

- It aims to advance theory, creativity, and product quality in the fields of electrical engineering, electronics radio and in all related branches of Engineering.
- It oversees the development and adoption of international standards for computing and communications. See http://standards.ieee.org/

**EIA, Electronic Industries Association:**

- It is a nonprofit organization devoted to the promotion of electronics manufacturing concerns.
- Its activities include public awareness education and lobbying efforts in addition to standards development.
- It also made significant contributions by defining physical connection interfaces and electronic signaling specifications for data communication.

**Forums**

- It work with universities and users to test, evaluate, and standardize new technologies.
- The forums are able to speed acceptance and use of those technologies in the telecommunications community.
- It present their conclusions to standard bodies.

**Regulatory Agencies:**

- Its purpose is to protect the public interest by regulating radio, television and wire cable communications.
- It has authority over interstate and international commerce as it relates to communication.

**Internet Standards**

- It is a thoroughly tested specification that is useful to and adhered to by those who work with the internet.
- It is a formalized regulation that must be followed.
- A specification begins as an internet draft and attains Internet standard status.
- An Internet draft is a working document and it may be published as Request for Comment (RFC).RFC is edited, assigned a number, and made available to all interested parties.

**OSI Reference Model**

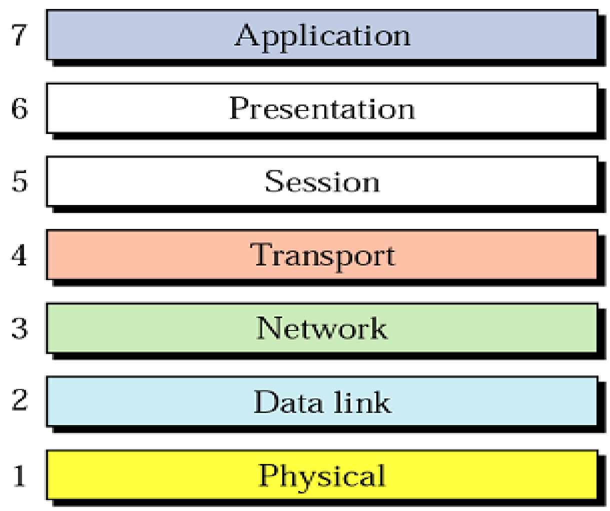



**Figure 1 OSI Model**

- The OSI model shown in figure 1 is based on the proposal developed by the International Standards Organization (ISO) as a first step towards international standardization of the protocols used in the various layers.
- The model is called the OSI (Open System Interconnection) reference model because it deals with connecting open systems, i.e., systems that are open for communication with other systems.
- The purpose of the OSI model is to show how to facilitate communication between different systems without requiring changes to the logic of the underlying hardware and software.
- The OSI model is not a protocol; it is a model for understanding and designing a network architecture that is flexible, robust and interoperable.
- 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. The principles that were applied to arrive at the seven layers are as follows:

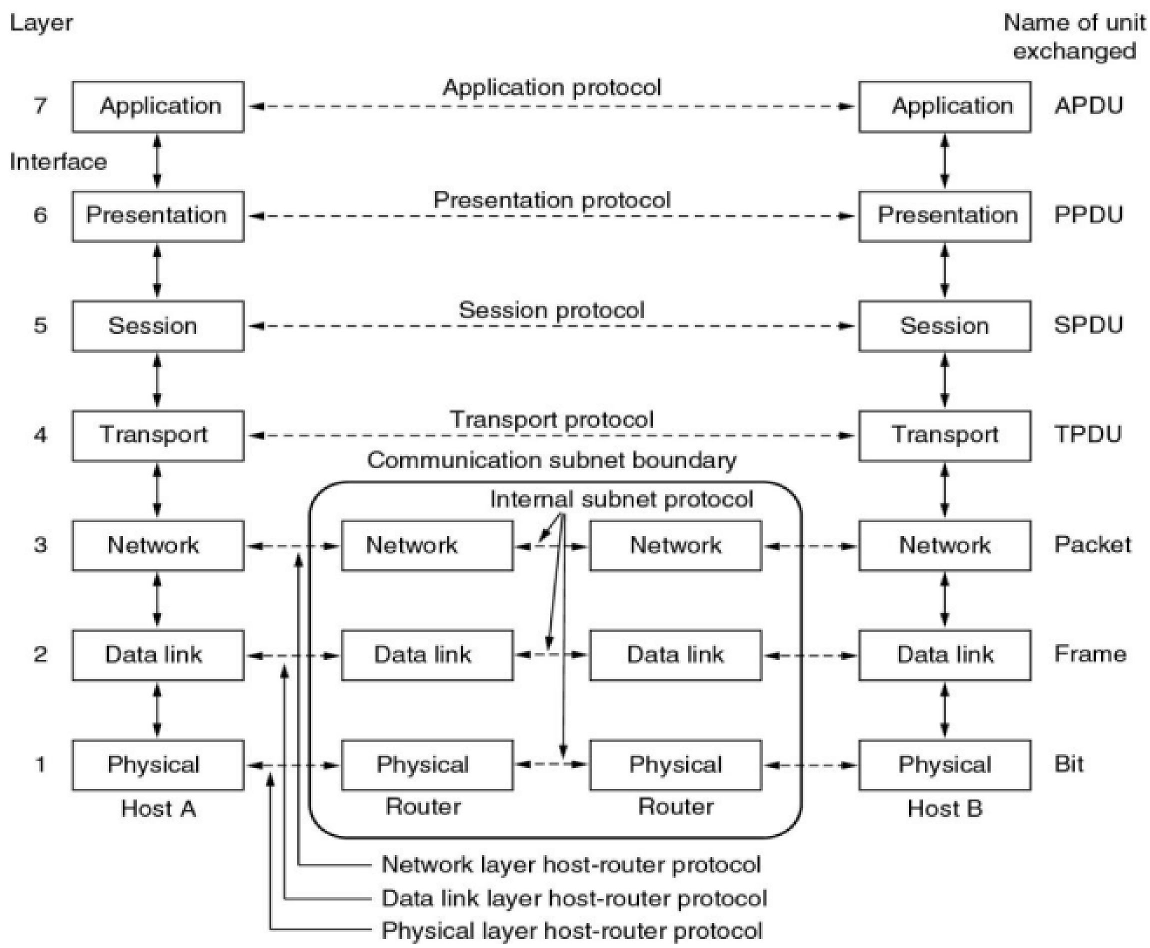
- A layer should be created where a different level of abstraction is needed.
- Each layer should perform a well-defined function.
- The function of each layer should be chosen with an eye toward defining internationally standardized protocols.
- The layer boundaries should be chosen to minimize the information flow across the interfaces.
- The number of layers should be large enough that distinct functions need not be thrown together in the same layer out of necessity and small enough that the architecture does not become unwieldy.

**Layered Architecture:**

The OSI model is composed of seven layers: Physical, Data link, Network, Transport, Session, Presentation, Application layers. Fig (iii) shows the layers involved when a message travels from A to B, it may pass through many intermediate nodes. These intermediate nodes involve only the first 3 layers of the OSI model.

Within a single machine, each layer calls upon the services of the layer just below it, layer 3 for ex. Uses the services provided by layer 2 & provides services for layer 4. Between machines, layer X on one machine communicates with layer X on another machine. This communication is governed by an agreed upon series of rules & Conventions called protocols. The processes on each machine that communicate at a given layer are called peer – to – peer processes.

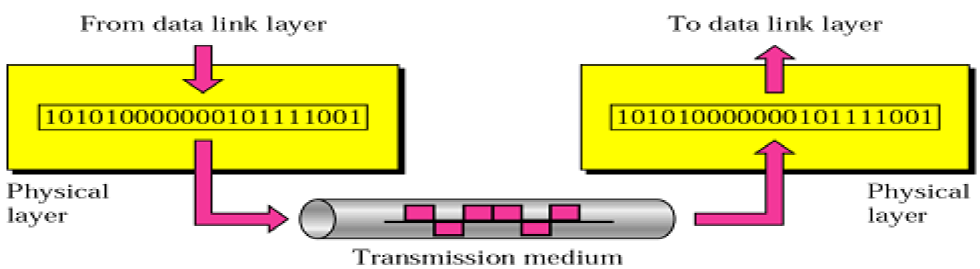
Communication between machines is therefore a peer – to –peer process using the protocols appropriate to a given layer.




**Layers in the OSI model:**

**1. Physical Layer:**

Physical Layer is responsible for movements of individual bits from one node to the next node.

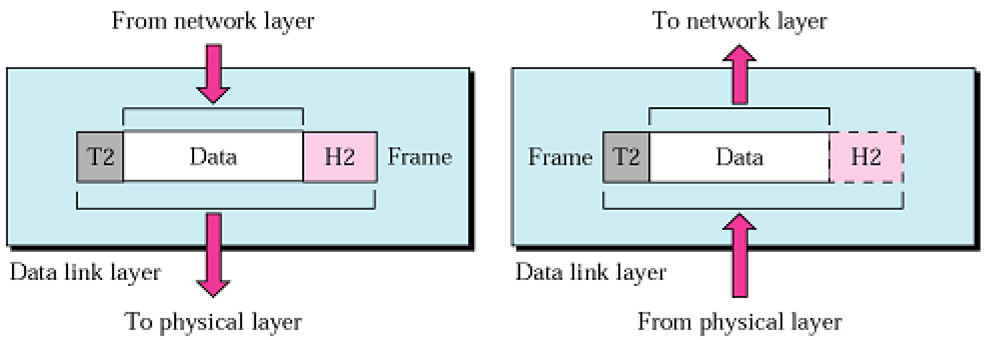



- Physical characteristics of interfaces & medium, type of transmission medium.
- Representation of bits.
- Data rate.
- Synchronization of bits.

- Line configuration.
- Physical topology – Mesh, Star, Ring, Bus, Hybrid.
- Transmission mode – Simplex, Half -duplex, Full-duplex.

## 2. Data Link Layer:

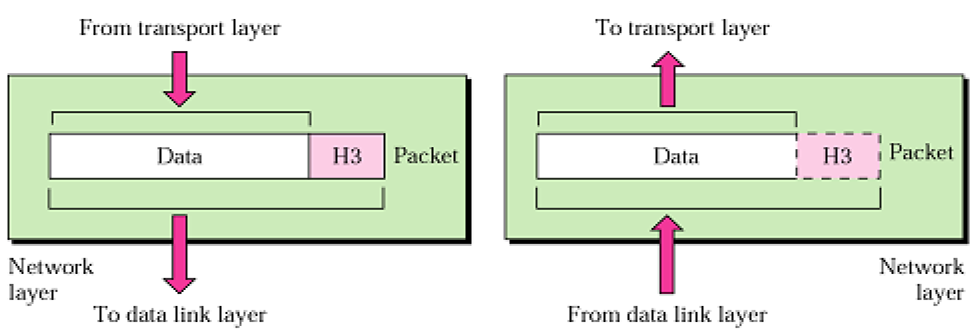
Data link layer is responsible for moving frames from one node to the next.




- Framing.
- Physical addressing.
- Flow control.
- Error control.
- Access control.

## 3. Network Layer:

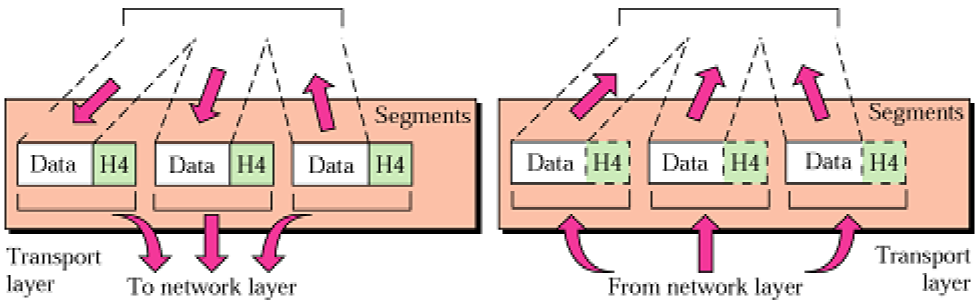
Network layer is responsible for the delivery of individual packets from the source host to the destination host.




- Logical addressing.
- Routing.

## 4. Transport Layer:

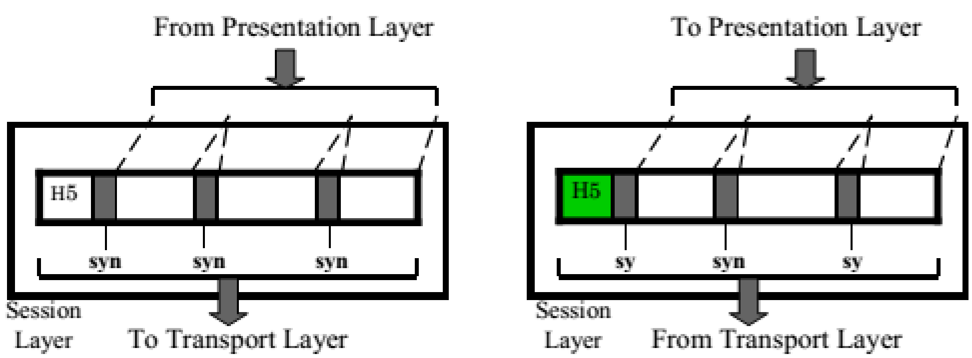
Transport layer is responsible for the delivery of a message from one process to another.




- Service-point addressing.
- Segmentation and reassembly.
- Connection control.
- Flow control.
- Error control.

**5. Session Layer:**

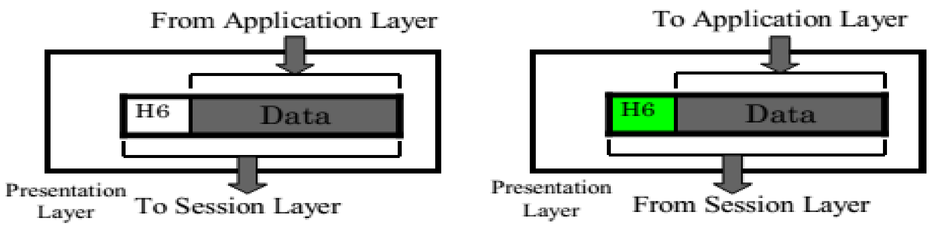
The session layer is responsible for dialog control and synchronization.




- Dialog control.
- Synchronization.

**6. Presentation Layer:**

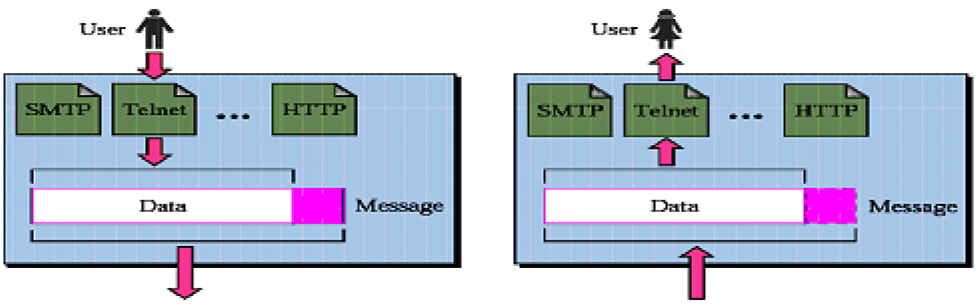
The Presentation layer is responsible for translation, compression, and encryption.




- Concerned with syntax and semantics of the information.
- Translation.
- Encryption.
- Compression.

**7. Application Layer:**

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




- Network virtual terminal.
- File transfer, access, and management.
- Mail services.
- Directory services.

**TCP/IP Protocol suite:**

The TCP/IP protocol suite has four layers: Host – to – Network, Internet, Transport and Application. Comparing TCP/IP to OSI model: the Host – to – Network layer is equivalent to the combination of physical and data link layers, the Internet layer is equivalent to the network layer, the Transport layer in TCP/IP taking care of part of the duties of the session layer, and the application layer is roughly doing the job of the session, presentation, & application layers.

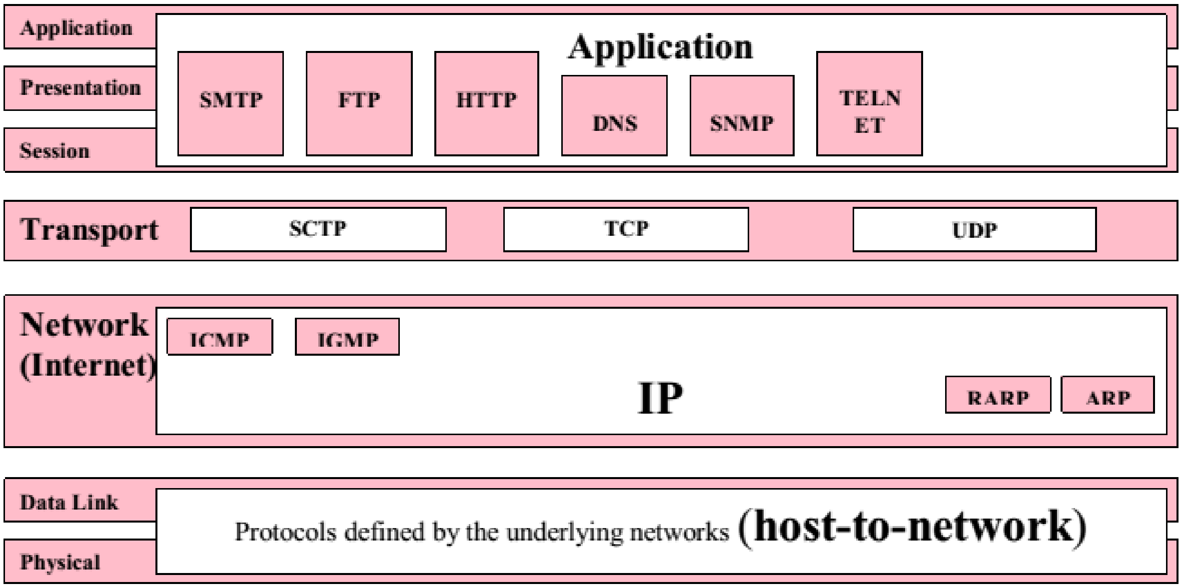
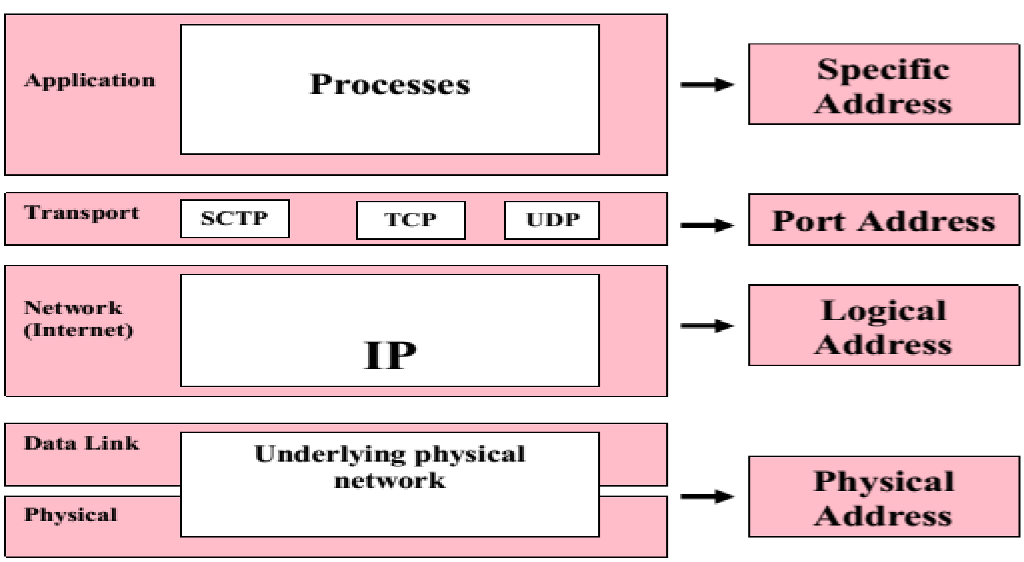



**Figure 2 TCP/IP Protocol suite**

**Addressing:**

Four levels of addresses are used in an internet employing the TCP/IP Protocols:

1. Physical addresses
2. Logical addresses
3. Port addresses
4. Specific addresses



**Physical Layer**

We start the discussion of the Internet model with the bottom-most layer, the physical layer. It is the layer that actually interacts with the transmission media, the physical part of the network that connects network components together. This layer is involved in physically carrying information from one node in the network to the next.

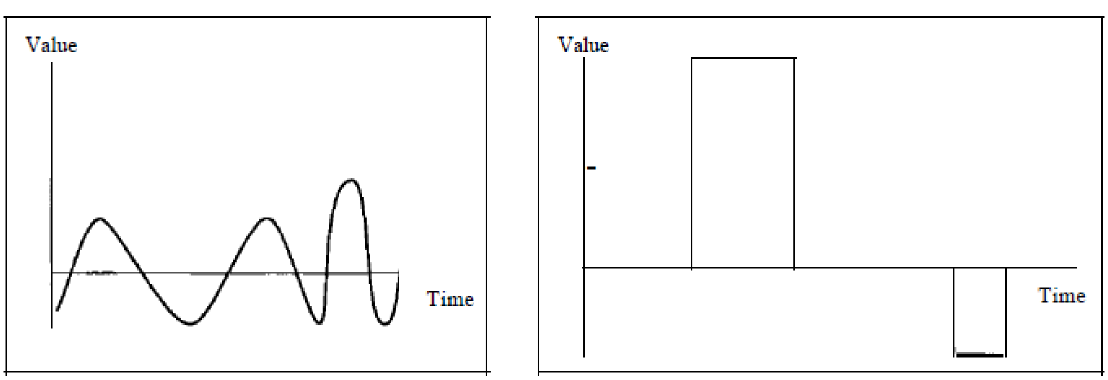
The physical layer has complex tasks to perform. One major task is to provide services for the data link layer. The data in the data link layer consists of 0s and 1s organized into frames that are ready to be sent across the transmission medium. This stream of 0s and 1s must first be converted into another entity: signals. One of the services provided by the physical layer is to create a signal that represents this stream of bits.

The physical layer must also take care of the physical network, the transmission medium. The transmission medium is a passive entity; it has no internal program or logic for control like other layers. The transmission medium must be controlled by the physical layer. The physical layer decides on the directions of data flow. The physical layer decides on the number of logical channels for transporting data coming from different sources.

**Analog and Digital:**

Both data and the signals that represent them can be either **analog or digital** in form. Data can be analog or digital. The term **analog data** refers to information that is continuous; **digital data** refers to information that has discrete states.

Analog data, 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 1s. They can be converted to a digital signal or modulated into an analog signal for transmission across a medium.



a. Analog signal b. Digital signal

## Periodic and Nonperiodic Signals:

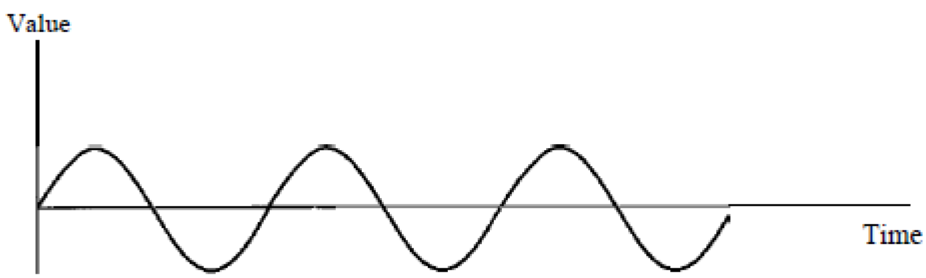
Both analog and digital signals can take one of two forms: periodic or nonperiodic. In data communications, we commonly use periodic analog signals

## Periodic Analog Signals:

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.

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

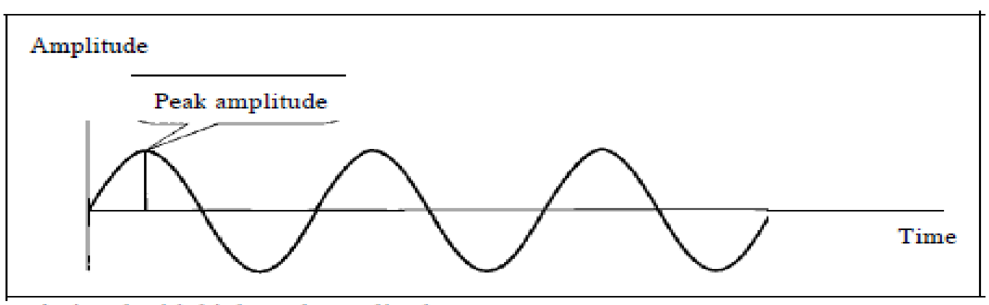
*A sine wave*



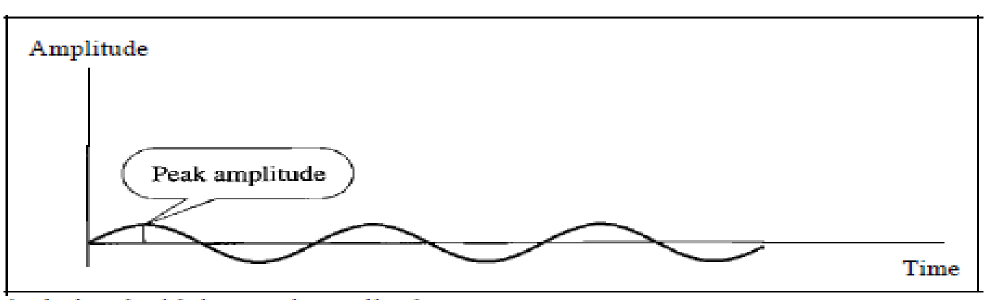

## Peak Amplitude:

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.

*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

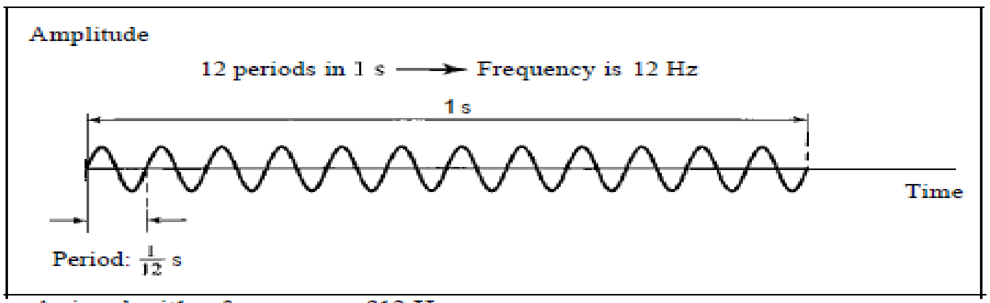
**Period and Frequency:**

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

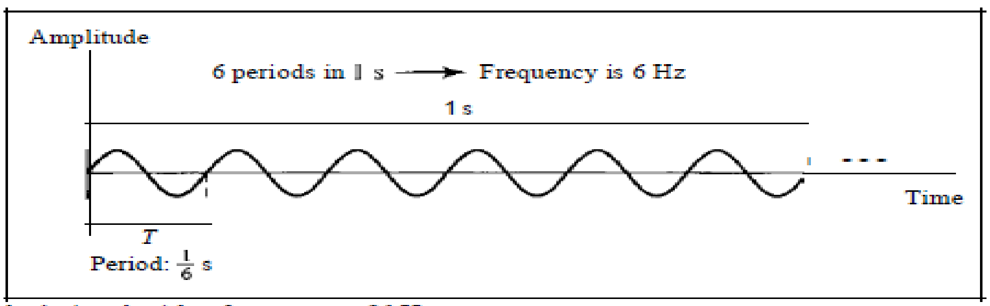
And

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

**Phase:**

The term phase describes the position of the waveform relative to time O. 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..

**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.

**Digital Signals:**

A digital signal can have more than two levels. We can send more than 1 bit for each level.

**Bit Rate:**

Most digital signals are non periodic, and thus period and frequency are not appropriate characteristics. Another term bit rate (instead 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 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.

Bit length =propagation speed x bit duration

**Digital Signal as a Composite Analog Signal:**

Based on Fourier analysis, a digital signal is a composite analog signal. The bandwidth is infinite, as you may have guessed. We can intuitively corne up with this concept when we consider a digital signal. A digital signal, in the time domain, comprises connected vertical and horizontal line segments.

**Analog vs Digital Signals:**

Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

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 O.

**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 10g2 *L*

**Noisy Channel: Shannon Capacity**

In reality, we cannot have a noiseless channel; the channel is always noisy. In 1944, Claude Shannon introduced a formula, called the Shannon capacity, to determine the theoretical highest data rate for a noisy channel:

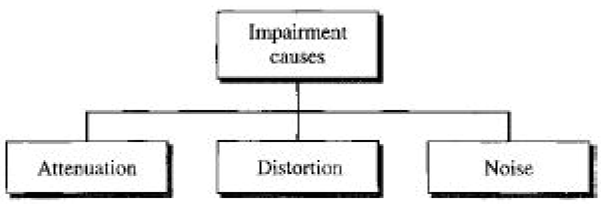
Capacity =bandwidth X log2 (1 +SNR)

## 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

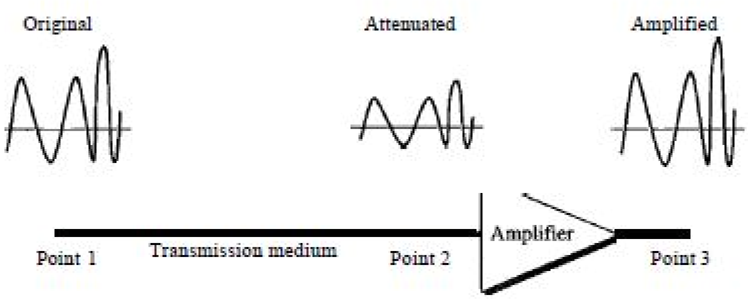
*Causes of impairment*




**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.

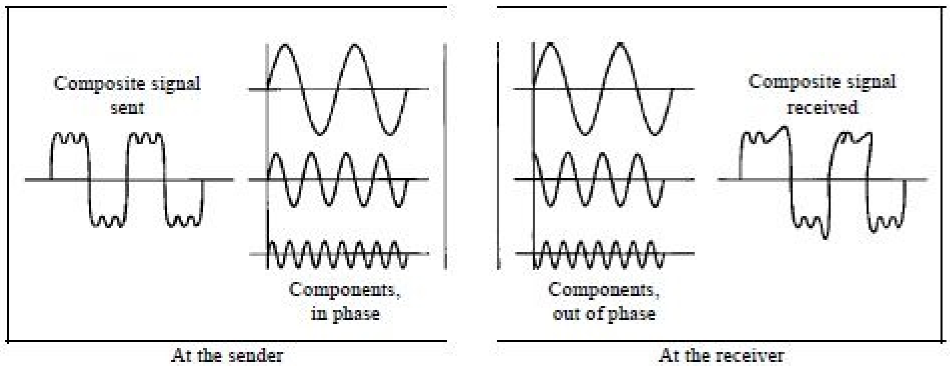
*Attenuation*




**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.

*Distortion*




**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.

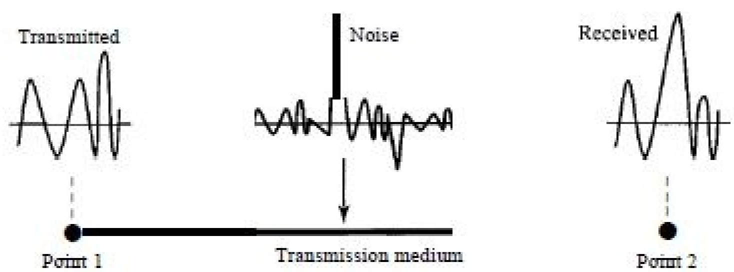
**Thermal noise:** is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.

**Induced noise:** comes from sources such as motors and appliances

**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 soon. Shows the effect of noise on a signal .

*Noise*




**<u>More about signals</u>**

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.

***Two Extremes***

What if a signal does not change at all? What if it maintains a constant voltage level for the entire time it is active? In such a case, its frequency is zero. Conceptually, this idea is a simple one. If a signal does not change at all, it never completes a cycle, so its frequency is aHz. But what if a signal changes instantaneously? What if it jumps from one level to another in no time? Then its frequency is infinite. In other words, when a signal changes instantaneously, its period is zero; since frequency is the inverse of period, in this case, the frequency is 1/0, or infinite.

## Digital Transmission: (DIGITAL TO DIGITAL CONVERSION)

Signals that represent data can also be digital or analog. The conversion from digital to digital involves three techniques: line coding, block coding, and scrambling. Line coding is always needed block coding and scrambling may or may not be needed.

### Line coding:

- Line coding is the process of converting digital data to digital signals. We assume that data, in the form of text, numbers, graphical images, audio, or video, are stored in computer memory as sequences of bits.
- Line coding converts a sequence of bits to a digital signal.
- 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 1shows the process.

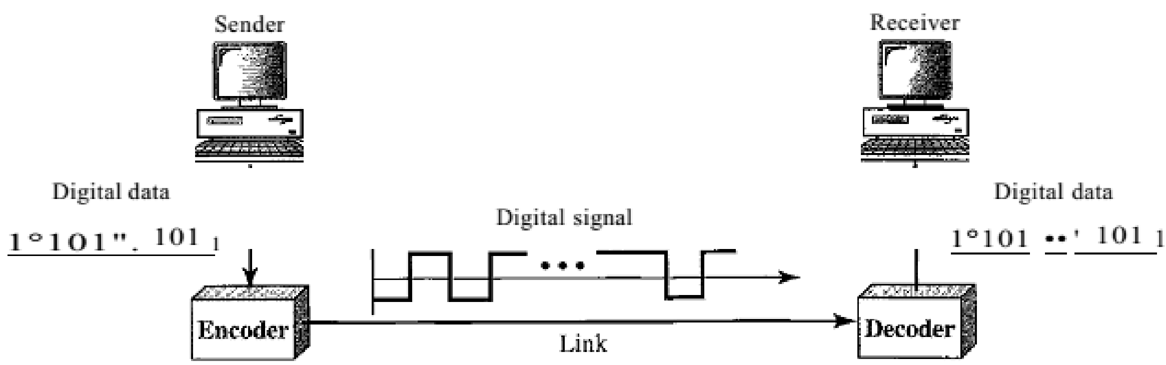



**Figure 3 Line coding Decoding**

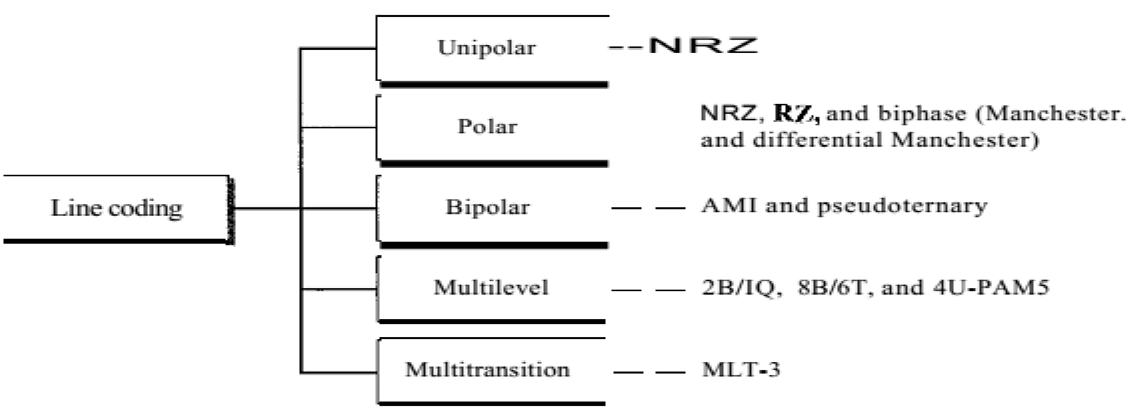
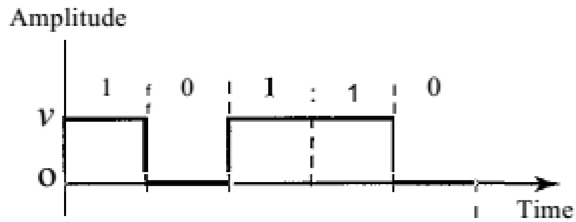



**Figure 4 Line Coding Schemes**

### 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 O. It is called NRZ because the signal does not return to zero at the middle of the bit. Figure 3 show a unipolar NRZ scheme




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

**Figure 5 Unipolar NRZ scheme**

**Polar Schemes**

In polar schemes, the voltages are on the 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, as shown in Figure 4. The figure also shows the value of r, the average baud rate, and the bandwidth.

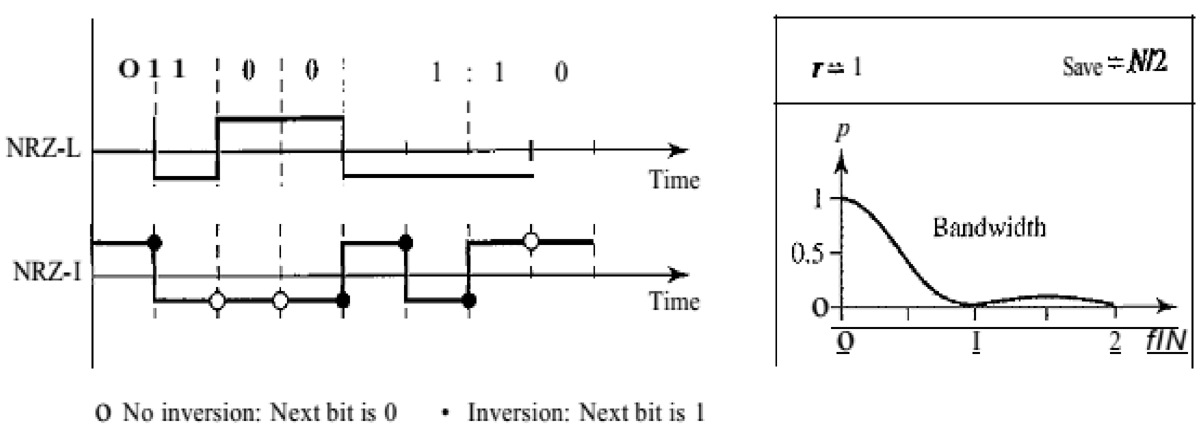



**Figure 6 Polar NRZ-L and NRZ-I scheme**

- **NRZ-L (NRZ-Level)**
  - The level of the voltage determines the value of the bit.
  - In NRZ-L encoding, the polarity of the signal changes only when the incoming signal changes from a 1 to a 0 or from a 0 to a 1.

- NRZ-L method looks just like the NRZ method, except for the first input one data bit. This is because NRZ does not consider the first data bit to be a polarity change, where NRZ-L does.

- **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.
    - Transition at the beginning of bit interval = bit 1 and No Transition at beginning of bit interval = bit 0 or vice versa. This technique is known as differential encoding.

NRZ-I has an advantage over NRZ-L. Consider the situation when two data wires are wrongly connected in each other's place. In NRZ-L all bit sequences will get reversed (B'coz voltage levels get swapped). Whereas in NRZ-I since bits are recognized by transition the bits will be correctly interpreted. A disadvantage in NRZ codes is that a string of 0's or 1's will prevent synchronization of transmitter clock with receiver clock and a separate clock line need to be provided.

**Biphase encoding:** It has following characteristics:

- Modulation rate twice that of NRZ and bandwidth correspondingly greater. (Modulation is the rate at which signal level is changed).
- Because there is predictable transition during each bit time, the receiver can synchronize on that transition i.e. clock is extracted from the signal itself.
- Since there can be transition at the beginning as well as in the middle of the bit interval the clock operates at twice the data transfer rate.

**Manchester scheme:**

- 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.

**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. Figure 5 shows both Manchester and differential Manchester encoding.

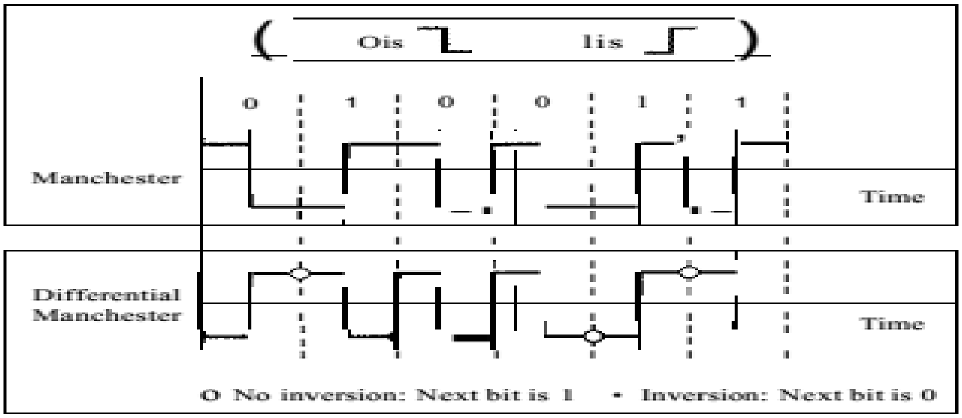



Figure 7 Biphase encoding

**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.
- AMI and Pseudoternary Figure 6 shows two variations of bipolar encoding: 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 alternateI inversion. A neutral zero voltage represents binary O. 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.

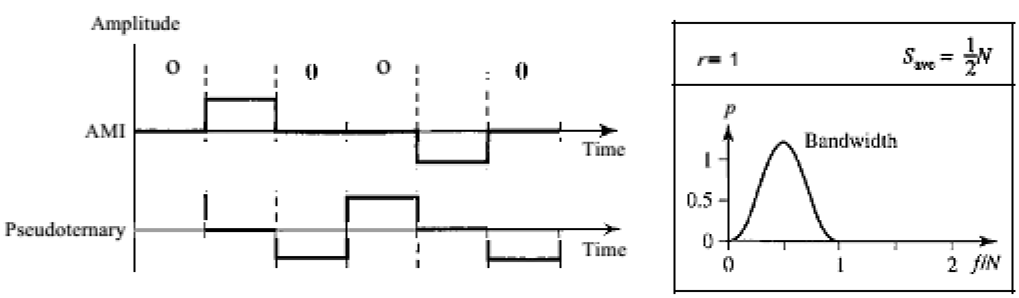



Figure 8 Bipolar Schemes

**Multilevel Schemes**

- The goal is to increase the number of bits per baud by encoding a pattern of m data elements into a pattern of n signal elements. We only have two types of data elements (Os and 1s), which means that a group of m data elements can produce a combination of $2^m$ data patterns.
- We can have different types of signal elements by allowing different signal levels. If we have L different levels, then we can produce $L^n$ combinations of signal patterns.
- If $2^m=L^n$, then each data pattern is encoded into one signal pattern.

- If $2^m < L^n$, data patterns occupy only a subset of signal patterns. The subset can be carefully designed to prevent baseline wandering, to provide synchronization, and to detect errors that occurred during data transmission.
- Data encoding is not possible if $2^m < L^n$ because some of the data patterns cannot be encoded.
- The code designers have classified these types of coding as mBnL, where m is the length of the binary pattern, B means binary data, n is the length of the signal pattern, and L is the number of levels in the signalling. A letter is often used in place of L: B (binary) for L=2 ,T (ternary) for L=3, and Q(quaternary) for L=4. Note that the first two letters define the data pattern, and the second two define the signal pattern.
- **2B1Q**
    - The first mBnL scheme we discuss, two binary, one quaternary(2BIQ),uses data patterns of size 2 and encodes the 2-bit patterns as one signal element belonging to a four-level signal. In this type of encoding m=2, n=1,and L=4 (quatemary). Figure 7 shows an example of a 2B1Q signal.
    - The average signal rate of 2BlQ is S=N/4.This means that using2BIQ, we can send data 2 times faster than by using NRZ-L. However, 2BlQ uses four different signal levels, which means the receiver has to discern four different thresholds. The reduced bandwidth comes with a price. There are no redundant signal patterns in this scheme because $2^2=4$ [1]

.

| | Previous level: positive | Previous level: negative |
|---|---|---|
| Next bits | Next level | Next level |
| 00 | +1 | -1 |
| 01 | +3 | -3 |
| 10 | -1 | +1 |
| 11 | -3 | +3 |

Transition table

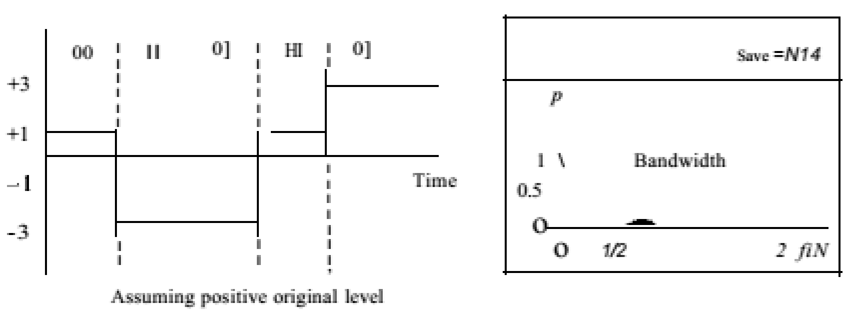



**Figure 9 Multilevel 2B1Q**

**Multitransition:**

The multiline transmission, three level (MLT-3) scheme uses three levels (+*v,* 0, and - *V)* and three transition rules to move between the levels.

a) If the next bit is 0, there is no transition.
b) If the next bit is 1 and the current level is not 0, the next level is 0.
c) If the next bit is 1 and the cut Tent level is 0, the next level is the opposite of the last nonzero level.

**Block coding**

- 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.

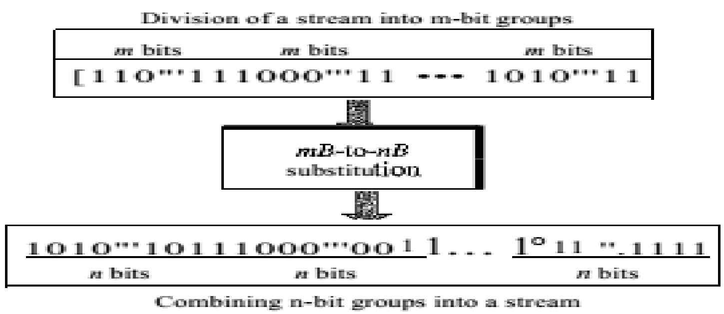



Figure 10 Block Encoding concept

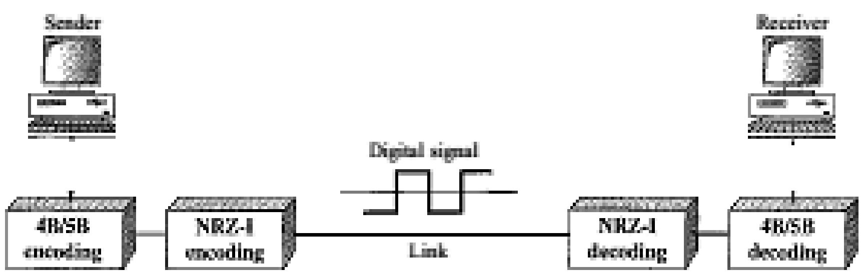



Figure 11 Using block coding 4B/5B with NRZ-I line coding Scheme

**Analog to Digital Conversion:**

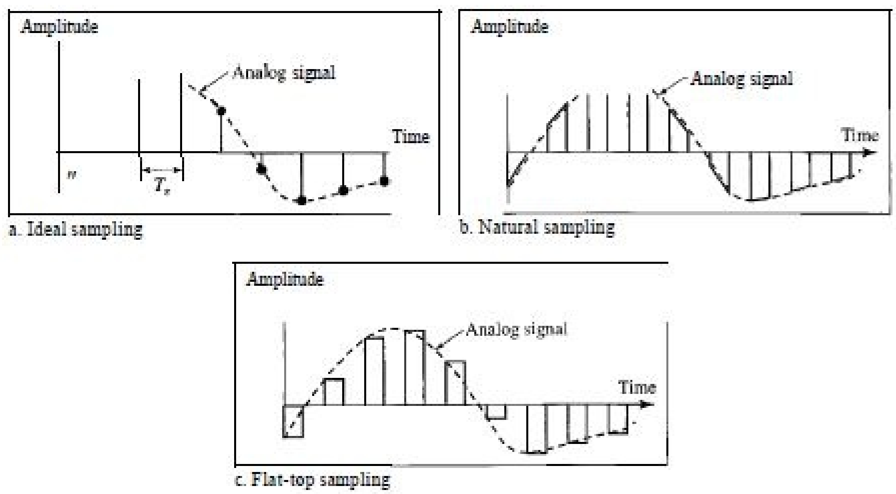
Microphones creates analog voice and camera creates analog videos, which here in our case is treated is analog data. To transmit this analog data over digital signals we need an analog to digital conversion. Analog data is wave form continuous stream of data whereas digital data is discrete. To convert analog wave into digital data we use Pulse Code Modulation. Pulse Code Modulation is one of the most commonly used method to convert analog data into digital form. It involves three steps: Sampling, Quantization and Encoding.

**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 *is,* where *is = IITs'*

There are three sampling methods: Ideal, Natural, and Flat-top

*Three different sampling methods for PCM*




**Ideal Sampling:**

In ideal sampling, pulses from the analog signal are sampled. This is an ideal sampling method and cannot be easily implemented.

**Natural Sampling:**

In natural sampling, a high-speed switch is turned on for only the small period of time when the sampling occurs.

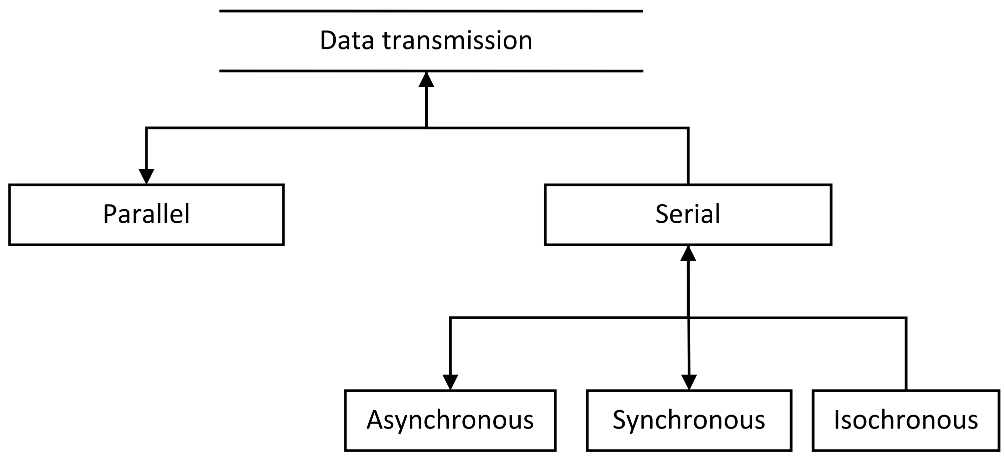
**Flat-top:**

The most common sampling method, called sample and hold, however, creates flat-top samples by using a circuit.

**Transmission mode**

The transmission of data from one device to another is the wiring, and of primary concern when we are considering the wiring is the data stream.

The transmission of binary data across a link can be accomplished in either parallel or serial mode.

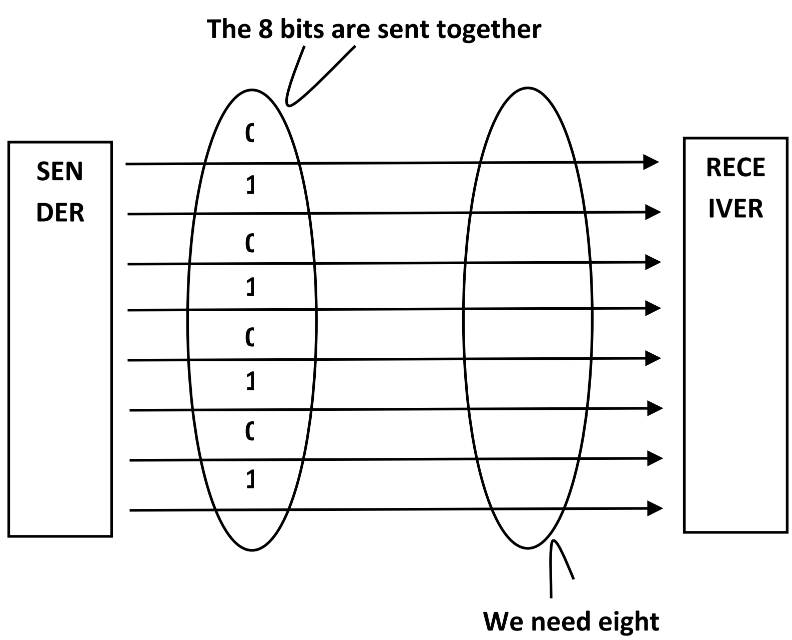



[Data transmission and modes]

**Parallel Transmission:**

Binary data, consisting of 1s and Os, may be organized into groups of *n* bits each.

Computers produce and consume data in groups of bits much as we conceive of and use spoken language in the form of words rather than letters. By grouping, we can send data *n* bits at a time instead of 1. This is called parallel transmission.

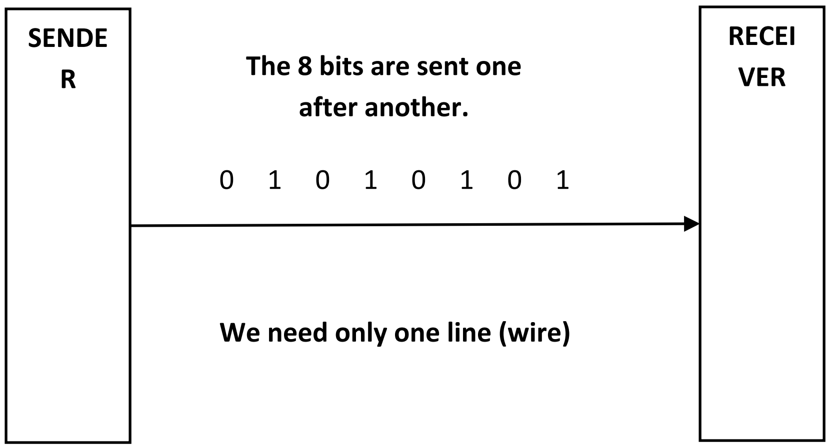



[Parallel Transmission]

The mechanism for parallel transmission is a conceptually simple one: Use *n* wires to send *n* bits at one time. The advantage of parallel transmission is speed

**Serial Transmission:**

In serial transmission one bit follows another, so we need only one communication channel rather than *n* to transmit data between two communicating devices.




[Serial Transmission]

The advantage of serial over parallel transmission is that with only one communication channel, serial transmission reduces the cost of transmission over parallel by roughly a factor of *n*.

Serial transmission occurs in one of three ways:

1. **Asynchronous**
2. **Synchronous**
3. **Isochronous**

**Asynchronous :**

- Asynchronous transmission is so named because the timing of a signal is unimportant. Instead, information is received and translated by agreed upon patterns.
- In this mode an extra bits are added with the data to indicate beginning and ending of the data.

| | | |
|---|---|---|
| START bit | DATA | STOP Bit |

**Synchronous :**

In synchronous transmission, the bit stream is combined into longer "frames," which may contain multiple bytes. Each byte, however, is introduced onto the transmission link without a gap between it and the next one.

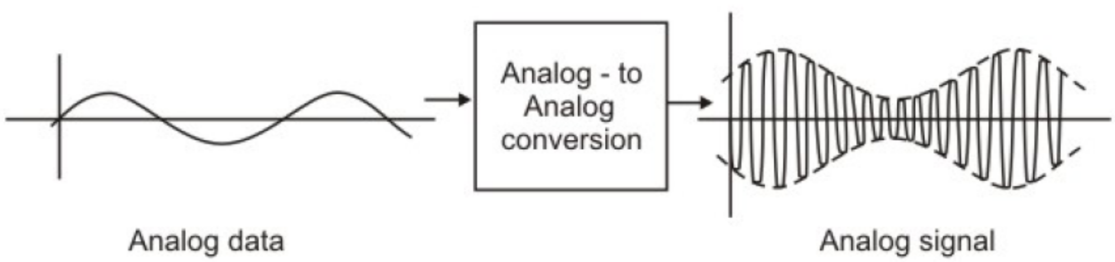
**Isochronous :**

The isochronous transmission guarantees that the data arrive at a fixed rate.

**Analog Transmission:**

**ANALOG TRANSMISSION**

An analog transmission requires lower bandwidth having band pass characteristics. The process involved in analog transmission is known as **modulation**, which requires manipulation of one or more of the parameters of the carrier that characterizes the analog signal.




Some of the important advantages of modulation are summarized below:

**Frequency translation**:

Modulation translates the signal from one region of frequency domain to another region. This helps to transmit the modulated signal with minimum attenuation through a particular medium.

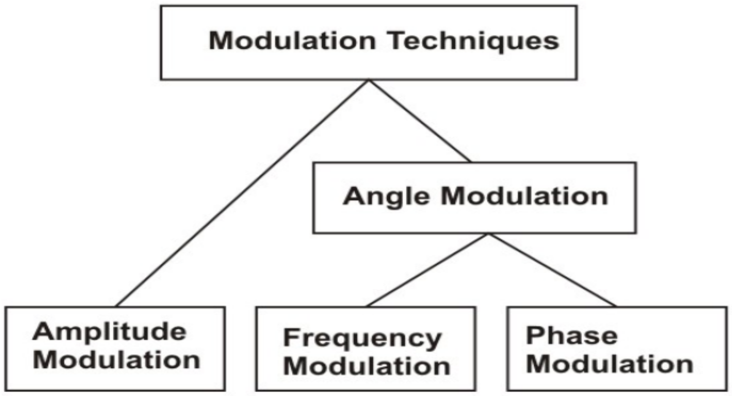
**Practical size of antenna**:

Modulation translates baseband signal to higher frequency, which can be transmitted through a bandpass channel using an antenna of smaller size. This has made communication practical.

**Narrowbanding**:

As modulation translates a signal from lower frequency domain to higher frequency domain, the ratio between highest to lowest frequency of the modulated signal becomes close to 1.

The **modulation technique** can be broadly divided into two basic categories; Amplitude modulation and Angle modulation. The Angle modulation can be further divided into two more categories;




**Amplitude Modulation (AM)**

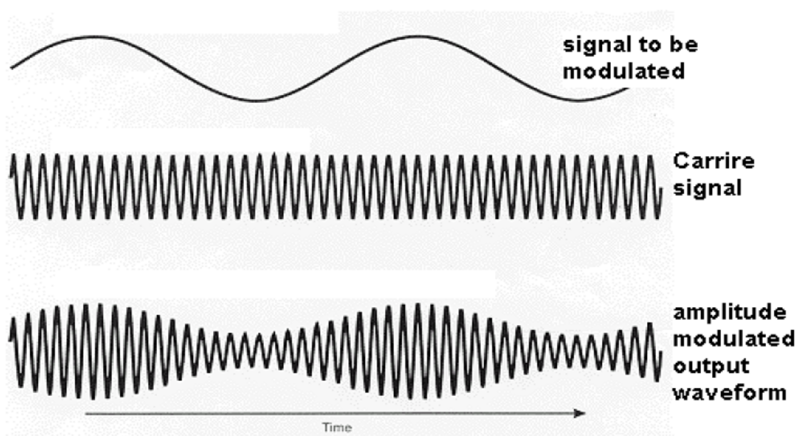
This is the simplest form of modulation where the amplitude of the carrier wave is modulated by the analog signal known as the *modulating signal*.

**Modulation Index:** The modulation index, represented by m, is given by

m = (Emax - Emin )/ (Emax + Emin ) = Em / Ec,

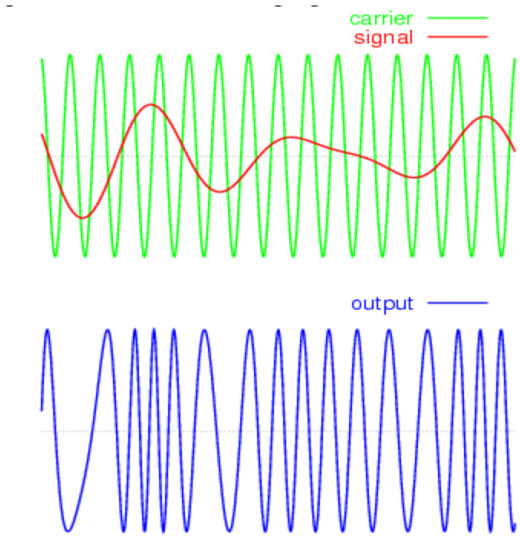
whereEmax = Ec + Em ,

Emin = Ec - Em, and s(t) = Ec (1 + m cos 2πfmt) cos 2πfct,




**Angle Modulation**

Angle modulation noted that the amplitude of the modulated signal is constant. *Frequency Modulation* (FM) and *Phase Modulation* (PM) are the special cases of Angle modulation.




**Frequency modulation**

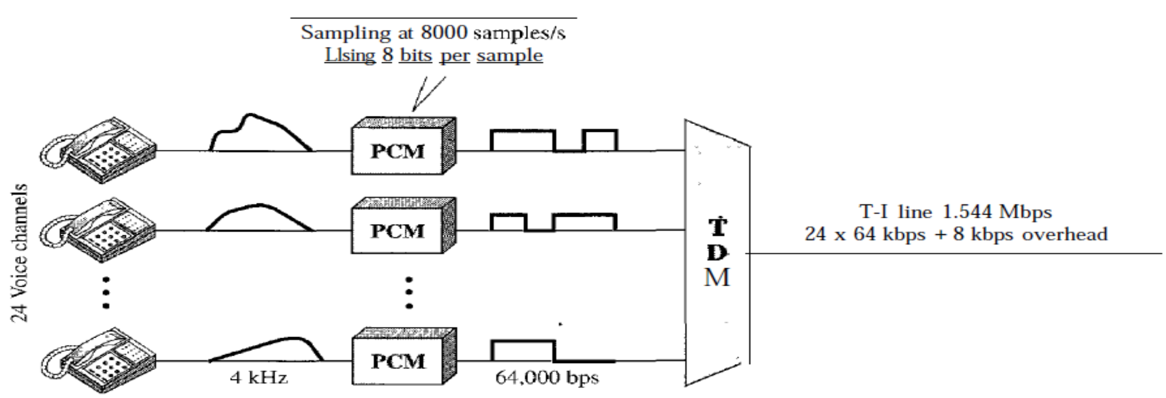
In case of frequency modulation, the modulating signal em(t) is used to vary the carrier frequency. The change is frequency is proportional to the modulating voltage kem(t), where k is a constant known as frequency deviation constant, expressed in Hz/V.

**T Lines**

DS-O, DS-l, and so on are the names of services. To implement those services, the telephone companies use **T lines** (T-l to T-4). These are lines with capacities precisely matched to the data rates of the DS-l to DS-4 services . So far only T-l and T-3 lines are commercially available.

**T Lines for Analog Transmission**

T lines are digital lines designed for the transmission of digital data, audio, or video. However, they also can be used for analog transmission (regular telephone connections), Provided the analog signals are first sampled, then time-division multiplexed. The possibility of using T lines as analog carriers opened up a new generation of services for the telephone companies. Earlier, when an organization wanted 24 separate telephone lines, it needed to run 24 twisted-pair cables from the company to the central exchange.



## MULTIPLEXING

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link.

The process of making the most effective use of the available channel capacity is called **Multiplexing**. Most common use of multiplexing is in long-haul communication using coaxial cable, microwave and optical fibre.

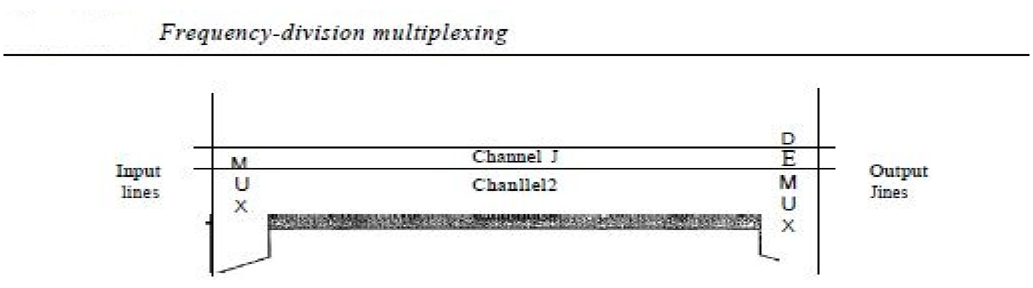
Multiplexing techniques can be categorized into the following three types:

***frequency-division multiplexing (FDM)*:** It is most popular and is used extensively in radio and TV transmission. Here the frequency spectrum is divided into several logical channels, giving each user exclusive possession of a particular frequency band.

***Time-division Multiplexing (TDM):*** It is also called synchronous TDM, which is commonly used for multiplexing digitized voice stream. The users take turns using the entire channel for short burst of time.

***Statistical TDM:*** This is also called asynchronous TDM, which simply improves on the efficiency of synchronous TDM.

## Frequency-Division Multiplexing (FDM)



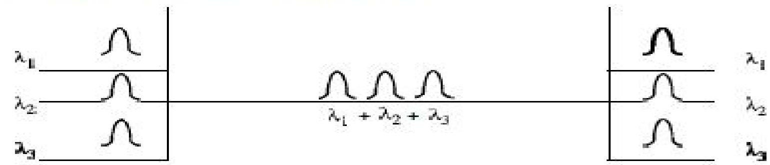

In frequency division multiplexing, the available bandwidth of a single physical medium is subdivided into several independent frequency channels. Independent message signals are translated into different frequency bands using modulation techniques, which are combined by a linear summing circuit in the multiplexer, to a composite signal.

FDM are commonly used in radio broadcasts and TV networks. Since, the frequency band used for voice transmission in a telephone network is 4000 Hz, for a particular cable of 48 KHz bandwidth, in the 70 to 108 KHz range.

## Wavelength-Division Multiplexing

Wavelength-division multiplexing (WDM) is conceptually same as the FDM, except that the multiplexing and demultiplexing involves light signals transmitted through fibre-optic channels.

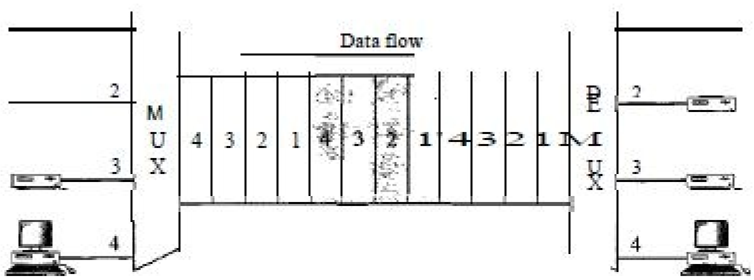
Wavelength-division multiplexing




The idea is the same: we are combining different frequency signals. However, the difference is that the frequencies are very high. It is designed to utilize the high data rate capability of fibre-optic cable. Very narrow band of light signal from different source are combined to make a wider band of light. At the receiver the signals are separated with the help of a demultiplexer.

## Time-Division Multiplexing (TDM)

TDM




In frequency division multiplexing, all signals operate at the same time with different frequencies, but in Time-division multiplexing all signals operate with same frequency at different times.

This is a base band transmission system, where an electronic commutator sequentially samples all data source and combines them to form a composite base band signal, which travels through the media and is being demultiplexed into appropriate independent message signals by the corresponding communatator at the receiving end.

## TRANSMISSION MEDIA

A **transmission medium** (plural *transmission media*) is a material substance (solid, liquid, gas, or plasma) which can propagate energy waves. For example, the transmission medium for sound received by the ears is usually air, but solids and liquids may also act as transmission media for sound.

Transmission media are the physical pathways that connect computers, other devices, and people on a network.

A transmission medium can be classified as a:

- ***Linear medium***, if different waves at any particular point in the medium can be superposed;
- ***Bounded medium***, if it is finite in extent, otherwise *unbounded medium*;
- ***Uniform medium*** or ***homogeneous medium***, if its physical properties are unchanged at different points;
- ***Isotropic medium***, if its physical properties are the same in different directions.

**Types of Transmission media:**

The means through which data is transformed from one place to another is called transmission or communication media.

There are two categories of transmission media used in computer communications.

- **GUIDED MEDIA**
- **UNGUIDED MEDIA**

**1. GUIDED MEDIA:**

Bounded media are the physical links through which signals are confined to narrow path. These are also called guide media. Bounded media are made up o a external conductor (Usually Copper) bounded by jacket material. Bounded media are great for LABS because they offer high speed, good security and low cast. However, some time they cannot be used due distance communication.

Three common types of bounded media are used these are :

- Coaxial Cable.
- Twisted pair cable.
- Fiber optics

**COAXIAL CABLE:**

Coaxial cable is very common & widely used commutation media. For example TV wire is usually coaxial. Coaxial cable gets its name because it contains two conductors that are parallel to each other.

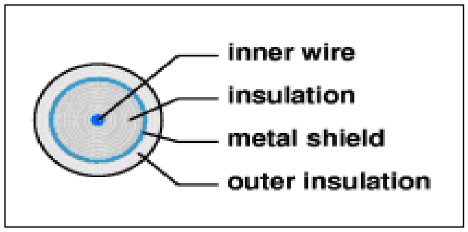



**Fig.: Cross-section of a coaxial cable**

**ADVANTAGES :**

- Inexpensive
- Easy to wire
- Moderate level of EMI immunity

**DISADVANTAGE :**

- Single cable failure can take down an entire network

**TWISTED PAIR CABLE :**

The most popular network cabling is Twisted pair. It is light weight, easy to install, inexpensive and support many different types of network. It also supports the speed of **100 mps.** Twisted pair cabling is made of pairs of solid or stranded copper twisted along each other.

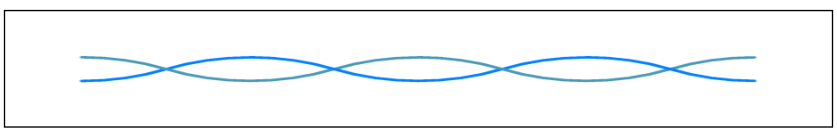


**Fig.: Twisted pair wire**

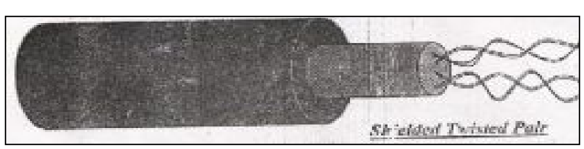
There are two types of twisted pairs cabling

**1. Unshielded twisted pair (UTP)**

**2. Shielded twisted pair (STP)**

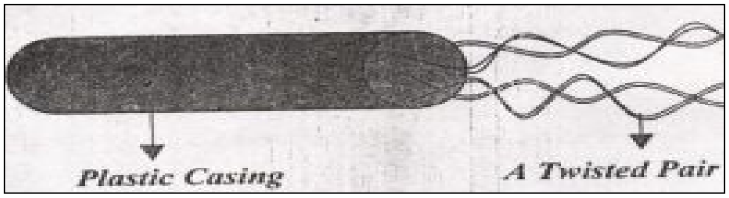
**Unshielded twisted pair (UTP)**

UTP is more common. It can be either voice grade or data grade depending on the condition. UTP cable normally has an impedance of 100 ohm. UTP cost less than STP and easily available.



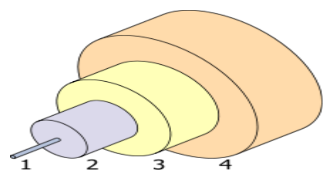
**Shielded twisted pair (STP)**

It is similar to UTP but has a mesh shielding that's protects it from EMI which allows for higher transmission rate.




**FIBER OPTICS:**

Fiber optic cable uses electrical signals to transmit data. It uses light. In fiber optic cable light only moves in one direction for two way communication to take place a second connection must be made between the two devices. It is actually two stands of cable.




1. Core: 8 µm diameter.
2. Cladding: 125 µm diameter.
3. Buffer: 250 µm diameter.
4. Jacket: 400 µm diameter.

**Fig.: Structure of fiber optic cable**

**ADVANTAGES:**

- Fast
- Low attenuation
- No EMI interference

**DISADVANTAGES:**

- Very costly
- Hard to install

**2. UNBOUNDED MEDIA:**

**Unguided transmission media** are methods that allow the transmission of data without the use of physical means to define the path it takes. Unguided media provide a means for transmitting electromagnetic waves but do not guide them; examples are propagation through air, vacuum and seawater.

Examples of Unguided media are:

- microwave
- radio waves
- infrared waves
- Satellites

**Microwave:** Microwave transmission is usually point-to-point using directional antennae with a clear path between transmitter and receiver.

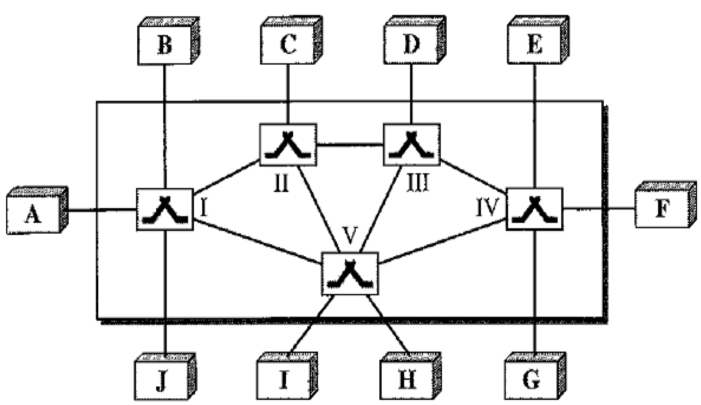
**Radio:** Radio is the transmission of signals by modulation of electromagnetic waves with frequencies below those of visible light.

**Infrared:** Infrared (IR) light is electromagnetic radiation with a wavelength between 0.7 and 300 micrometers, which equates to a frequency range between approximately 1 and 430 THz.

**Satellites:** `When used for communications, a satellite acts as a repeater. Its height above the Earth means that signals can be transmitted over distances that are very much greater than the line of sight.

**Circuit switching**

A network is a collection of inter connected system. In a network we have in one to one communication. To resolves this one of the solution is to make point to point connection between each pair of system(using mesh topology)or connecting centralized system to every other system(using star topology). But still this is not a cost effective as number of system grows and it is limited to small distance between inter connected system.



A solution to the above problem is switching. A switched network consists of a series of interlinked device called switches (shown in figure 10). It is a device which can create a temporary connections between two or more system linked to the switch. In switched network some of the nodes are system and other are used for routing.

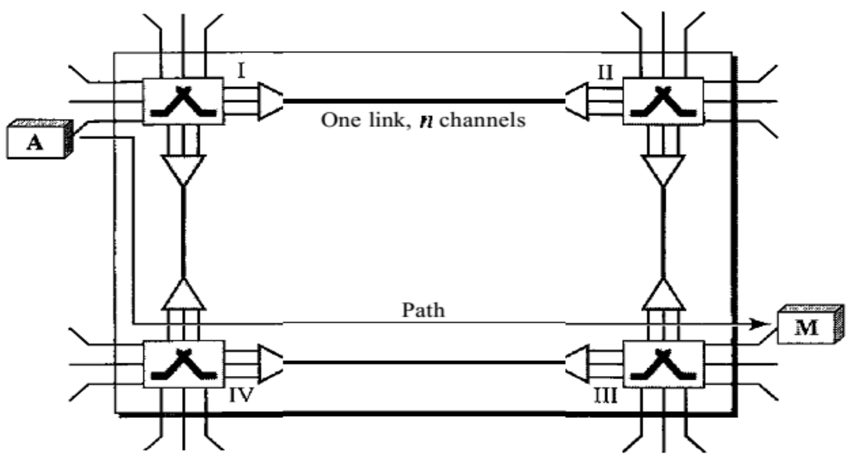
The end systems (communicating devices) are labeled A, B, C, D, and so on, and the switches are labeled I, II, III, IV, and V. Each switch is connected to multiple links.

**There are three method of switching**

1. Circuit Switched Networks
2. Packet Switched Networks
   A. Datagram Networks B. Virtual- circuit Networks
3. Message Switched Networks

## 1. Circuit Switched Network:

- In circuit-switched networks, a dedicated path is needed for communication between the end systems, are reserved for the duration of the session.
- Each connection uses only one dedicated channel on each link.
- Each link is divided into n channels by using FDM (frequency division Multiplexing) or TDM (Time Division multiplexing).




In the above figure one link is divided into n channel (here n=3).A circuit switched network requires following three phase during the session.

1. **Setup Phase:** First of all two system needs to create dedicated circuit or path for communication. For example in figure 11 when system A needs to connect to system M, it sends a setup request that includes the address of system M, to switch I. Switch I finds a channel between itself and switch II that can be dedicated for this purpose. Switch I

then sends the request to switch II, which finds a dedicated channel between itself and switch III. Switch III informs system M of about system A.
To establish a path system M must send an acknowledgement for the request of A. Only after system A receives this acknowledgement the connection is established. Only end to end addressing is required for establishing connection between two end systems.

2. **Data Transfer Phase**
   After the establishment of the dedicated path (channels), the two systems can transfer data.
3. **Teardown Phase**
   When one of the systems needs to disconnect, a signal is sent to each switch to release the resources.

Not efficient coz the link is reserved and can't be used by other system during the connection.
Minimum delay in data transfer.

Example: Let us consider how long it takes to send a file of 640 Kbits from host A to host B over a circuit-switched network. Suppose that all links in the network use TDM with 24 slots and have bit rate 1.536 Mbps. Also suppose that it takes 500 msec to establish an end-to-end circuit before A can begin to transmit the file. How long does it take to send the file?

Each circuit has a transmission rate of (1.536 Mbps)/24 = 64 Kbps, so it takes (640 Kbits)/(64 Kbps) = 10 seconds to transmit the file. To this 10 seconds we add the circuit establishment time, giving 10.5 seconds to send the file. Note that the transmission time is independent of the number links: the transmission time would be 10 seconds if the end-to-end circuit passes through one link or one-hundred links.

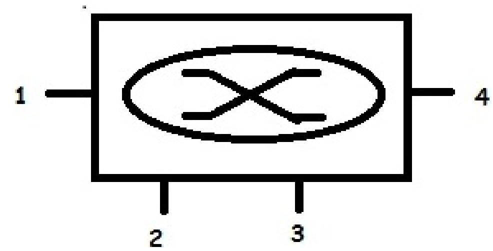
## 2. Packet Switched Networks

### 2. A. Datagram Networks

- In packet switched network message is divided into number of packets. Each packet is of fixed size defined by network or protocol.
- **Datagram switched network is also known as Connectionless packet switching**
- There is no dedicated link between source and destination.
- No dedicated Resources are allocated for packet. Resources are allocated on demand and it follows first come first basis. When a switch receives a packet, irrespective of the source or destination, the packet must wait if the other packets being processed.
- A single message is divided into number of packets. During the transfer of packets from source to destination, each packet is treated independently. Destination can receive unordered packets and later packet can be ordered and combine the packets to extract the message.
- Packets are referred as datagrams in this type of switching. Datagram switching is normally done at the network layer.
- The datagram networks are referred to as connectionless networks. Connectionless means switches have no connection state information.
- There is no setup and teardown phase. So a routing table is required in every switch to route packet from source to destination. A Routing table is based on the destination address. The routing table updated periodically. The destination addresses and the

corresponding forwarding output ports are recorded in the tables. This is different from the table of a circuit switched network in which each entry is created when the setup phase is completed and deleted when the teardown phase is over. Figure 12`shows the routing table for a switch.

| Destination address | Output Port |
|---|---|
| 1234<br>4444<br>6666<br>….. | 1<br>2<br>3<br>. |




**Destination Address**

Every packet in a datagram network carries a header that contains information of the destination address of the packet. When the switch receives the packet, this destination address is examined; the routing table is consulted to find the corresponding port through which the packet should be forwarded. This address, unlike the address in a virtual-circuit-switched network, remains the same during the entire journey of the packet.

**Efficiency**

The efficiency of a datagram network is better than that of a circuit-switched network; resources are allocated only when there are packets to be transferred. If a source sends a packet and there is a delay of a few minutes before another packet can be sent, the resources can be reallocated during these minutes for other packets from other sources.

**Delay**

There may be greater delay in a datagram network than in a virtual-circuit network .Although there are no setup and teardown phases, each packet may experience a wait at a switch before it is forwarded. In addition, since not all packets in a message necessarily travel through the same switches, the delay is not uniform for the packets of a message.

**Switching in the Internet is done by using the datagram approach to packet switching at the network layer.**

**2.B. <u>Virtual –Circuit Networks:</u>**

A virtual-circuit network uses the characteristics of both the circuit switched network and the datagram network. A virtual-circuit network is normally implemented in the data link layer, while a circuit-switched network is implemented in the physical layer and a datagram network in the network layer. Virtual-circuit network is also known as Connection-oriented packet switching.

**Addressing**

Two types of addressing is used in virtual-circuit network

- Global Address: It is an address which can uniquely identify the systems (source or destination) in a network or internet. This address is used to create virtual circuit identifier only.
- Virtual Circuit Identifier: The identifier that is actually used for data transfer is known as virtual circuit identifier (VCI). It is a number which is used in a frame between two switches. This VCI changes from one switch to another. Every switch uses a fixed range of values for VCI.

**Three phases of Virtual –Circuit Networks:**

1. **Data Transfer Phase**
   To transfer a frame from a source to its destination, all switches need to have a table entry for this virtual circuit. The table, in its simplest form, has four columns. This means that the switch holds four pieces of information for each virtual circuit that is already setup. Figure 13 shows such a switch and its corresponding table. Figure 13 shows a frame arriving at port 1with a VCI of 14. When the frame arrives, the switch looks in its table to find port 1 and VCI of 14.When it is found, the switch knows to change the VCI to 22 and send out the frame from port 3.

The data transfer phase is active until the source sends all its frames to the destination. The procedure at the switch is the same for each frame of a message. The process creates a virtual circuit, not a real circuit, between the source and destination.

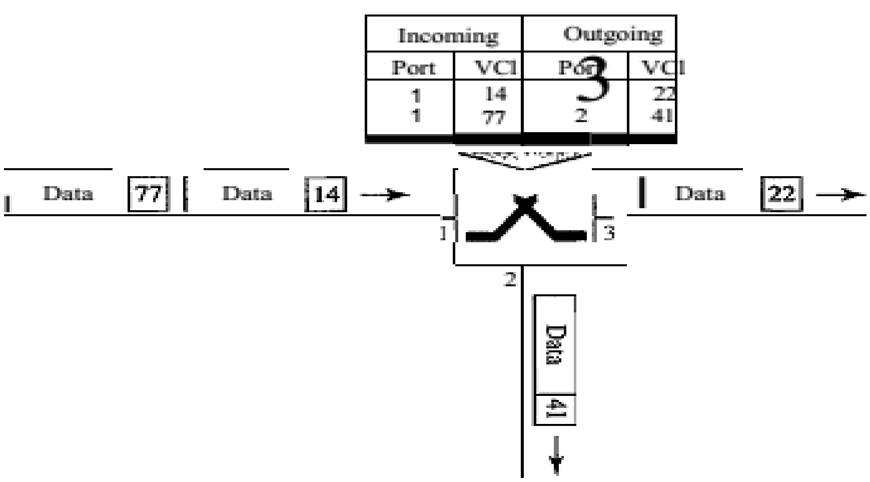



Figure 15 Switch and tables in a virtual-circuit network

2. **Setup Phase**

In the setup phase, a switch creates an entry for a virtual circuit. For example, suppose source A needs to create a virtual circuit to B. Two steps are required: the setup request and the acknowledgment.

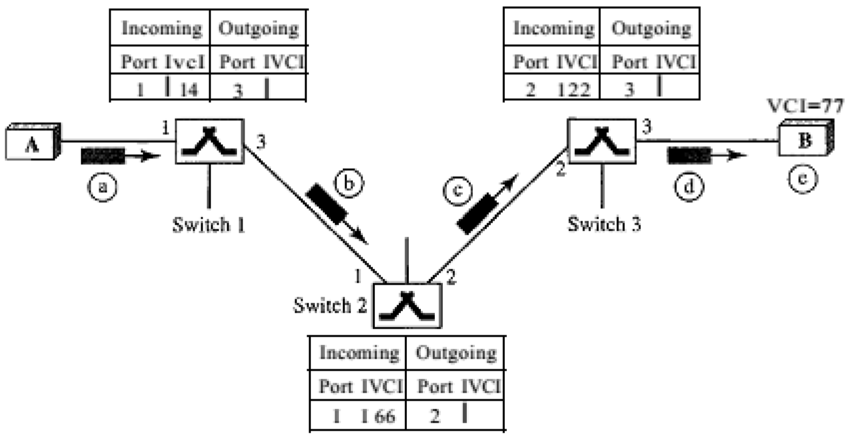



**Figure 16 Setup request in a virtual-circuit network**

**2.1. Setup Request:** A setup request frame is sent from the source to the destination. Figure 14 shows the process.

a. Source A sends a setup frame to switch 1.
b. Switch 1 receives the setup request frame. It knows that a frame going from A to B goes out through port 3.The switch, in the setup phase, acts as a packet switch; it has a routing table which is different from the switching table. For the moment, assume that it knows the output port. The switch creates an entry in its table for this virtual circuit, but it is only able to fill three of the four columns. The switch assigns the incoming port (1) and chooses an available incoming VCI (14) and the outgoing port (3). It does not yet know the outgoing VCI, which will be found during the acknowledgment step. The switch then forwards the frame through port3 to switch 2.
c. Switch 2 receives the setup request frames. The same events happen here as at switch1; three columns of the table are completed: in this case, incoming port (l), incoming VCI (66), and outgoing port (2).
d. Switch 3 receives the setup request frame. Again, three columns are completed: Incoming port (2), incoming VCI (22), and outgoing port (3).
e. Destination B receives the setup frame, and if it is ready to receive frames from A, it assigns a VCI to the incoming frames that come from A, in this case 77. This VCI lets the destination know that the frames come from A, and not other sources.

**2.2. Acknowledgment:** A special frame, called the acknowledgment frame, completes the entries in the switching tables. Figure 15 shows the process.

a. The destination sends an acknowledgment to switch 3. The acknowledgment carries the global source and destination addresses so the switch knows which entry in the table is to be completed. The frame also carries VCI 77, chosen by the destination as the incoming VCI for frames from A. Switch 3 uses this VCI to complete the outgoing VCI column for this entry. Note that 77 is the incoming VCI for destination B, but the outgoing VCI for switch 3.
b. Switch 3 sends an acknowledgment to switch 2 that contains its incoming VCI in the table, chosen in the previous step. Switch 2 uses this as the outgoing VCI in the table.
c. Switch 2 sends an acknowledgment to switch 1that contains its incoming VCI in the table, chosen in the previous step. Switch 1uses this as the outgoing VCI in the table.
d. Finally switch 1 sends an acknowledgment to source A that contains its incoming VCI in the table, chosen in the previous step.
e. The source uses this as the outgoing VCI for the data frames to be sent to destination B.

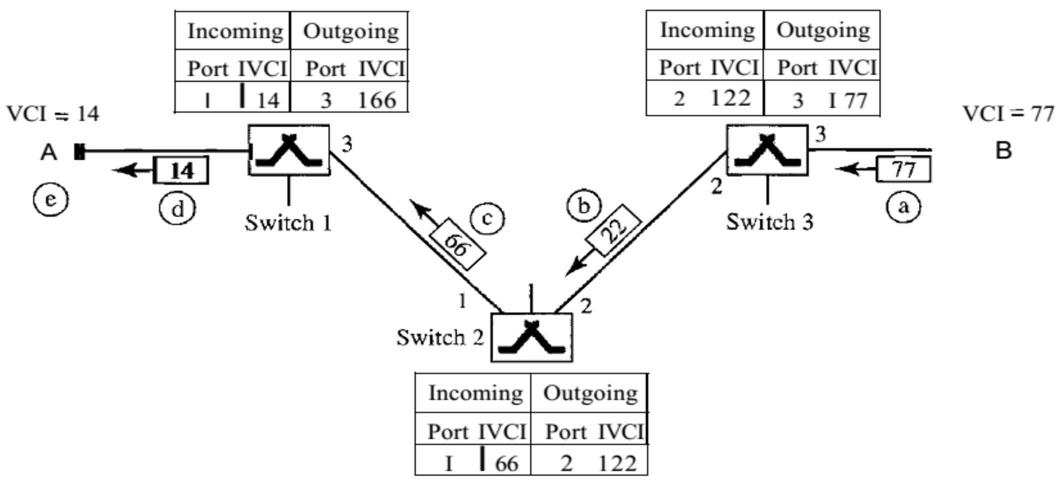



Figure 17 Setup acknowledgment in a virtual-circuit network

### 3. Teardown Phase

In this phase, source A, after sending all frames to B, sends a special frame called a teardown request. Destination B responds with a teardown confirmation frame. All switches delete the corresponding entry from their tables.

*<u>Note:</u> In virtual-circuit switching, all packets belonging to the same source and destination travel the same path; but the packets may arrive at the destination with different delays if resource allocation is on demand.*

**Efficiency of Virtual-Circuit Networks:**

Virtual-Circuit Networks uses the resources efficiently and it reduces the waiting time of data frame.

**Delay in Virtual-Circuit Networks:**

In a virtual-circuit network, there is a delay for setup and for teardown. If resources are allocated during the setup phase, there is no wait time for individual packets. Figure 16 shows the delay for a packet traveling through two switches in a virtual-circuit network.

The packet is traveling through two switches (routers). There are three transmission times (3T), three propagation times (3T), data transfer depicted by the sloping lines, a setup delay (which includes transmission and propagation in two directions), and a teardown delay (which includes transmission and propagation in one direction).
We ignore the processing time in each switch. The total delay time is

Total delay=3T+3 T +setup delay + tear down delay

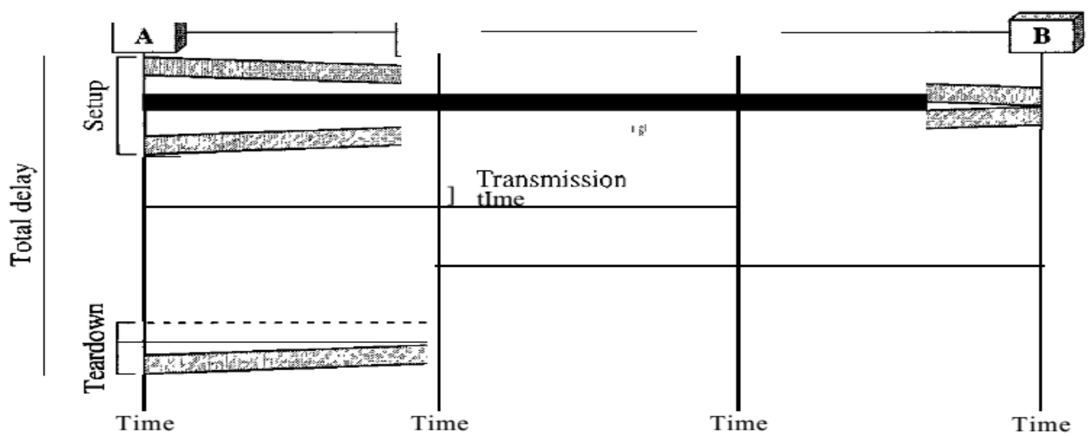



Figure 18 Delay in a virtual-circuit network

**Packet Switching versus Circuit Switching**

| **Packet Switching** | **Circuit Switching** |
|---|---|
| 1. Packet switched network is implemented in the physical layer. | 1. Circuit-switched network is implemented in the physical layer. |
| 2. Message is divided into number of packets or frames. | 2. Complete message is transfer from source to destination. |
| 3. Resources are allocated on demand if available (or free). | 3. Resources are reserved during the data transfer. |
| 4. More efficient and less costly. | |
| 5. A link can be used by any number of user. | 4. Less efficient and more costly. |

| | |
|---|---|
| | 5. As the number of users increases, the bandwidth for each user decreases. But most of the time fixed number of user can use a link because number of channel is fixed. |
| 6. It has unpredictable delay due to waiting of packets/frames at switch, if resources are not available. | 6. It has less delay in data transmission. |
| 1. 7. Suitable for most of the Internet applications. 3. | 7. Suitable for real time applications. |

## TELEPHONE NETWORK

A telephone network is a telecommunications network used for telephone calls between two or more telephone. The telephone network had its beginnings in the late 1800s. The entire network, which is referred to as the plain old telephone system (POTS), was originally an analog system using analog signals to transmit voice. With the advent of the computer era, the network, in the 1980s, began to carry data in addition to voice. During the last decade, the telephone network has undergone many technical changes. The network is now digital as well as analog.

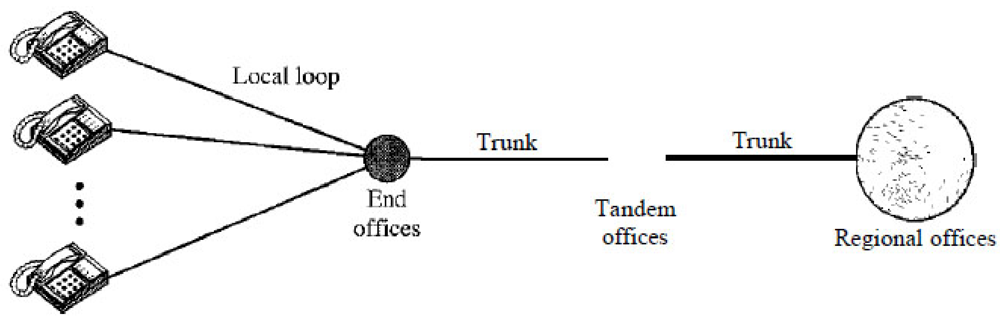
There are a number of different types of telephone network:

- A landline network where the telephones must be directly wired into a single telephone exchange. This is known as the public switched telephone network or PSTN.
- A wireless network where the telephones are mobile and can move around anywhere within the coverage area.
- A private network where a closed group of telephones are connected primarily to each other and use a gateway to reach the outside world. This is usually used inside companies and call centres and is called a private branch exchange (PBX).

### Major Components Of Telephone Network:

The telephone network, as shown in Figure 9.1, is made of three major components: local loops, trunks, and switching offices. The telephone network has several levels of switching offices such as end offices, tandem offices, and regional offices.

***A telephone system:***




***Local Loops***

One component of the telephone network is the local loop, a twisted-pair cable that connects the subscriber telephone to the nearest end office or local central office. The local loop, when used for voice, has a bandwidth of 4000 Hz (4 kHz). It is interesting to examine the telephone number associated with each local loop. The first three digits of a local telephone number define the office, and the next four digits define the local loop number.

***Trunks***

Trunks are transmission media that handle the communication between offices. A trunk normally handles hundreds or thousands of connections through multiplexing. Transmission is usually through optical fibers or satellite links.

***Switching Offices***

To avoid having a permanent physical link between any two subscribers, the telephone company has switches located in a switching office. A switch connects several local loops or trunks and allows a connection between different subscribers.