Transform Yourself

20MCT31-DATA COMMUNICATION NETWORKS
UNIT-1

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Introduction

- When we communicate, we are sharing information. This sharing can be local or remote. Between individuals, local communication usually occurs face to face, while remote communication takes place over distance.
- Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable. For data communications to occur, the communicating devices must be part of a communication system made up of a combination of hardware (physical equipment) and software (programs).
- The effectiveness of a data communications system depends on four fundamental characteristics:
  - ✔ Delivery
  - ✔ accuracy
  - ✔ timeliness
  - ✔ jitter

- **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.

- **Accuracy**

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

- **Timeliness**

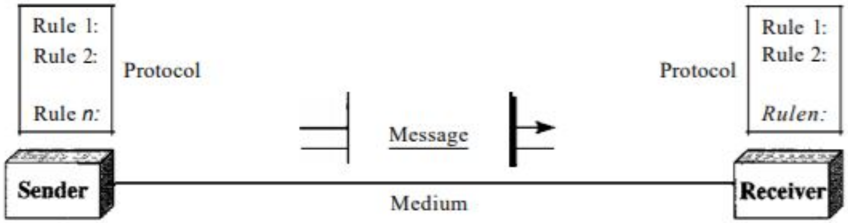
The system must deliver data in a timely manner. Data delivered late are useless. In the case of video and audio, timely delivery means delivering data as they are produced, in the same order that they are produced, and without significant delay. This kind of delivery is called real-time transmission.

- **Jitter**

Jitter refers to the variation in the packet arrival time. It is the uneven delay in the delivery of audio or video packets.

COMPONENTS

- A data communications system has five components



- ✔ **Message-**The message is the information (data) to be communicated. Popular forms of information include text, numbers, pictures, audio, and video.
- ✔ **Sender-** The sender is the device that sends the data message. It can be a computer, workstation, telephone handset, video camera, and so on.
- ✔ **Receiver-** The receiver is the device that receives the message. It can be a computer, workstation, telephone handset, television, and so on.
- ✔ **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.
- ✔ **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 comes in different forms such as text, numbers, images, audio, and video.

1.Text

- ✔ Text In data communications, text is represented as a bit pattern, a sequence of bits (Os or Is). Different sets of bit patterns have been designed to represent text symbols. Each set is called a code, and the process of representing symbols is called coding. Today, the prevalent coding system is called Unicode, which uses 32 bits to represent a symbol or character used in any language in the world. The American Standard Code for Information Interchange (ASCII), developed some decades ago in the United States, now constitutes the first 127 characters in Unicode and is also referred to as Basic Latin. Appendix A includes part of the Unicode

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. Appendix B discusses several different numbering systems.

3.Image

- Images are also represented by bit patterns. In its simplest form, an image is composed of a matrix of pixels (picture elements), where each pixel is a small dot. The size of the pixel depends on the resolution. For example, an image can be divided into 1000 pixels or 10,000 pixels. In the second case, there is a better representation of the image (better resolution), but more memory is needed to store the image.
- After an image is divided into pixels, each pixel is assigned a bit pattern. The size and the value of the pattern depend on the image. For an image made of only black and-white dots (e.g., a chessboard), a I-bit pattern is enough to represent a pixel.
- If an image is not made of pure white and pure black pixels, you can increase the size of the bit pattern to include gray scale. For example, to show four levels of gray scale, you can use 2-bit patterns. A black pixel can be represented by 00, a dark gray pixel by 01, a light gray pixel by 10, and a white pixel by 11.

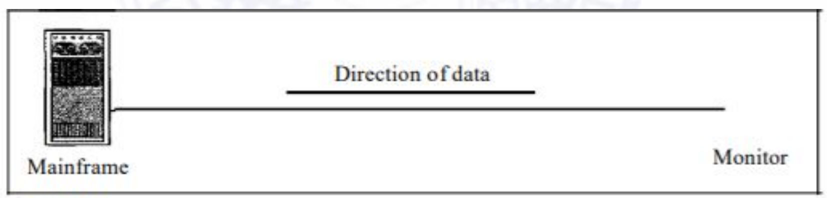
4.Audio

- ✔ Audio refers to the recording or broadcasting of sound or music. Audio is by nature different from text, numbers, or images. It is continuous, not discrete.

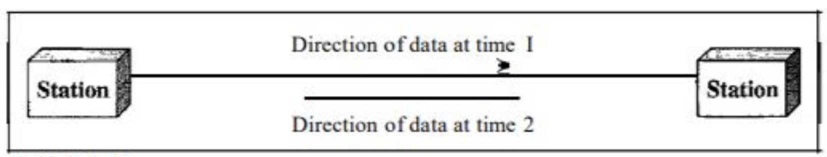
5.Video

- ✔ 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.

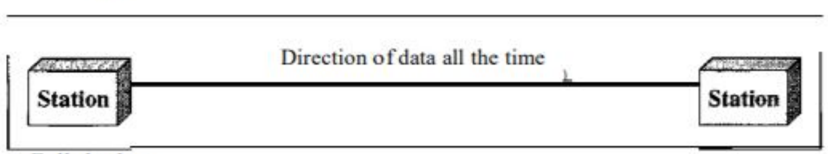
Data Flow- Communication between two devices can be simplex, half-duplex, or full-duplex



a. Simplex



b. Half-duplex



c. Full·duplex

Simplex

- In simplex mode, the communication is unidirectional, as on a one-way street. Only one of the two devices on a link can transmit; the other can only receive. Keyboards and traditional monitors are examples of simplex devices.
- The keyboard can only introduce input; the monitor can only accept output. The simplex mode can use the entire capacity of the channel to send data in one direction

Half-Duplex

- In half-duplex mode, each station can both transmit and receive, but not at the same time. When one device is sending, the other can only receive, and vice versa. The half-duplex mode is like a one-lane road with traffic allowed in both directions. When cars are traveling in one direction, cars going the other way must wait.
- In a half-duplex transmission, the entire capacity of a channel is taken over by whichever of the two devices is transmitting at the time. Walkie-talkies and CB (citizens band) radios are both half-duplex systems.
- The half-duplex mode is used in cases where there is no need for communication in both directions at the same time; the entire capacity of the channel can be utilized for each direction

Full-Duplex

- In full-duplex mode (also called duplex), 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. In full-duplex mode, signals going in one direction share the capacity of the link: with signals going in the other direction.
- This sharing can occur in two ways: Either the link must contain two physically separate transmission paths one for sending and the other for receiving; or the capacity of the channel is divided between signals traveling in both directions.
- One common example of full-duplex communication is the telephone network. When two people are communicating by a telephone line, both can talk and listen at the same time.
- The full-duplex mode is used when communication in both directions is required all the time. The capacity of the channel, however, must be divided between the two directions.

Networks

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

Types 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. For visualization purposes, it is simplest to imagine any link as a line drawn between two points. For communication to occur, two devices must be connected in some way to the same link at the same time.
- There are two possible types of connections:
  - ✔ point-to-point
  - ✔ multipoint.

Point-to-Point

- A point-to-point connection provides a dedicated link between two devices. The entire capacity of the link is reserved for transmission between those two devices.
- Most point-to-point connections use an actual length of wire or cable to connect the two ends, but other options, such as microwave or satellite links, are also possible.
- When you change television channels by infrared remote control, you are establishing a point-to-point connection between the remote control and the television's control system.

Multipoint

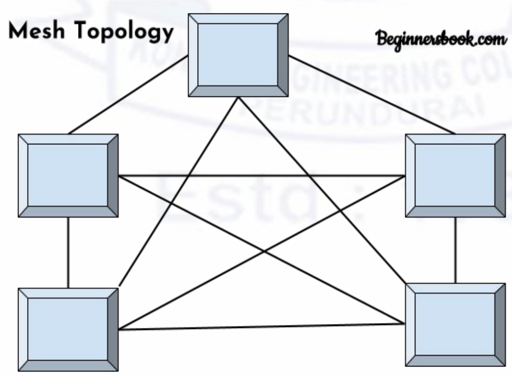
- A multipoint (also called multidrop) connection is one in which more than two specific devices share a single link.
- In a multipoint environment, the capacity of the channel is shared, either spatially or temporally.
- If several devices can use the link simultaneously, it is a spatially shared connection. If users must take turns, it is a timeshared connection.

Physical Topology

- The term physical topology refers to the way in which a network is laid out physically. One or more devices connect to a link; two or more links form a topology.
- The topology of a network is the geometric representation of the relationship of all the links and linking devices (usually called nodes) to one another. There are four basic topologies possible: mesh, star, bus, and ring.

1.Mesh Topology

- In mesh topology each device is connected to every other device on the network through a dedicated point-to-point link. When we say dedicated it means that the link only carries data for the two connected devices only. Lets say we have n devices in the network then each device must be connected with (n-1) devices of the network. Number of links in a mesh topology of n devices would be n(n-1)/2.



Advantages of Mesh topology

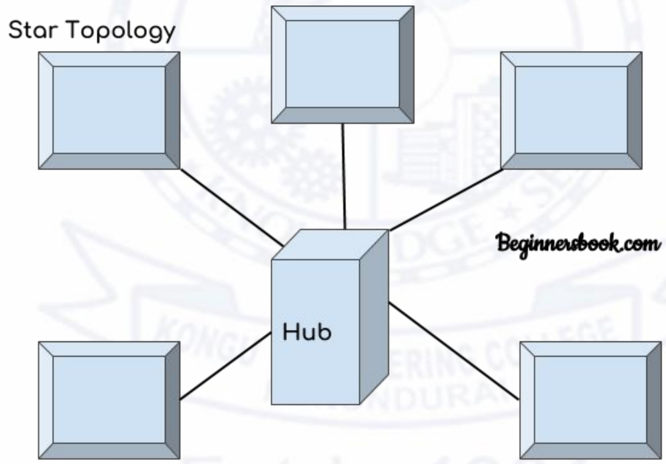
1. No data traffic issues as there is a dedicated link between two devices which means the link is only available for those two devices.
2. Mesh topology is reliable and robust as failure of one link doesn't affect other links and the communication between other devices on the network.
3. Mesh topology is secure because there is a point to point link thus unauthorized access is not possible.
4. Fault detection is easy.

Disadvantages of Mesh topology

1. Amount of wires required to connected each system is tedious and headache.
2. Since each device needs to be connected with other devices, number of I/O ports required must be huge.
3. Scalability issues because a device cannot be connected with large number of devices with a dedicated point to point link.

Star Topology

- In star topology each device in the network is connected to a central device called hub. Unlike Mesh topology, star topology doesn't allow direct communication between devices, a device must have to communicate through hub.
- If one device wants to send data to other device, it has to first send the data to hub and then the hub transmit that data to the designated device.



Advantages of Star topology

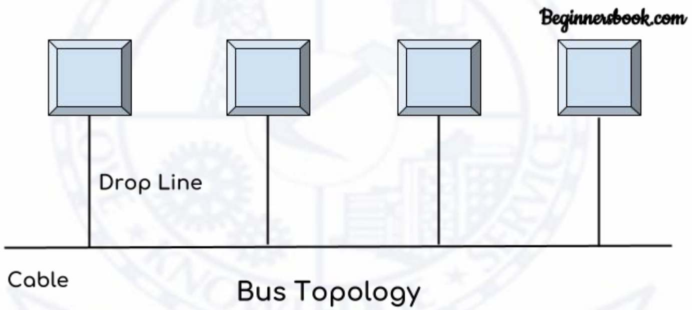
1. Less expensive because each device only need one I/O port and needs to be connected with hub with one link.
2. Easier to install
3. Less amount of cables required because each device needs to be connected with the hub only.
4. Robust, if one link fails, other links will work just fine.
5. Easy fault detection because the link can be easily identified.

Disadvantages of Star topology

1. If hub goes down everything goes down, none of the devices can work without hub.
2. Hub requires more resources and regular maintenance because it is the central system of star topology.

Bus Topology

- In bus topology there is a main cable and all the devices are connected to this main cable through drop lines.
- There is a device called tap that connects the drop line to the main cable. Since all the data is transmitted over the main cable, there is a limit of drop lines and the distance a main cable can have.



Advantages of bus topology

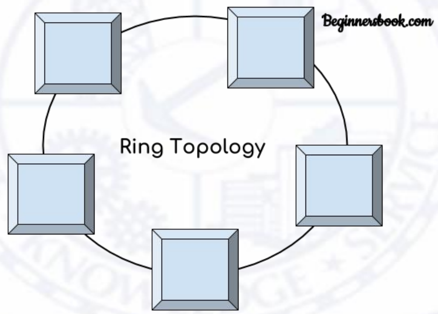
- 1. Easy installation, each cable needs to be connected with backbone cable.
  2. Less cables required than Mesh and star topology

Disadvantages of bus topology

- 1. Difficultly in fault detection.
  2. Not scalable as there is a limit of how many nodes you can connect with backbone cable.

Ring Topology

- In ring topology each device is connected with the two devices on either side of it. There are two dedicated point to point links a device has with the devices on the either side of it. This structure forms a ring thus it is known as ring topology. If a device wants to send data to another device then it sends the data in one direction, each device in ring topology has a repeater, if the received data is intended for other device then repeater forwards this data until the intended device receives it.



Advantages of Ring Topology

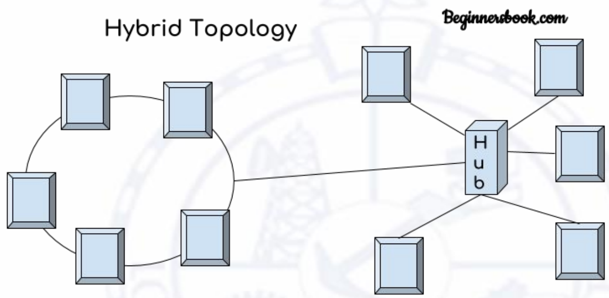
- 1. Easy to install.
   2. Managing is easier as to add or remove a device from the topology only two links are required to be changed.

Disadvantages of Ring Topology

- 1. A link failure can fail the entire network as the signal will not travel forward due to failure.
   2. Data traffic issues, since all the data is circulating in a ring.

Hybrid Topology

A combination of two or more topology is known as hybrid topology. For example a combination of star and mesh topology is known as hybrid topology.



Advantages of Hybrid topology

1. We can choose the topology based on the requirement for example, scalability is our concern then we can use star topology instead of bus technology.
2. Scalable as we can further connect other computer networks with the existing networks with different topologies.

Disadvantages of Hybrid topology

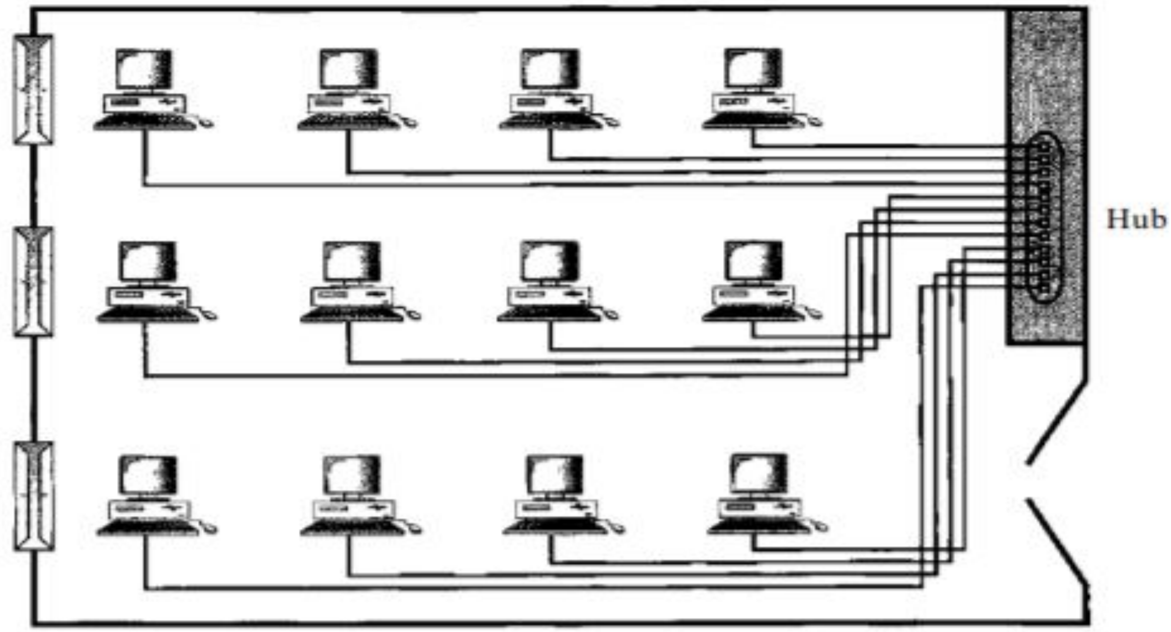
1. Fault detection is difficult.
2. Installation is difficult.
3. Design is complex so maintenance is high thus expensive.

Categories of Networks

Local Area Network

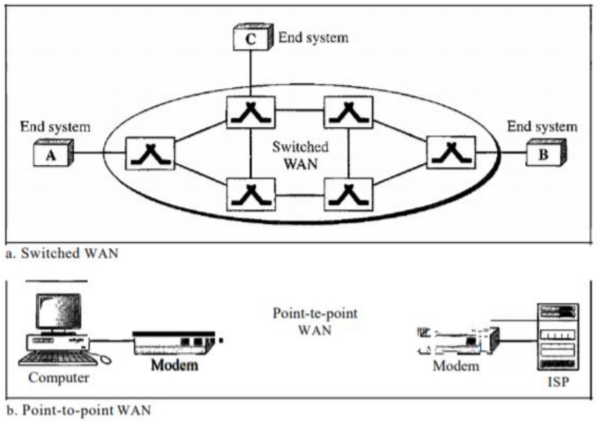
- A local area network (LAN) is usually privately owned and links the devices in a single office, building, or campus. Currently, LAN size is limited to a few kilometers.
- LANs are designed to allow resources to be shared between personal computers or workstations. The resources to be shared can include hardware (e.g., a printer), software (e.g., an application program), or data.
- A common example of a LAN, found in many business environments, links a workgroup of task-related computers, for example, engineering workstations or accounting PCs.
- One of the computers may be given a large capacity disk drive and may become a server to clients. Software can be stored on this central server and used as needed by the whole group.
- 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.

An isolated LAN connecting 12 computers to a hub in a closet



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 switched WAN connects the end systems, which usually comprise a router (internetworking connecting device) that connects to another LAN or 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 (ISP). This type of WAN is often used to provide Internet access.



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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.
- Another example is the cable TV network that originally was designed for cable TV, but today can also be used for high-speed data connection to the Internet.

Network Models

- A network is a combination of hardware and software that sends data from one location to another.
- The hardware consists of the physical equipment that carries signals from one point of the network to another.
- The software consists of instruction sets that make possible the services that we expect from a network.

THE OSI MODEL

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

Peer-to-Peer Processes

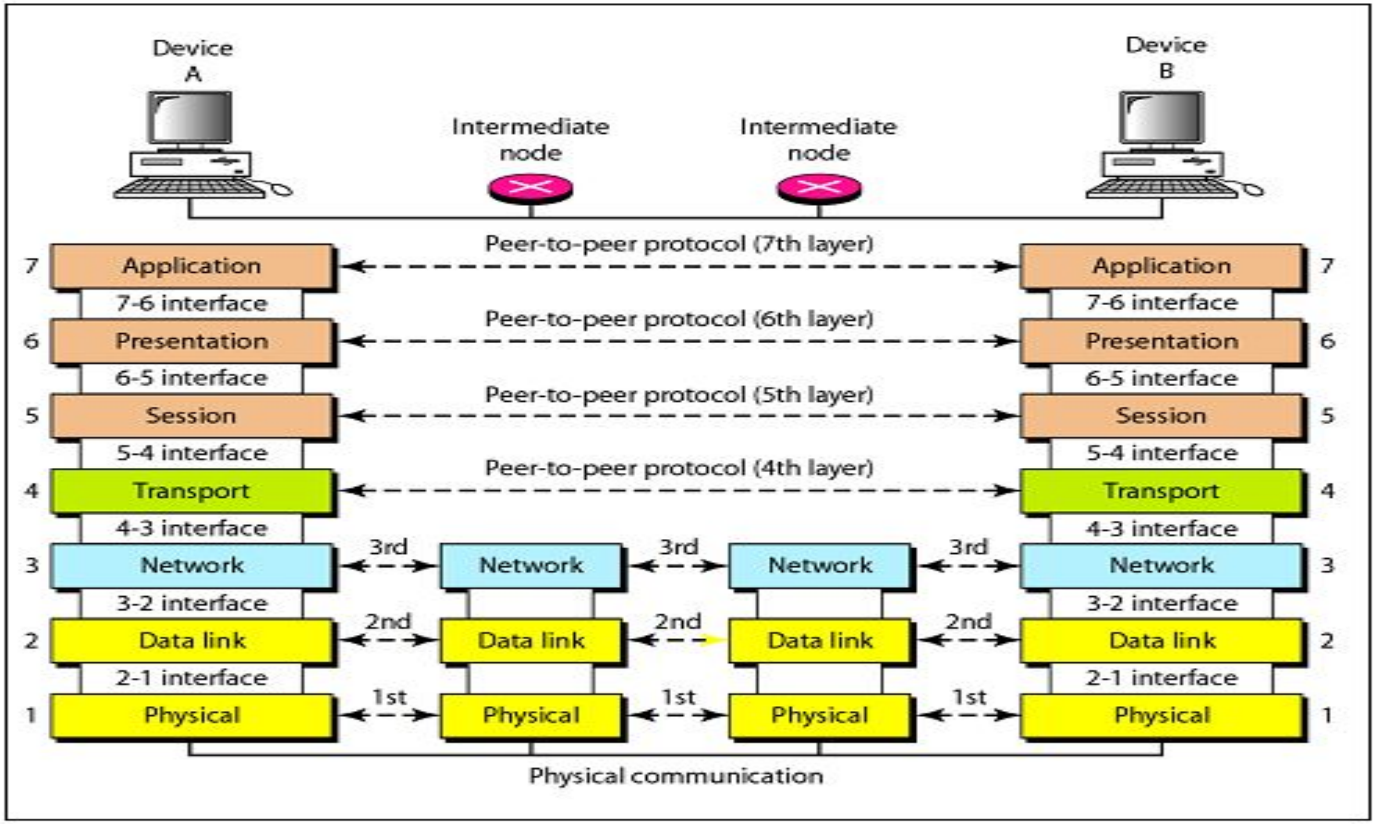

Fig: Communication & Interfaces in the OSI model

- At the physical layer, communication is direct: device A sends a stream of bits to device B (through intermediate nodes).
- At the higher layers, however, communication must move down through the layers on device A, over to device B, and then back up through the layers.
- Each layer in the sending device adds its own information to the message it receives from the layer just above it and passes the whole package to the layer just below it.

Interfaces Between Layers

- The passing of the data and network information down through the layers of the sending device and back up through the layers of the receiving device is made possible by an interface between each pair of adjacent layers.
- Each interface defines the information and services a layer must provide for the layer above it. Well-defined interfaces and layer functions provide modularity to a network.

Organization of the Layers

- The seven layers can be thought of as belonging to three subgroups. Layers I, 2, and 3-physical, data link, and network-are the network support layers; they deal with the physical aspects of moving data from one device to another
- Layers 5, 6, and 7-session, presentation, and application-can be thought of as the user support layers; they allow interoperability among unrelated software systems.
- Layer 4, the transport layer, links the two subgroups and ensures that what the lower layers have transmitted is in a form that the upper layers can use.
- The upper OSI layers are almost always implemented in software; lower layers are a combination of hardware and software, except for the physical layer, which is mostly hardware.

LAYERS IN THE OSI MODEL

1. Physical Layer (Layer 1) :

- The lowest layer of the OSI reference model is the physical layer. It is responsible for the actual physical connection between the devices. The physical layer contains information in the form of bits.
- It is responsible for transmitting individual bits from one node to the next. When receiving data, this layer will get the signal received and convert it into 0s and 1s and send them to the Data Link layer, which will put the frame back together.

The functions of the physical layer are :

i. **Bit synchronization:** The physical layer provides the synchronization of the bits by providing a clock. This clock controls both sender and receiver thus providing synchronization at bit level.

ii. **Bit rate control:** The Physical layer also defines the transmission rate i.e. the number of bits sent per second.

iii. **Physical topologies:** Physical layer specifies the way in which the different, devices/nodes are arranged in a network i.e. bus, star or mesh topolgy.

iv. **Transmission mode:** Physical layer also defines the way in which the data flows between the two connected devices. The various transmission modes possible are: Simplex, half-duplex and full-duplex

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2. Data Link Layer (DLL) (Layer 2) :

- The data link layer is responsible for the node to node delivery of the message. The main function of this layer is to make sure data transfer is error-free from one node to another, over the physical layer. When a packet arrives in a network, it is the responsibility of DLL to transmit it to the Host using its MAC address. Data Link Layer is divided into two sub layers :

1. Logical Link Control (LLC)
2. Media Access Control (MAC)

- The packet received from Network layer is further divided into frames depending on the frame size of NIC(Network Interface Card). DLL also encapsulates Sender and Receiver's MAC address in the header.
- The Receiver's MAC address is obtained by placing an ARP(Address Resolution Protocol) request onto the wire asking "Who has that IP address?" and the destination host will reply with its MAC address.

The functions of the data Link layer are :

i. **Framing:** Framing is a function of the data link layer. It provides a way for a sender to transmit a set of bits that are meaningful to the receiver. This can be accomplished by attaching special bit patterns to the beginning and end of the frame.

ii. **Physical addressing:** After creating frames, Data link layer adds physical addresses (MAC address) of sender and/or receiver in the header of each frame.

iii. **Error control:** Data link layer provides the mechanism of error control in which it detects and retransmits damaged or lost frames.

iv. **Flow Control:** The data rate must be constant on both sides else the data may get corrupted thus , flow control coordinates that amount of data that can be sent before receiving acknowledgement.

v. **Access control:** When a single communication channel is shared by multiple devices, MAC sub-layer of data link layer helps to determine which device has control over the channel at a given time.

3. Network Layer (Layer 3) :

- Network layer works for the transmission of data from one host to the other located in different networks.
- It also takes care of packet routing i.e. selection of the shortest path to transmit the packet, from the number of routes available.
- The sender & receiver's IP address are placed in the header by the network layer.

The functions of the Network layer are :

i. **Routing:** The network layer protocols determine which route is suitable from source to destination. This function of network layer is known as routing.

ii. **Logical Addressing:** In order to identify each device on internetwork uniquely, network layer defines an addressing scheme. The sender & receiver's IP address are placed in the header by network layer. Such an address distinguishes each device uniquely and universally.

4. Transport Layer (Layer 4) :

- Transport layer provides services to application layer and takes services from network layer. The data in the transport layer is referred to as *Segments*.
- It is responsible for the End to End Delivery of the complete message. The transport layer also provides the acknowledgement of the successful data transmission and re-transmits the data if an error is found.

• **At sender's side:**

Transport layer receives the formatted data from the upper layers, performs **Segmentation** and also implements **Flow & Error control** to ensure proper data transmission. It also adds Source and Destination port number in its header and forwards the segmented data to the Network Layer.

• **At receiver's side:**

Transport Layer reads the port number from its header and forwards the Data which it has received to the respective application. It also performs sequencing and reassembling of the segmented data.

The functions of the transport layer are :

i. **Segmentation and Reassembly:** This layer accepts the message from the (session) layer , breaks the message into smaller units . Each of the segment produced has a header associated with it. The transport layer at the destination station reassembles the message.

ii. **Service Point Addressing:** In order to deliver the message to correct process, transport layer header includes a type of address called service point address or port address. Thus by specifying this address, transport layer makes sure that the message is delivered to the correct process.

The services provided by the transport layer :

i. **Connection Oriented Service:** It is a three-phase process which include
   – Connection Establishment
   – Data Transfer
   – Termination / disconnection
   In this type of transmission, the receiving device sends an acknowledgement, back to the source after a packet or group of packet is received. This type of transmission is reliable and secure.

ii. **Connection less service:** It is a one-phase process and includes Data Transfer. In this type of transmission, the receiver does not acknowledge receipt of a packet. This approach allows for much faster communication between devices. Connection-oriented service is more reliable than connectionless Service.

5. Session Layer (Layer 5) :

- This layer is responsible for establishment of connection, maintenance of sessions, authentication and also ensures security.

The functions of the session layer are :

i. **Session establishment, maintenance and termination:** The layer allows the two processes to establish, use and terminate a connection.

ii. **Synchronization :** This layer allows a process to add checkpoints which are considered as synchronization points into the data. These synchronization point help to identify the error so that the data is re-synchronized properly, and ends of the messages are not cut prematurely and data loss is avoided.

iii. **Dialog Control :** The session layer allows two systems to start communication with each other in half-duplex or full-duplex.

6. Presentation Layer (Layer 6) :

- Presentation layer is also called the **Translation layer.** The data from the application layer is extracted here and manipulated as per the required format to transmit over the network.
- The functions of the presentation layer are :

i. **Translation :** For example, ASCII to EBCDIC.

ii. **Encryption/ Decryption :** Data encryption translates the data into another form or code. The encrypted data is known as the cipher text and the decrypted data is known as plain text. A key value is used for encrypting as well as decrypting data.

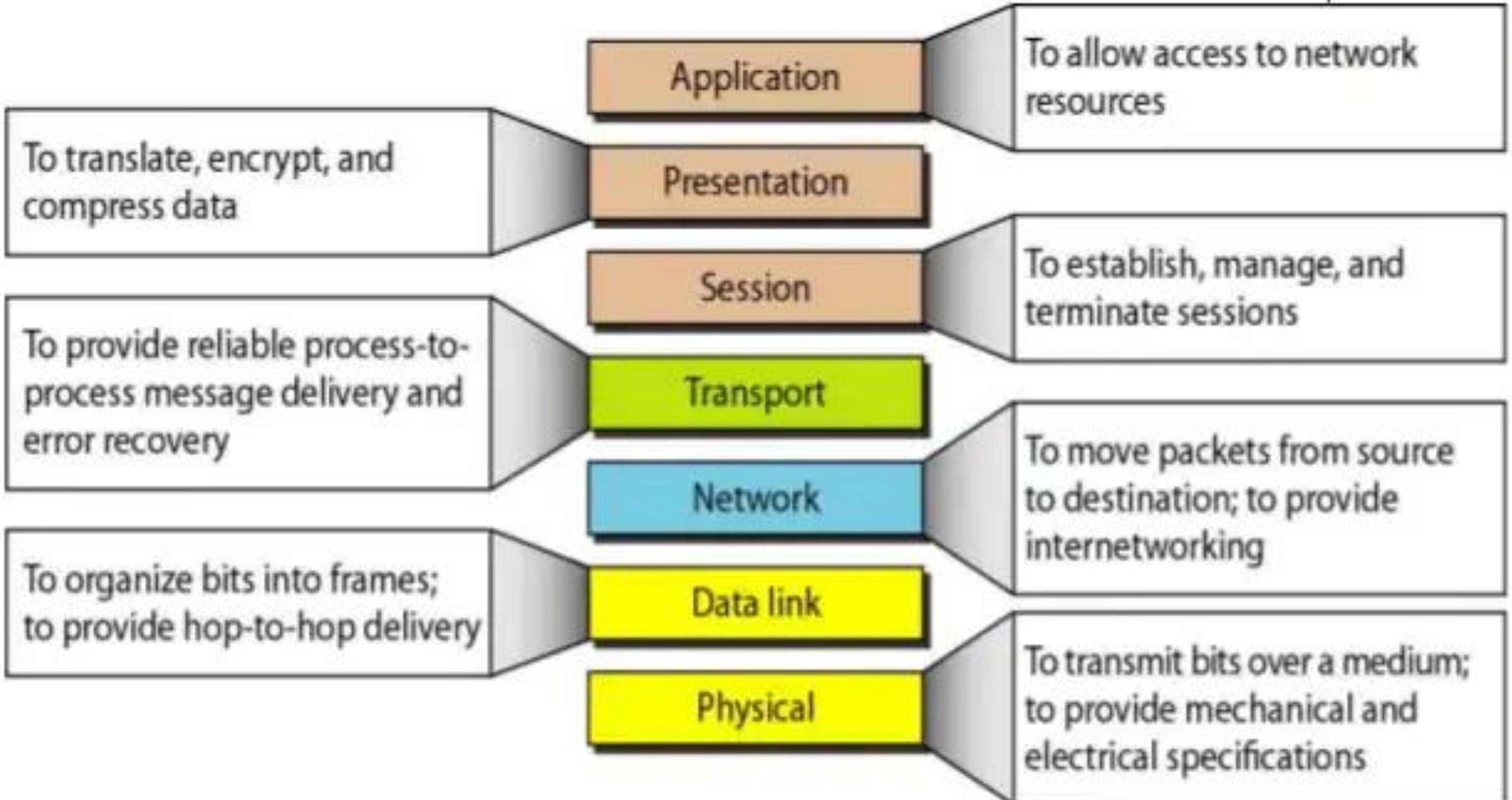
iii. **Compression:** Reduces the number of bits that need to be transmitted on the network.

7. Application Layer (Layer 7) :

- At the very top of the OSI Reference Model stack of layers, we find Application layer which is implemented by the network applications.
- These applications produce the data, which has to be transferred over the network. This layer also serves as a window for the application services to access the network and for displaying the received information to the user.
- Ex: Application – Browsers, Skype Messenger etc.

Summary of Layers

Summary of layers



TCP/IP PROTOCOL SUITE

- The protocol stack used on the Internet is the Internet Protocol Suite. It is usually called TCP/IP after two of its most prominent protocols, but there are other protocols as well. The TCP/IP model is based on a five-layer model for networking.
- TCP/IP is a hierarchical protocol made up of interactive modules, each of which provides a specific functionality; however, the modules are not necessarily interdependent.
- Whereas the OSI model specifies which functions belong to each of its layers, the layers of the TCP/IP protocol suite contain relatively independent protocols that can be mixed and matched depending on the needs of the system.
- The term hierarchical means that each upper-level protocol is supported by one or more lower-level protocols.

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The 4 layers of the TCP/IP model

1. The **application layer** provides applications with standardized data exchange. Its protocols include HTTP, FTP, Post Office Protocol, Simple Mail Transfer Protocol and Simple Network Management Protocol. At the application layer, the payload is the actual application data.
2. The **transport layer** is responsible for maintaining end-to-end communications across the network. TCP handles communications between hosts and provides flow control, multiplexing and reliability. The transport protocols include TCP and User Datagram Protocol, which is sometimes used instead of TCP for special purposes.
3. The **network layer**, also called the internet layer, deals with packets and connects independent networks to transport the packets across network boundaries. The network layer protocols are IP and Internet Control Message Protocol, which is used for error reporting.
4. The **physical layer**, also known as the network interface layer or data link layer, consists of protocols that operate only on a link -- the network component that interconnects nodes or hosts in the network. The protocols in this lowest layer include Ethernet for local area networks and Address Resolution Protocol.

Data and Signals

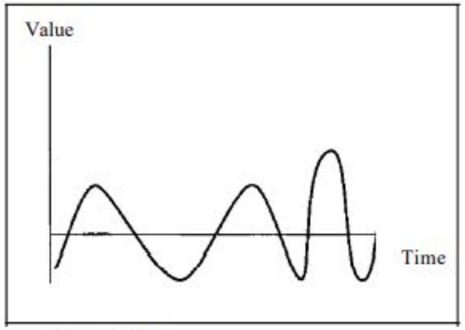
- One of the major functions of the physical layer is to move data in the form of electromagnetic signals across a transmission medium.
- Generally, the data usable to a person or application are not in a form that can be transmitted over a network.

ANALOG AND DIGITAL DATA

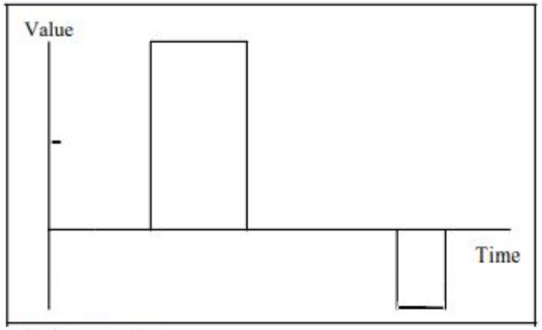
- Both data and the signals that represent them can be either analog or digital in form.
- The term analog data refers to information that is continuous.
- Digital data refers to information that has discrete states.
- Analog data, such as the sounds made by a human voice, take on continuous values. 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.

Analog and Digital Signals

- 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.
- The simplest way to show signals is by plotting them on a pair of perpendicular axes. The vertical axis represents the value or strength of a signal. The horizontal axis represents time.
- The curve representing the analog signal passes through an infinite number of points. The vertical lines of the digital signal, however, demonstrate the sudden jump that the signal makes from value to value.



a. Analog signal



b. Digital signal

Periodic and Nonperiodic Signals

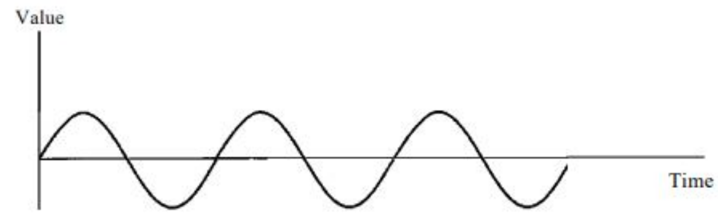
- Both analog and digital signals can take one of two forms: periodic or nonperiodic.
- A periodic signal completes a pattern within a measurable time frame, called a period, and repeats that pattern over subsequent identical periods. The completion of one full pattern is called a cycle.
- A nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time

PERIODIC ANALOG SIGNALS

- Periodic analog signals can be classified as simple or composite.
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves

Sine Wave

- The sine wave is the most fundamental form of a periodic analog signal. When we visualize it as a simple oscillating curve, its change over the course of a cycle is smooth and consistent, a continuous, rolling flow.
- Each cycle consists of a single arc above the time axis followed by a single arc below it.

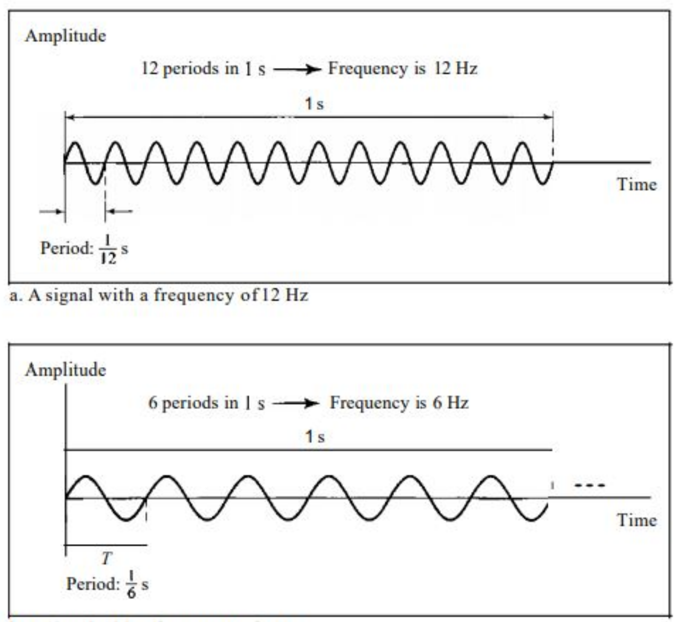


- A sine wave can be represented by three parameters:
  - i. the peak amplitude
  - ii. the frequency
  - iii. the phase.

These three parameters fully describe 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.
- **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. **1 f= - T and 1 T=-1/f**.

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

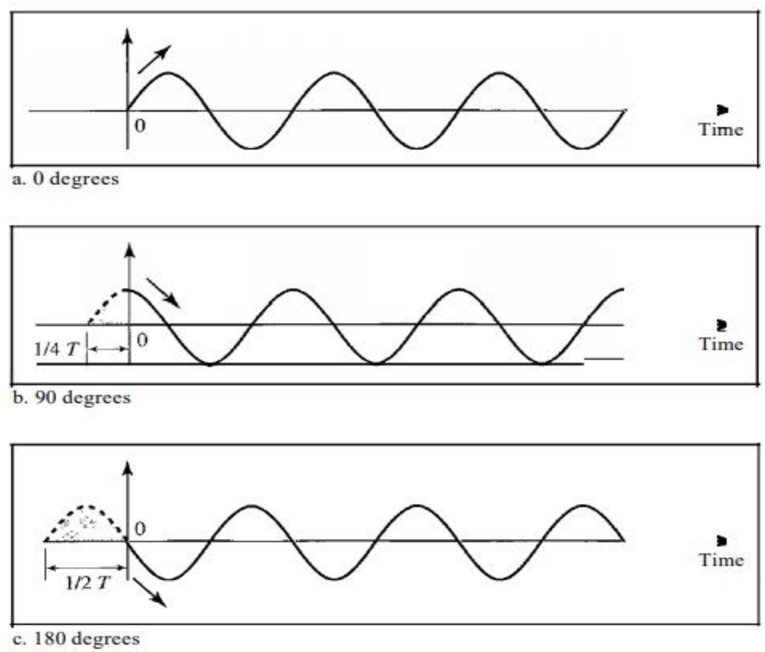


a. A signal with a frequency of 12 Hz

b. A signal with a frequency of 6 Hz

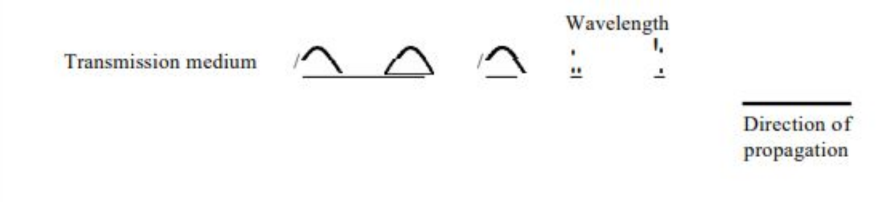
- **Phase** The term phase describes the position of the waveform relative to time O. If we think of the wave as something that can be shifted backward or forward along the time axis, phase describes the amount of that shift. It indicates the status of the first cycle.
- Phase is measured in **degrees or radians** [360° is 2n rad; 1° is 2n/360 rad, and 1 rad is 360/(2n)]. A phase shift of 360° corresponds to a shift of a complete period; a phase shift of 180° corresponds to a shift of one-half of a period; and a phase shift of 90° corresponds to a shift of one-quarter of a period.

Three sine waves with the same amplitude andfrequency, but different phases



- Looking at previous figure, we can say that
  - ✔ A sine wave with a phase of 0° starts at time 0 with a zero amplitude. The amplitude is increasing.
  - ✔ A sine wave with a phase of 90° starts at time 0 with a peak amplitude. The amplitude is decreasing.
  - ✔ A sine wave with a phase of 180° starts at time 0 with a zero amplitude. The amplitude is decreasing.
- Another way to look at the phase is in terms of shift or offset. We can say that
  - ✔ A sine wave with a phase of 0° is not shifted.
  - ✔ A sine wave with a phase of 90° is shifted to the left by ! cycle. However, note that the signal does not really exist before time O.
  - ✔ A sine wave with a phase of 180° is shifted to the left by cycle. However, note that the signal does not really exist before time O.

- **Wavelength** is another characteristic of a signal traveling through a transmission medium. Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium.



- While the frequency of a signal is independent of the medium, the wavelength depends on both the frequency and the medium. Wavelength is a property of any type of signal.
- In data communications, we often use wavelength to describe the transmission of light in an optical fiber.
- The wavelength is the distance a simple signal can travel in one period. Wavelength can be calculated if one is given the propagation speed (the speed of light) and the period of the signal.

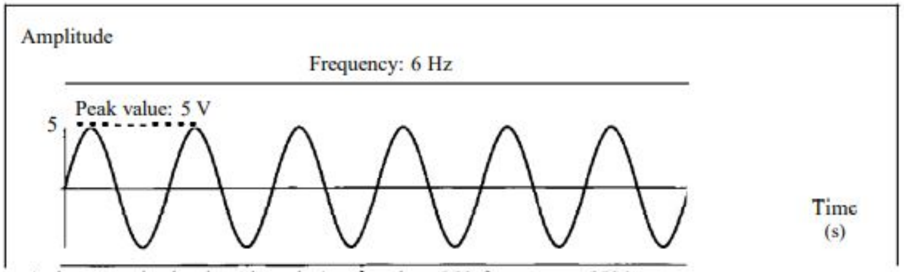
- However, since period and frequency are related to each other, if we represent wavelength by A, propagation speed by c (speed of light), and frequency by1, we get

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

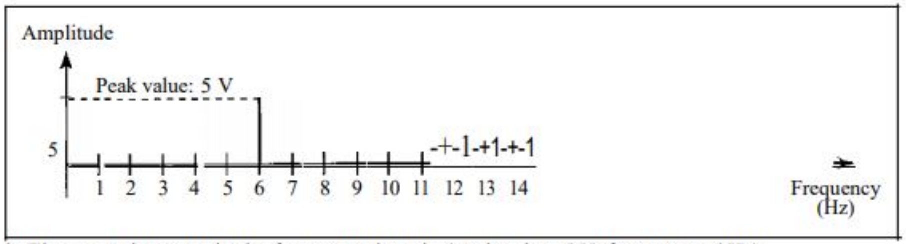
- The propagation speed of electromagnetic signals depends on the medium and on the frequency of the signal.
- For example, in a vacuum, light is propagated with a speed of 3 x 108 mls. That speed is lower in air and even lower in cable. The wavelength is normally measured in micrometers (microns) instead of meters.
- For example, the wavelength of red light (frequency =4 x 1014) in air is 8 c 3xlO -6 A= - = =0.75 x 10 m=0.75!J.m f 4x 1014
- In a coaxial or fiber-optic cable, however, the wavelength is shorter (0.5 !Jm) because the propagation speed in the cable is decreased

Time and Frequency Domains

- A sine wave is comprehensively defined by its amplitude, frequency, and phase.
- The time-domain plot shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot). Phase is not explicitly shown on a time-domain plot.
- To show the relationship between amplitude and frequency, we can use what is called a frequency-domain plot.
- A frequency-domain plot is concerned with only the peak value and the frequency. Changes of amplitude during one period are not shown.



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

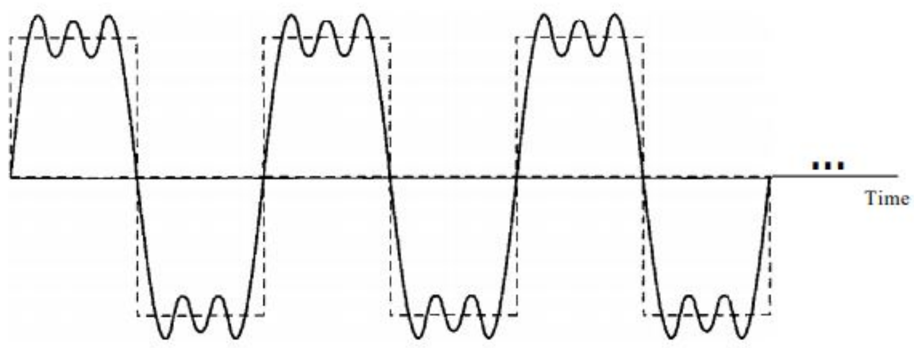


b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

The time-domain and frequency-domain plots of a sine wave

Composite Signals

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



A composite periodic signal

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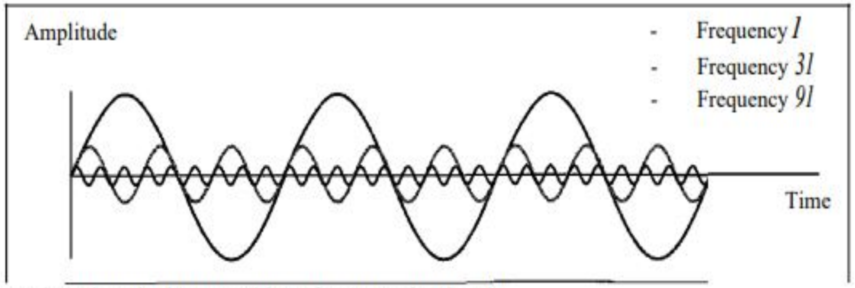
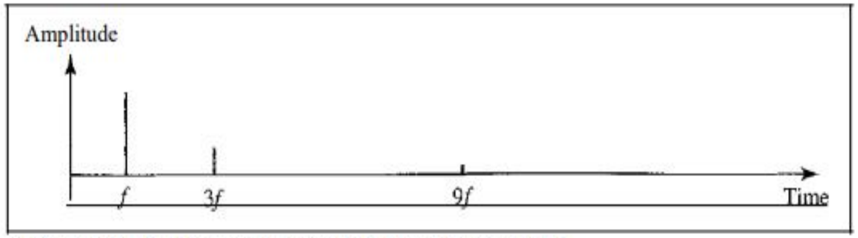
- It is very difficult to manually decompose this signal into a series of simple sine waves.
- The amplitude of the sine wave with frequency is almost the same as the peak amplitude of the composite signal.
- The amplitude of the sine wave with frequency 3f is one-third of that of the first, and the amplitude of the sine wave with frequency 9fis one-ninth of the first.
- The frequency of the sine wave with frequency f is the same as the frequency of the composite signal; it is called the fundamental frequency, or first harmonic.
- The sine wave with frequency 3f has a frequency of 3 times the fundamental frequency; it is called the third harmonic.
- The third sine wave with frequency 9fhas a frequency of 9 times the fundamental frequency; it is called the ninth harm.
- Note that the frequency decomposition of the signal is discrete; it has frequencies f, 3f, and 9f Because f is an integral number, 3f and 9f are also integral numbers.
- There are no frequencies such as 1.2f or 2.6f The frequency domain of a periodic composite signal is always made of discrete spikes.

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



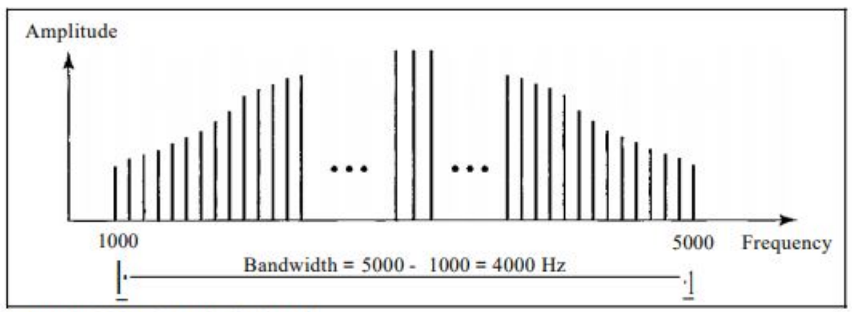
a. Time-domain decomposition of a composite signal



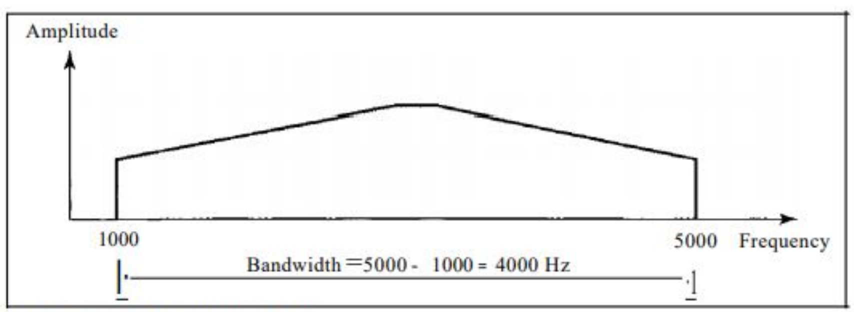
b. Frequency-domain decomposition of the composite signal

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 the nonperiodic signals has the same range, but the frequencies are continuous.



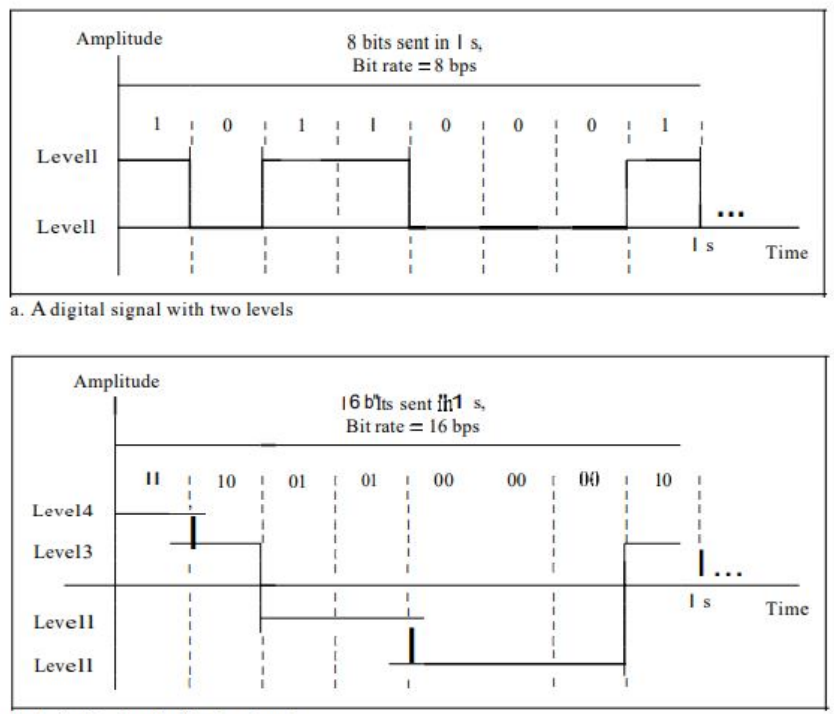
a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

DIGITAL SIGNALS

- In addition to being represented by an analog signal, information can also be represented by a digital signal.
- For example, a I can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels.
- In this case, we can 72 send more than 1 bit for each level.



a. A digital signal with two levels

b. A digital signal with four levels

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

Bit Rate

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

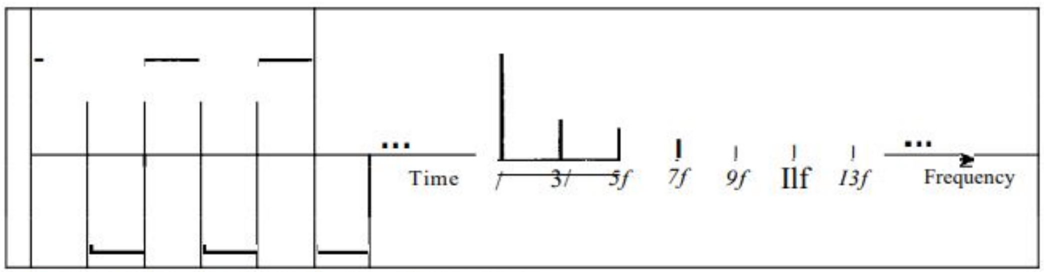
Bit Length

- The bit length is the distance one bit occupies on the transmission medium.
- Bit length = propagation speed x bit duration

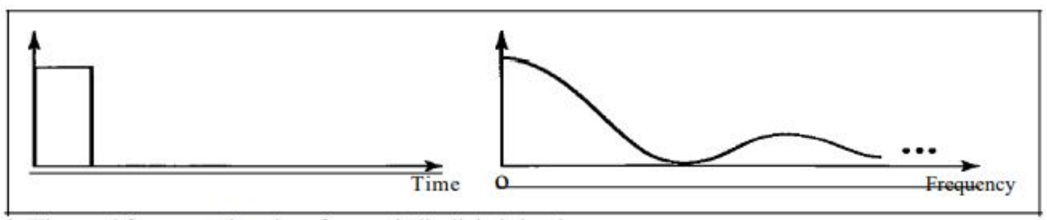
Digital Signal as a Composite Analog Signal

- A digital signal is a composite analog signal. The bandwidth is infinite, as you may have guessed.
- A digital signal, in the time domain, comprises connected vertical and horizontal line segments. A vertical line in the time domain means a frequency of infinity (sudden change in time).
- A horizontal line in the time domain means a frequency of zero (no change in time). Going from a frequency of zero to a frequency of infinity (and vice versa) implies all frequencies in between are part of the domain.

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



a. Time and frequency domains of **periodic** digital signal



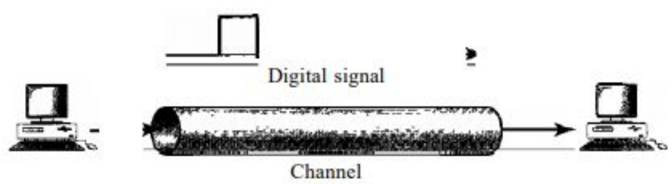
b. Time and frequency domains of nonperiodic digital signal

The time and frequency domains of periodic and nonperiodic digital signals

Transmission of Digital Signals

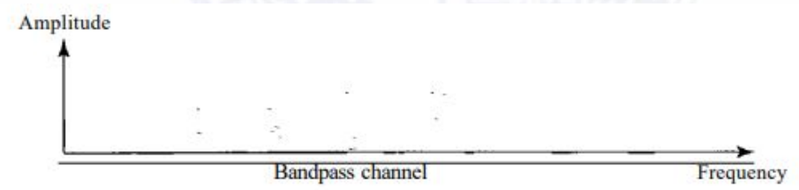
Baseband Transmission

- Baseband transmission means sending a digital signal over a channel without changing the digital signal to an analog signal.
- Baseband transmission requires that we have a low-pass channel, a channel with a bandwidth that starts from zero.
- This is the case if we have a dedicated medium with a bandwidth constituting only one channel.
- For example, the entire bandwidth of a cable connecting two computers is one single channel.

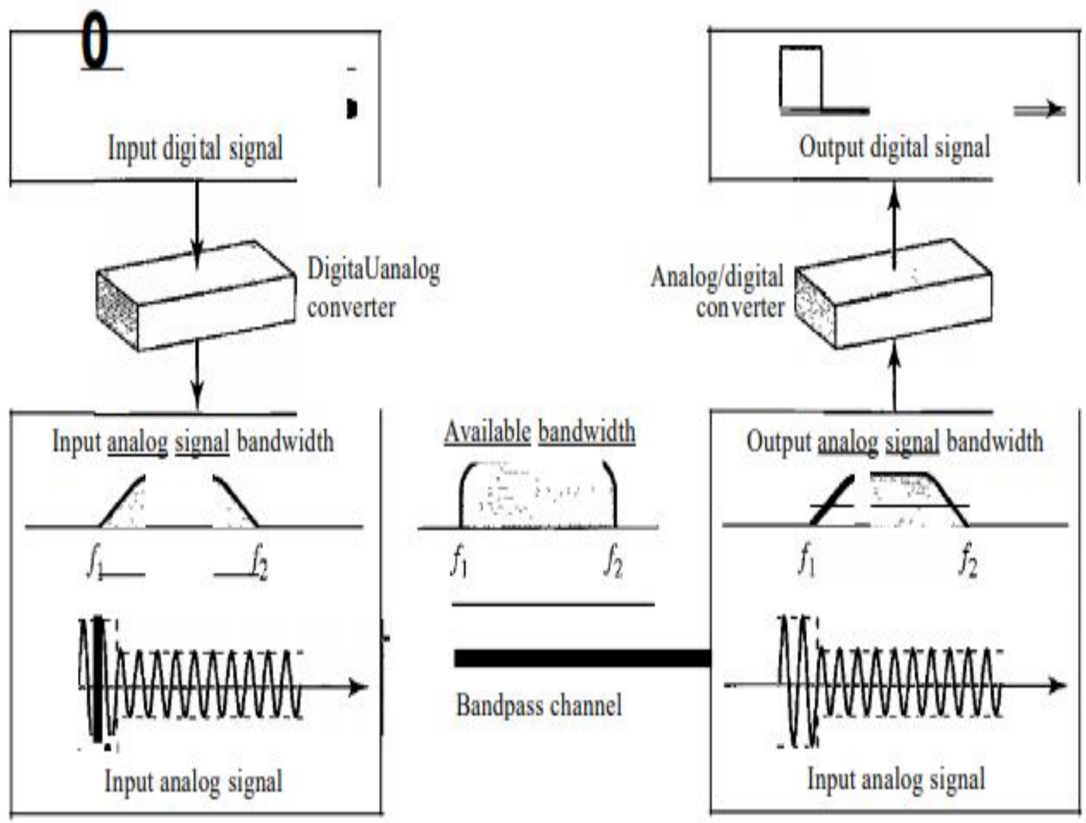


Broadband Transmission (Using Modulation)

- 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.
- 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.



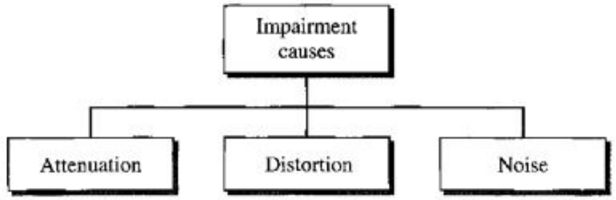
- A digital signal is converted to a composite analog signal. We have used a single-frequency analog signal (called a carrier); the amplitude of the carrier has been changed to look like the digital signal.



Modulation of a digital signal for transmission on a bandpass channel

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.

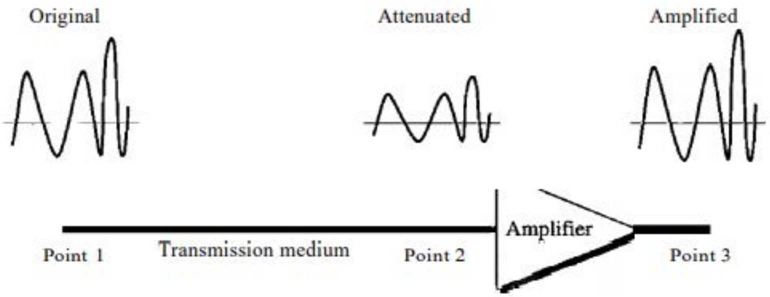


Consequences

- For Analog Signals : degradation of signal quality
- For Digital Signals : Bit Error

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. Some of the electrical energy in the signal is converted to heat.
- To compensate for this loss, amplifiers are used to amplify the signal.



Decibel

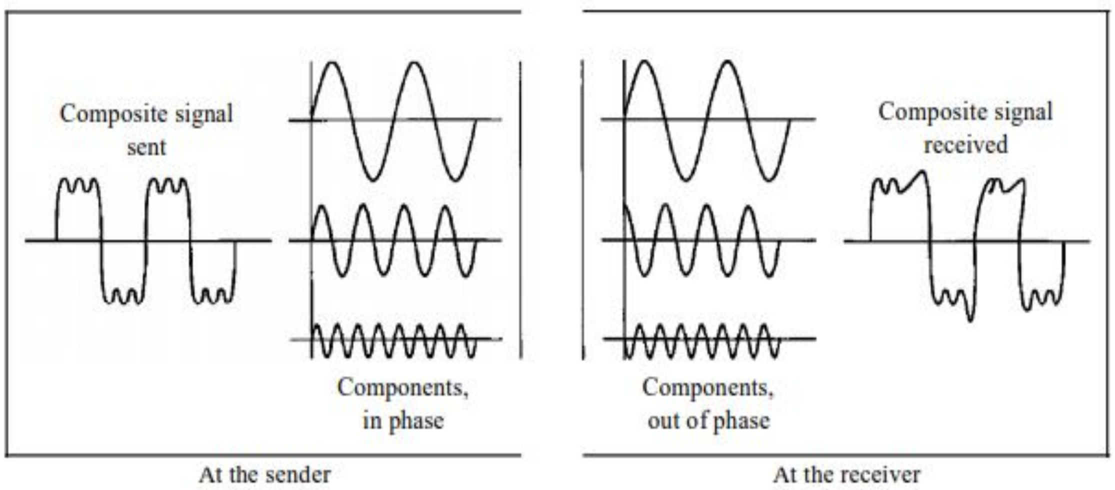
- To show that a signal has lost or gained strength, engineers use the unit of the decibel. The decibel (dB) measures the relative strengths of two signals or one signal at two different points. Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

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

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

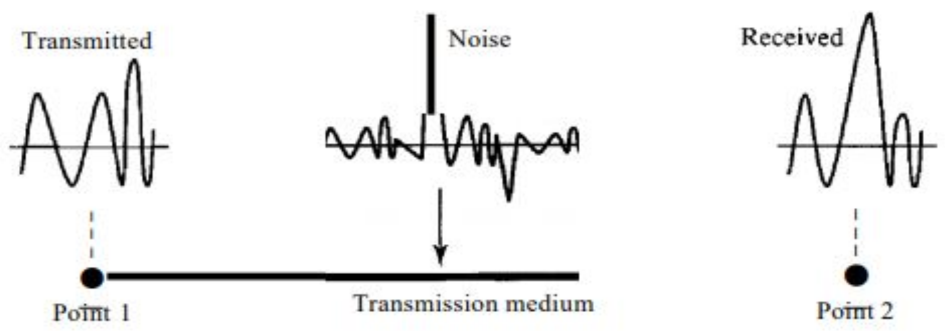
Distortion

- 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 (see the next section) through a medium and, therefore, its own delay in arriving at the final destination.
- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.
- In other words, signal components at the receiver have phases different from what they had at the sender.
- The shape of the composite signal is therefore not the same.



Noise

- Noise is another cause of impairment. Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.
- Thermal noise is the random motion of electrons in a wire which creates an extra signal not originally sent by the transmitter.
- Induced noise comes from sources such as motors and appliances. These devices act as a sending antenna, and the transmission medium acts as the receiving antenna.
- Crosstalk is the effect of one wire on the other. One wire acts as a sending antenna and the other as the receiving antenna.
- Impulse noise is a spike (a signal with high energy in a very short time) that comes from power lines, lightning, and so on.



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