Data Communication

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References :

- Data Communication and Networking - Behrouz A. Forouzan
- Mumbai University Archives
- Articles
- https://www.youtube.com/playlist?list=PLgF4R05NShg0Tm1n0__cOWTlVBcWB6EGv

Chapter 01: Introduction

Data: Data refers to the **raw facts** that are **collected**.

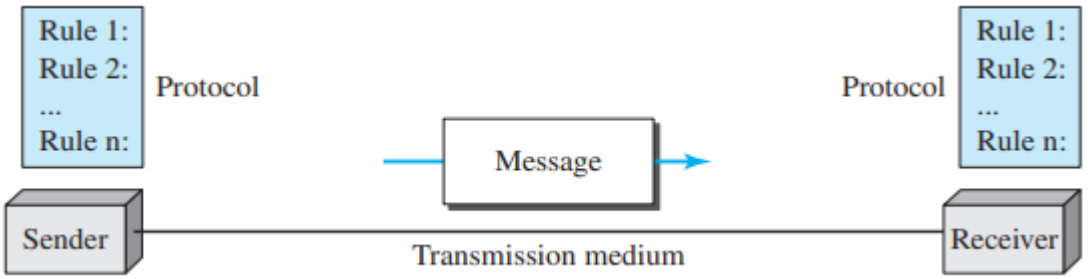
Information: Information refers to **processed data** that enables us to take decision.

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

The effectiveness of data communication:

- **Delivery :** Deliver data to the **correct destination**.
- **Accuracy :** Deliver the data **accurately**.
- **Timeliness :** Deliver data in **timely manner**. Audio and Video data has to be delivered in a timely manner without any delay; such a data delivery is called real time transmission of data.
- **Jitter :** It is the **variation in the packer arrival time**. Uneven jitter may affect the timeliness of data being transmitted.

The components of data communication: There are five components.

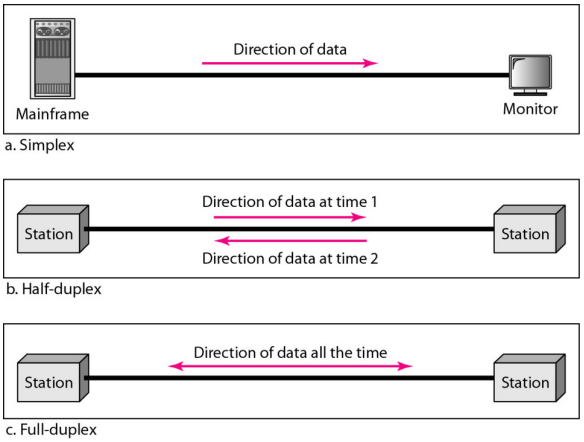


- **Message:** the **information** or data to be communicated
- **Sender:** the **device that sends** the data message.
- **Receiver:** the **device that receives** the message.
- **Transmission medium:** the **physical path by which a message travels** from sender to receiver.
- **Protocol:** A protocol is **a set of rules that govern** data communication. It is an **agreed upon set or rules used by the sender and receiver** to communicate data. Without protocol, they may be connected but not communicating.

Data Representation

Text	Numbers	Images	Audio	Video
- Represented by bit pattern, a sequence of bit. - Encoding System: ASCII, Unicode	- Stored as a patter of bits	- A pixel is the smallest element of an image represented by bits. - Image is a matrix of pixels	- the recording or broadcasting of sound or music - Continuous signal	- the recording or broadcasting of a picture or movie.

Data flow



Data flow is the **movement of data through a system** comprised of software, hardware or a combination of both.

Basic for Comparison	Simplex	Half Duplex	Full Duplex
Direction of Communication	Unidirectional	Two-directional, one at a time	Two-directional, simultaneously
Send/Receive	The sender can only send data	The sender can send and receive data, but one a time	The sender can send and receive data simultaneously
Performance	Worst	Better	Best
Example	Keyboard	Walkie-Talkie	Telephone

Network

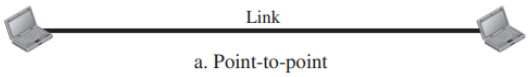
A network is the **interconnection of a set of devices capable of communication.**

- Host
- **Connecting-device:** connects the network to other networks, router
- **Switch:** connects devices together, modem

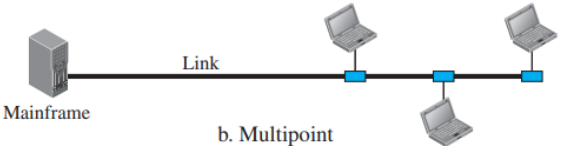
A network criteria:

	Reliability	Security	Performance
Measured by	- the frequency of failure - the time it takes a link to recover from a failure	- protecting data from unauthorized access, damage and development	many ways - transit time, response time - achieving by higher throughput and smaller delay

Type of Connection



a. Point-to-point

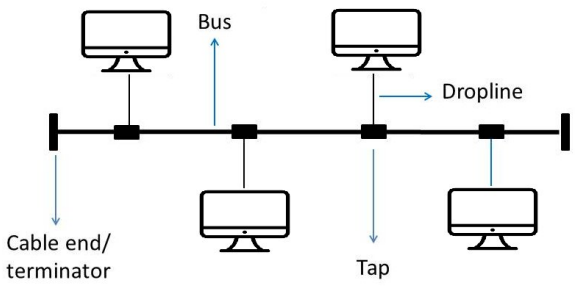


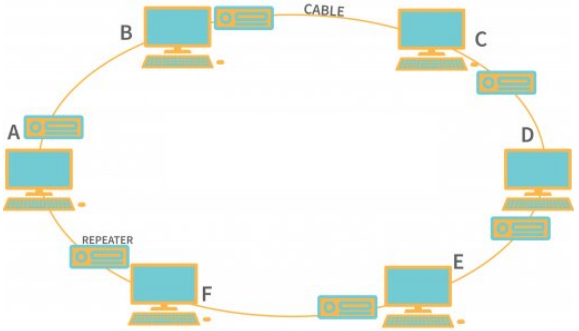
b. Multipoint

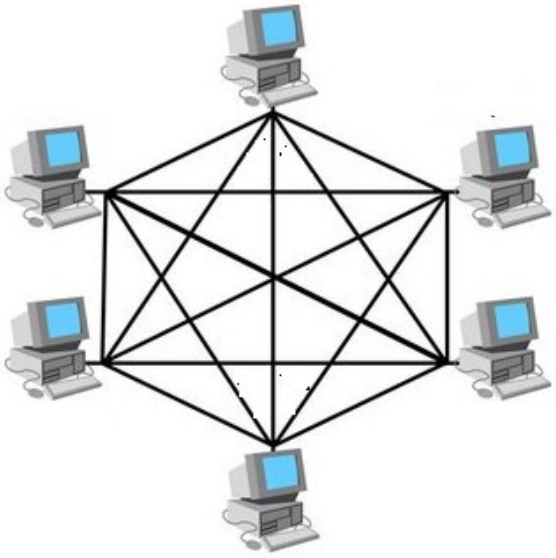
Basis for Comparison	Point-to-Potin Connection	Multipoint Connection
Definition	a dedicated link between **two** devices	more than two devices share a single link
Sender/Receiver	there is one transmitter and one receiver	one transmitter but **many receivers**
Security	Provides **security**	Doesn't provide security and privacy
Complexity	**Simple** and Straightforward	Complex
Cost	**Costlier**	Lower
Suitability	Ideal for **dedicated**, **reliable** communications	Beneficial for **integrated systems** with multiple devices

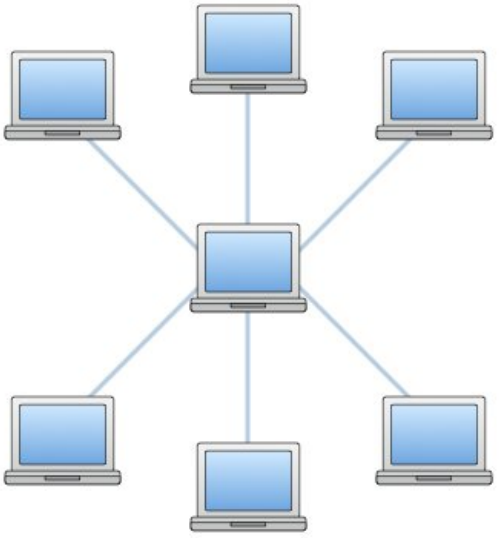
Physical Topology

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









Topology	How does it works?	Advantages	Disadvantages
Bus	- All device connected to a single cable, with terminators at each end. The main cable serves the network's spine. All nodes are linked to the **Taps and Drop lines**. Drop lines are the **connection between the bus and the nodes.** The taps are **three way connector** that aids in connecting the dropline to the main central cable. - The	- Less Cabling - Less Expensive - Small network - Upgradeable	- Reduced signal strength - Core failure - Low Security

Topology	How does it works?	Advantages	Disadvantages
	travels only one direction, and when it reaches the end the terminal removes it. one computer acts as a server and **other computers act as clients.** Example: Connection two floors with a single line.		
Mesh	- Every device has **a dedicated point to point link to every other device.** Duplex-mode links : n*(n-1)/2 n : Total Nodes Fully-connected mesh : each computer is linked with all Partially connected mesh: only specific computers are connected to those with whom they frequently communicate Example: Internet	- Consistent : reliable - High-speed information exchange - Easier reconfiguration	- Costly - High-maintenance - Reducing network efficiency
Ring	- **Devices are connected in a closed loop, with each device connected to two other devices.** The last computer is linked to the first, forming a loop. Each computer has exactly **two neighbors**. The central computer in this topology is the **monitor station**, which in charge all operations. Devices **use tokens for**	- Token System - Less Cabling - Easier troubleshooting	- Difficult to upgrade - When one system crashes, it disturbs the overall network activity.

Topology	How does it works?	Advantages	Disadvantages
	data transmission between them. The computer station must have the token to transmit data. The token is released when the transmission ends, and other computer stations can use it to send data. Example: **Industrial Control System**, where device are interconnected in a ring to monitor and control processes.		
Star	- All devices are connected to a central hub or switch. Each node is connected to the hub with a point-to-point connection. All traffic passes through the hub that serves a repeater.	- Easy to install and wire. - No disruptions to the network when connecting or removing. - Easy to detect faults and remove parts.	- Requires more cable length - If the hub, switch or concentrator fails, nodes attached are disables. - Expensive

Consideration When Choosing a Topology: Money. Length of cable needed, Future growth, Cable type

Network Types

Basis for Comparison	LAN	MAN	WAN
Full form	**Local** Area Network	**Metropolitan** Area Network	**Wide** Area Network
Definition	LAN is a network that usually connects a **small group of computers in a given geographical area**	MAN is comparatively wider network that **covers large region, like towns and cities.**	The WAN network spans to an even **large locality - like various countries together.**

Basis for Comparison	LAN	MAN	WAN
Ownership	Private hospitals, home, schools, office	Can be both private or public. Many organizations and telecom operators.	Can be both private or public.
Maintenance and design	Easy	Comparatively difficult	Very difficult
Speed	High	Moderate	Low
Propagation delay	Very short	Moderate	High
Faulty Tolerance	Better	Lesser	Lesser
Communication on allotment	Typically allows a single pair of devices to communicate. But it may support more too.	Allows multiple computers to interact simultaneously with each other.	A huge group of computers can easily interact with each other.
Congestion	Very low	Higher	Higher

Chapter 02: Network Models

Protocol Layering: A layer protocol architecture provides a conceptual framework for diving the complex task of exchanging information between remote hosts into simpler task.

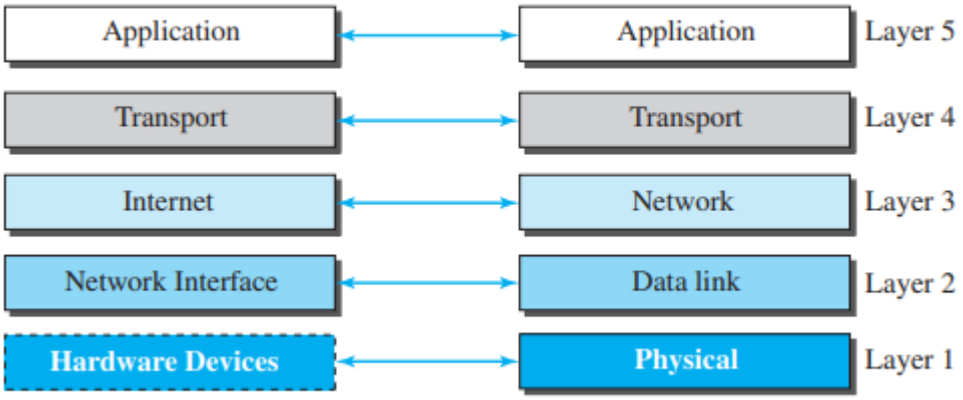
Principle of Protocol Layering:

- **First Principle :** The first principle dictates that if we want bidirectional communication, we need to make each layer so that it is able to perform two opposite task, once in each direction.
- **Second Principle:** The second principle that we need to follow in protocol layering is that the two objects under each layer at both sides should be identical.

Internet Protocol Suite/ TCP/IP : The internet protocol suite, commonly knowns as TCP/IP, is a framework for organizing the set of communication protocols used in the internet and similar computer net

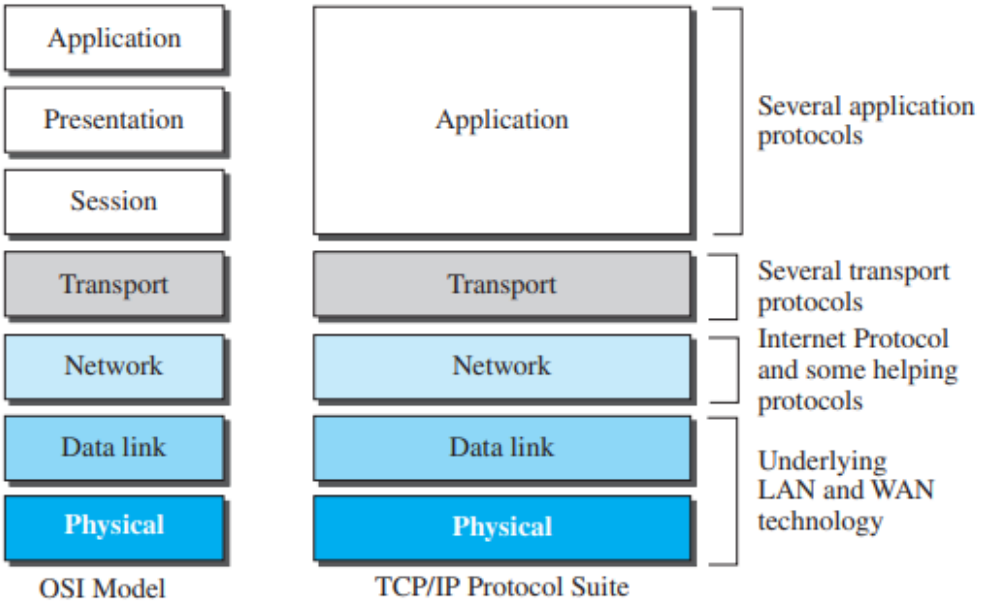
Layered Architecture

Layers in the TCP/IP protocol suite



OSI ：Open System Interconnection

Figure 2.12 *TCP/IP and OSI model*



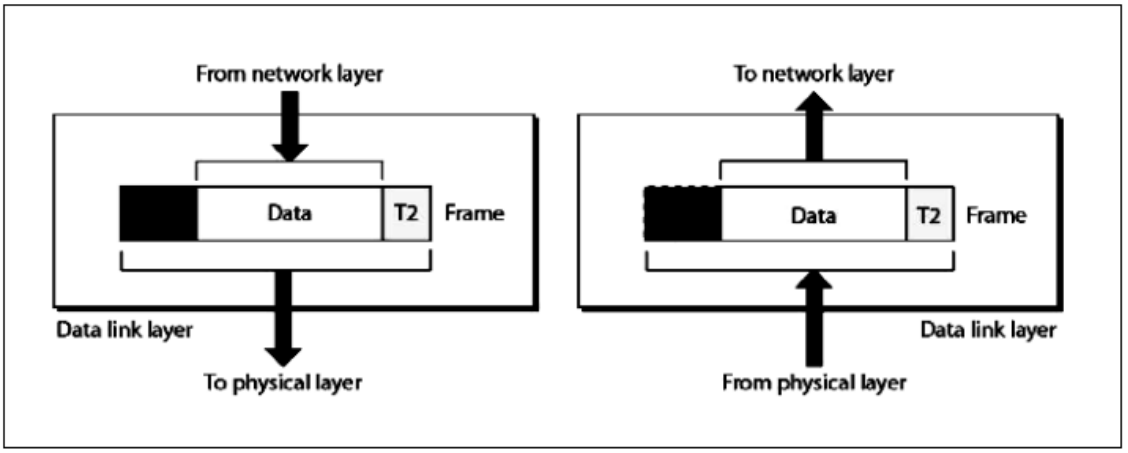
Description of Layers in OSI Model

- **Physical Layer**

    - The physical layer provides a standardized interface to physical transmission media.
    - On the sender side → it receives data from Data Link layer and encodes it to signals to be transmitted.
      On the receiver side → it receives the signal from the transmission medium decodes it back into data and sends it to Data Link Layer.

- **Data Link Layer**
- The Data Link layer adds reliability to the physical layer by providing **error detection and correction mechanism.**
- On the sender side → It receives the data from Network Layer and **divides the stream of bits into fixed size manageable units called as Frames** and sends it to the physical layer.

  On the receiver side → It receives data **from Physical Layer and regroups them intro frames and sends them to Network layer**. This process is called Framing.
- **Physical Addressing :** The data link layer appends the physical address in the header of the frame before sending it to physical layer. Physical layer contains sender and receiver.
- **Flow control:** It makes sure that the sender sends the data at a speed at which receiver can receive it.
- **Error control:** The data link layer imposes error control mechanism to identify lost or damaged frames, duplicate frames and the retransmit them.
- **Main responsibility:** hop to hop transmission of frames.



- **Network Layer**
  - The network layer makes sure that **the data is delivered to the receiver despite multiple intermediate devices**.
  - Sending side → it accepts data from transport layer divides in into packets, adds addressing information in the header and passes it to the data link layer.
    Receiving side → It receives the frames from data link layer, converts them into packets, verifies the physical addresses and send the packets to the transport layer.
  - The network layer is responsible for source to destination of delivery of data.
  - **Logical addressing:** The network layer uses logical address commonly known as IP address to recognize devices on the network.
    - An IP address is a universally unique address which enables the network layer to identify devices outside the sender's network.
  - **Routing:** The network layer divides data into units called packets of equal size and bears a sequence number for rearranging on the receiving end.
    - Every packets is independent of the other and may travel using different routes to reach the receiver hence may arrive out of at the receiver.
    - The process of finding the best path is called as Routing, using routing algorithms.

- It doesn’t perform any flow control or error control.
- **Main responsibility:** Transmission of packets from source to destination.

- **Transport Layer**
  - The transport layer takes care of process to process delivery of data and makes sure that it is intact and in order.
  - Sending side → the transport layer receives data from the session layer, divides it into unit called **segments** and sends it to the network layer.
    Receiving side → It receives packets from network layer, converts and arranges proper sequence of segments and sends it to the session layer.
  - To ensure process to process delivery it makes sure of port address to identify the data from the sending and receiving process.
    - A port address is the name or label given to a process. It is a 16 bit address. HTTP use port address 80.
  - Error control and flow control
- **Session Layer**
  - The session layer establishes a session between the communicating devices called dialog and synchronizes their interaction.
  - Sending side → Accept data from presentation layer adds checkpoint to it called syn bits and passes the data to the transport layer.
    Receiving side → It receives data from transport layer removes the checkpoints inserted previously and passes the data to the presentation layer.
  - The checkpoint or synchronization points is a way of informing the status of the data transfer.
- **Presentation Layer**
  - The presentation layer performs translation, encryption and compression of data.
  - Sending side → It receives data from the application layer adds header which contains information related to encryption and compression and sends it to the session layer.
    Receiving side → It receives data from session layer decompresses and

decrypts the data as required and translates it back as per the encoding scheme used at the receiver.

    - **Translation:** The sending and receiving device may run on different platforms. Hence, a translation service may be required.
    - **Compression:** It ensures faster data transfer. The data compressed at sender has to be decompressed at the receiving end.
    - **Encryption:** It is the process of transforming the original message to change its meaning before sending it. The revers process called decryption has be performed at the receiving end to recover the original message.
- **Application Layer**
    - **Main responsibility:** provide access to network resources
    - The application layer enables the user to communicate its data to the receiver by providing certain services.
    - Once the data is ready, the application layer initiates communication with the corresponding application on another device. This involves establishing a connection, if necessary, and sending the data packets over the network.
    - Once the data packets are processed, the application layer delivers the data to the appropriate user application running on the receiving device. This enables the application to interpret and utilize the received data for further processing or display to the user.
    - Ensures effective communication with another application program on a network.
    - Facilitating communication between clients and server.
    - User Authentication and authorization
    - Error handling and recovery

Multiplexing and Demultiplexing

- Multiplexing at the source and demultiplexing at the destination

- Multiplexing → A protocol at a layer can encapsulate a packet from several next-higher-layer protocols
- Demultiplexing → A protocol can decapsulate and deliver to a several next-higher layer protocols

Chapter 03: Introduction to Physical Layer

Analog Data	information that is continuous	Human voice
Digital Data	information that has discrete states	Data are stored in computer in the form of 0s and 1s

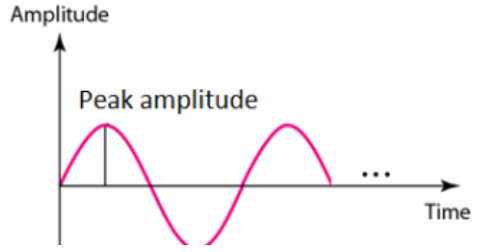
Periodic Signal	Signals which repeat itself after a fixed time period
Non-periodic Signal	Signal which do not repeat itself after a fixed time period

Analog Signal

- They have infinite value in a range

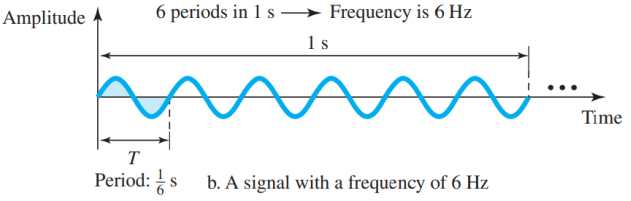
Characteristics of an analog signal (Sine wave is analog) : 3 characteristics

Peak Amplitude



- The peak amplitude of a signal is the absolute value of the highest intensity
- The amplitude of a signal is proportional to the energy carried by the signal

Frequency and Period



- Frequency (f) refers to the number of cycles completed by the wave in one second.
  Frequency is the rate of change w.r.t time.
  If signal doesn't change at all, f is 0. If it changes instantaneously, f is ∞
  Frequency is independent of the medium

- Period (T) refers to the time taken by the wave to complete one cycle

$$f = \frac{1}{T}$$

Phase

- Phase describes the position of the waveform w.r.t time.
- Phase indicates the forward and backward shift of the waveform from the axis.
- It is measured in degrees or radian

Example: A sine wave is offset $\frac{1}{6}$ cycle w.r.t time. What is phase degrees in degrees and radian.

$\frac{1}{6} \times 360 = 60^\circ$

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

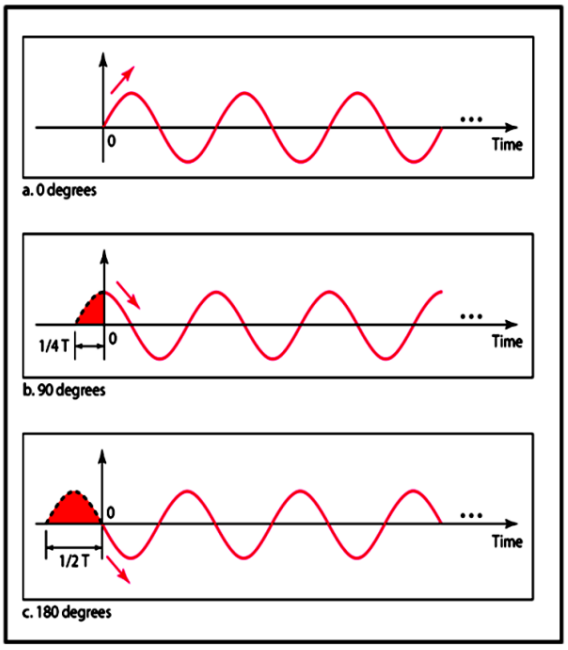


Fig: Phase of a sine wave

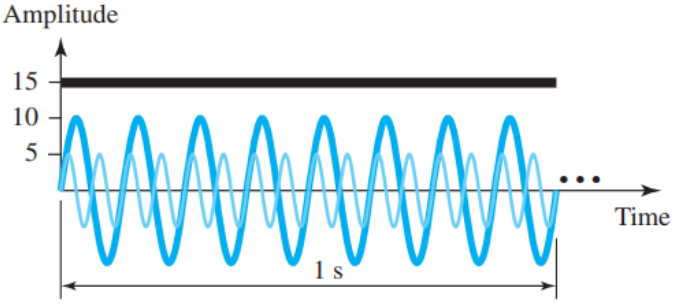
Wavelength

- The wavelength (λ) is the distance a signal travels in one period.
- It is depends on medium and frequency
- It is measured in micrometers

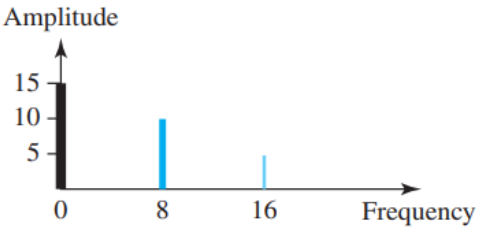
$$\lambda = \text{Propagation Speed} \times T$$

$$\lambda = \text{Propagation Speed} \times \frac{1}{f}$$

Time Domain and Frequency Domain



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

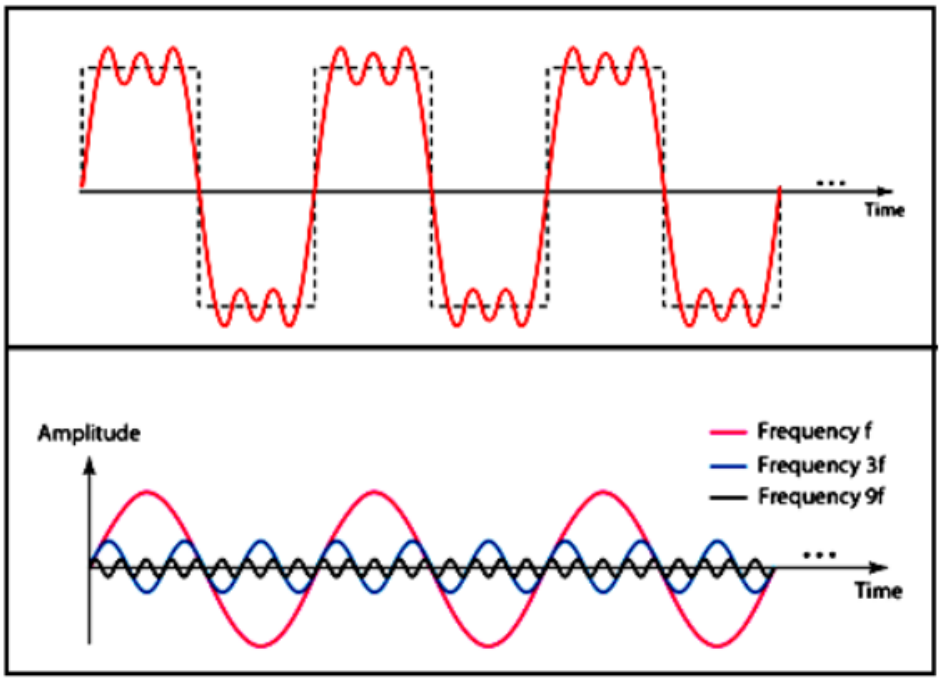


b. Frequency-domain representation of the same three signals

- The time-domain plot shows the changes in signal amplitude w.r.t time. **Time-amplitude** relation.
- The frequency-domain plot shows **the signal frequency and peak amplitude.**

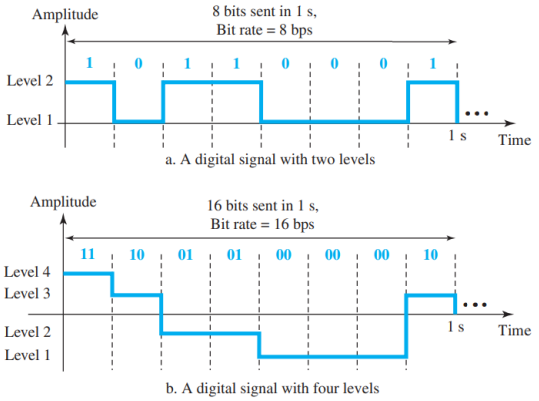
Composite Signal

- A composite signal is a **combination of two or more simple sine waves with different frequency, phase and amplitude**
- A periodic composite signal can be decomposed into a series of signals with discrete frequencies.
- A non-periodic signal when decomposed gives a combination of sine waves with continuous frequencies.



Digital Signal

- They have limited number of defined values
- Information in digital signal can be explained in the form of voltage levels
- If a signal has L levels, each level need $log_2 L$ bits.



For the second one 11 = Level 3, 10 = Level 2, ...

Bit Length or Interval

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

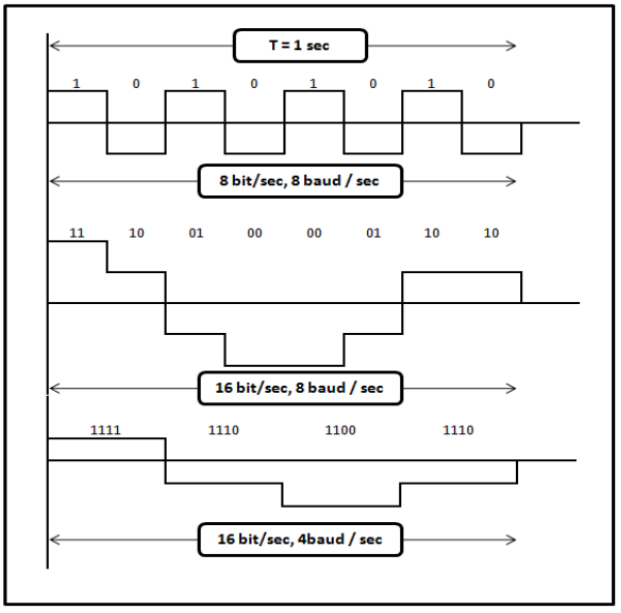
Baud Rate

- It is the rate of signal speed
- The number of signal units per second that are required to represent these bits

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

Bit Rate

- It is the the number of bits transmitted in one second
- Expressed as bits per second (bps)



Example: An analog signal carries 4 bits in each signal unit. If 1000 signal units are send per second. Find the baud rate and bit rate.

Baud rate : 1000 bauds

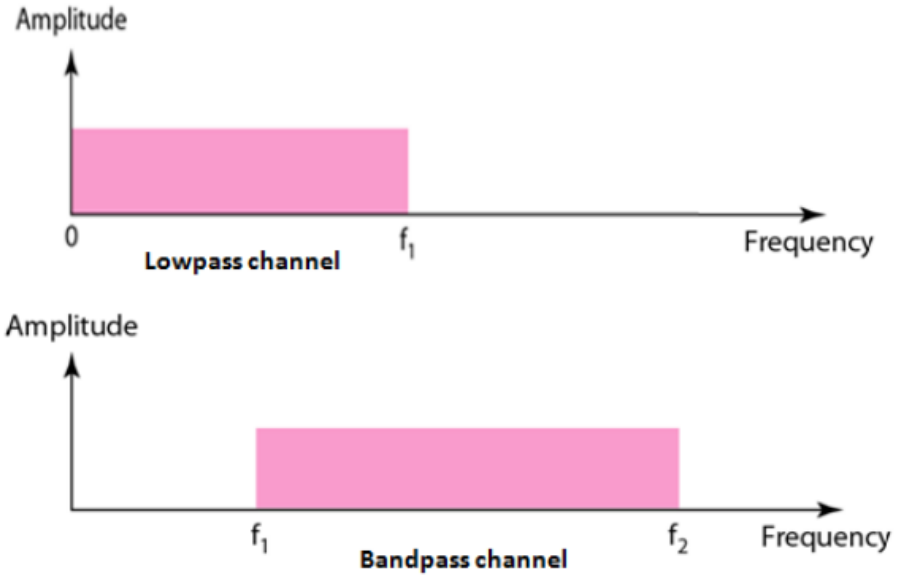
Bit rate = 4 * 1000 = 400 bps

Channel

- A channel is the medium through which the signal carrying information will be passed

Types of Channels

Low Pas Channel	Band Pass Channel
The channel has the lowest frequency as 0 and highest frequency as some non zero frequency f1.	The channel has the lowest frequency as some non-zero frequency ‘f1’ and highest frequency as some non-zero frequency ‘f2’
This channel can pass all the frequencies in the range 0 to f1.	The channel can pass all frequencies in the range f1 to f2.
Rough Approximation (minimum) : N/2 First two harmonics : 3N/2 First three harmonic : 5N/2 N = frequency	



- **Transmission of Digital Signal**

Baseband Transmission	Broad band transmission
The signal is transmitted without making any change to it	A digital signal cannot be transmitted directly through it
The bandwidth of the signal to be transmitted has to be less than the bandwidth of the channel	We use modulation. We change the signal to analog signal before transmitting it.
Ex. Consider a Baseband channel with lower frequency 0Hz and higher frequency 100Hz, hence its bandwidth is 100. We can easily transmit a signal with frequency below 100Hz. Logically a signal with frequency say 120Hz will be blocked	Ex. Consider the bandpass channel with lower frequency 50Hz and higher frequency 80Hz, and the signal to be transmitted has frequency 10Hz. To pass the analog signal through the bandpass channel, the signal is modulated using a carrier frequency. The analog signal (10Hz) is modulated by a carrier frequency of 50Hz resulting in an signal of frequency 60Hz which can pass through our bandpass channel.

Bandwidth

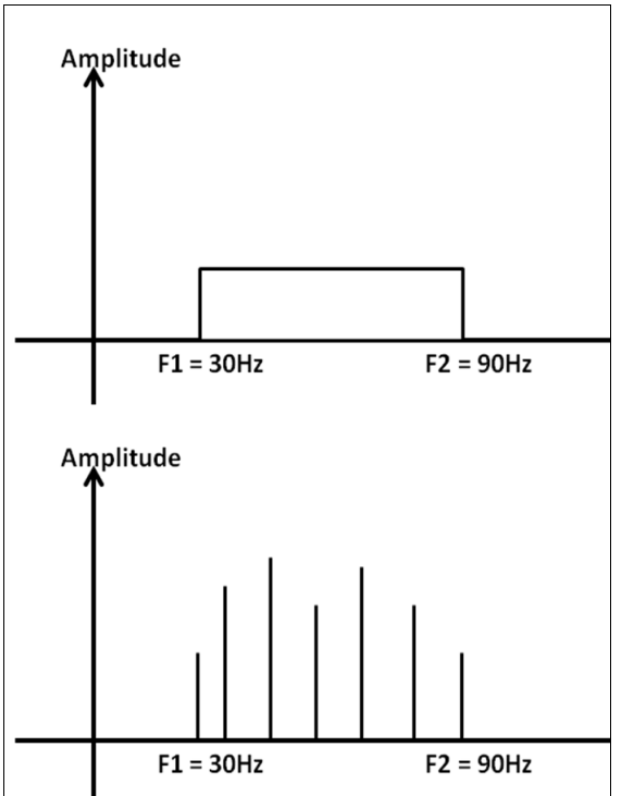
- Bandwidth can be defined as the portion of the electromagnetic spectrum occupied by the signal.

- It may be defined as the frequency range over which a signal transmitted.

Bandwidth of an analog signal:

- Bandwidth of an analog signal is expressed in term of its frequencies.
- It is calculated by the difference between the maximum and minimum frequency.

Bandwidth = 90 - 30 = 60 Hz



Bandwidth of an digital signal

- It is defined as the maximum bit rate of the signal to be transmitted
- it is measured in bits per second

Bandwidth of a Channel

- In terms of analog signal, bandwidth of the channel is the range of frequencies that the channel can carry.
- In terms of digital signal, bandwidth of the channel is the maximum bit rate supported by the channel.

- The Channel bandwidth determines the type of signal to be transmitted.

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

$$\text{Signal lost ot gained} = 10log_{10}\frac{P_2}{P_1}\ \text{dB}$$

Distortion: It means that the signal changes its form or shape. It can occur in a composite signal made of different frequencies. Each signal has its own propagation speed through a medium and therefore its own delay in arriving at the final destination.

SNR : Signal to Noise Ratio

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

$$\text{SNR}_{dB} = 10log_{10}\text{SNR}$$

The maximum data rate of a channel

Data rate depends on three factors:

- The bandwidth available
- The level of the signal we use
- The quality of the channel (noise level)

The Quality of the channel

Noiseless or Perfect Channel	Noisy Channel
An ideal channel with no noise	A realistic channel that has some noise
The Nyquist bit rate gives the bit rate	The Shannon Capacity gives the bit rate

Nyquist Bit Rate

$$\text{Bit Rate} = 2 \times \text{Bandwidth} \times log_2 L$$

Shannon Capacity

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

- SNR is the Signal to Noise Ratio
- Measured in bps

Propagation time : Time required for a bit to travel from the source to the destination.

$$\text{Propagation time} = \text{Distance}/\text{Propagation Speed}$$

Transmission Time

$$\text{Transmission Time} = \text{Message size}/\text{Bandwidth}$$

Chapter 05: Digital Transmission

Line Coding

- It is the process of converting digital data to digital signals.
- $r = \frac{\text{data element}}{\text{signal element}}$
- $\text{Signal rate (S)} = \frac{\text{Data rate (N)}}{r}$
- $\text{Average signal rate, } \text{S}_{ave} = c \times N \times \frac{1}{r} \text{ baud}$

Example: A signal is carrying data in which one data element is encoded as one signal element (r = 1). If the bit rate is 100 kbps, what is the average value of the baud rate if c is between 0 and 1?

$$S = c \times N \times 1/r = 1/2 \times 100000 \times 1/2 = 50 \text{ kbaud}$$

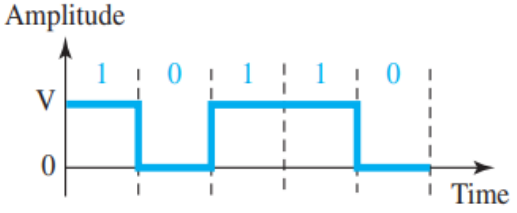
Line coding scheme line

- **Unipolar**

all the signal levels are on one side of the time axis

NRZ (Non-Return-to-Zero)

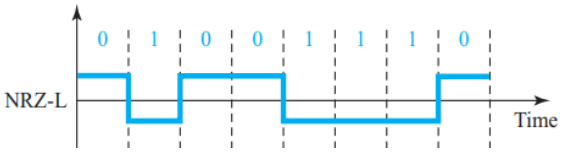
- Positive voltage defines bit 1 and the zero voltage defines bit 0;



- **Polar**

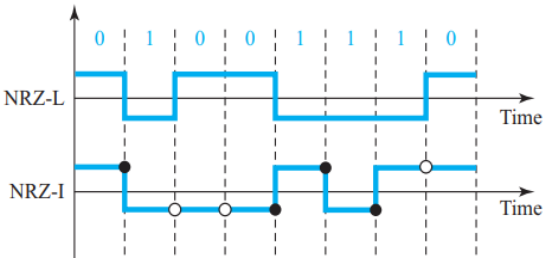
In polar schemes, the voltages are on both sides of the time axis.

NRZ-L (NRZ_Level)



If bit 0 : 1
if bit 1 : 0 (under the reference)

NRZ-I (NRZ Invert)

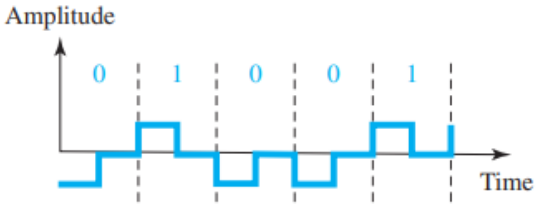


If bit 0 : No change

if bit 1 : Transition

NRZ-L and NRZ-I both have an average signal rate of N/2 Bd.

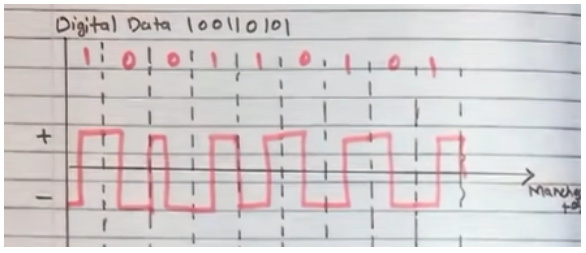
Polar RZ (Return to Zero)



1 → Z

0 → Reverse Z

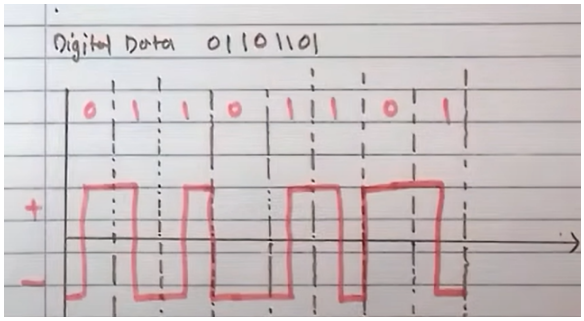
Polar Manchester



0 → + to - transition

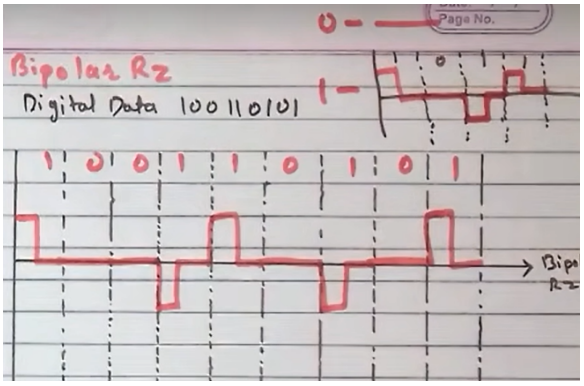
1 → - to + transition

Polar Differential Manchester



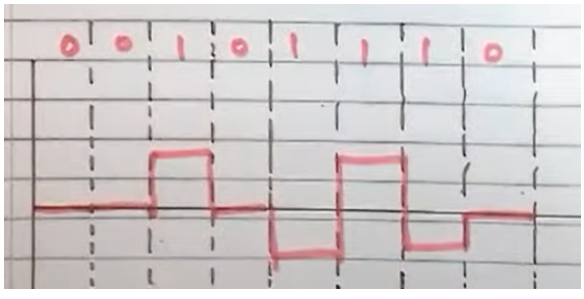
- **Bipolar**

Bipolar RZ



0 → Reference line
1 → Z, if again 1 reverse Z, continues ...

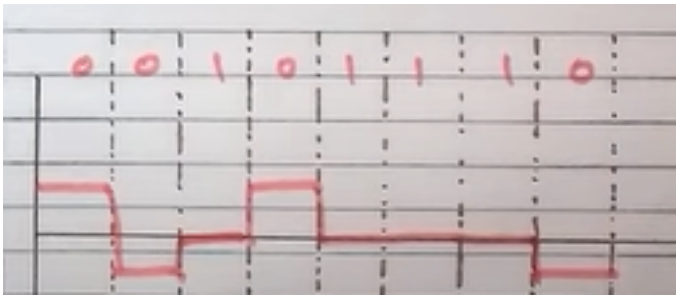
Bipolar AMI



0 → Draw line on reference

1 → Draw line above, then again below, alternating..

Bipolar Pseudoternary



1 → Draw line on reference

0 → Draw line above, below, alternating.

Skipped.

Chapter 05 : Analog Transmission

Digital to Analog Conversation

It is the process of changing one of the characteristics of an analog signal based on the information in digital data.

$S = N \times \frac{1}{r}; r = log_2 L$

$\mathrm{S} = \text{signal per second or baud rate}$

$\mathrm{N} = \text{data rate/ bit rate/ bits per second}$

$\mathrm{L} = \text{number of different signal elements}$

Analog Transmission

A method of sending/transmitting information over long distance by encoding it as an analogue signal.

Carrier Signal

In analog transmission. the sending device **produces a high-frequency signal that acts as a base for the information signal**. The base signal is known as carrier signal or frequency.

Chapter 06

Frame Size = Number of source * output slot carries + synchronization bit

Frame rate = source bandwidth/output slot carries

Frame duration = 1/frame rate

Data rate = frame rate * frame size

Efficiency =

$SNR_{\text{dB}} = 6.02 \times r + 1.76$

PCM bandwidth : $r \times B_{\text{analog}}$

- Assume that a voice channel occupies a bandwidth of 4 kHz. We need to multiplex 10 voice channels with guard bands of 500 Hz using FDM. Calculate the required bandwidth. Find the maximum effect of a 2-ms burst of noise on data transmitted a 12000 bps.

  10*4*1000 + 9*500
  2*10^-3 *12000

- What is the minimum number of bits in a pseudorandom noise (PN) sequence if we use FHSS with a channel bandwidth of B = 4 KHz and Bss = 128 KHz?

  The number of hops = 100 KHz/4 KHz = 25. So we need log225 = 4.64 ≈ 5 bits

Sr. No	Hub	Switch	Router
1.	Hub is a physical layer device i.e. layer 1.	Switch is a data link layer device i.e. layer 2.	Router is a network layer device i.e. layer 3.
2.	A Hub works on the basis of broadcasting.	Switch works on the basis of MAC address.	A router works on the basis of IP address.
3.	A Hub is a multiport repeater in which a signal introduced at the input of any	A Switch is a tele-communication device which receives a message	A router reads the header of incoming packet and forward it to the port for which it

Sr. No	Hub	Switch	Router
	port appears at the output of the all available ports.	from any device connected to it and then transmits the message only to the device for which the message is intended.	is intended there by determines the route. It can also perform filtering and encapsulation.
4.	Hub is not an intelligent device that may include amplifier on repeater.	A Switch is an intelligent device as it passes on the message to the selective device by inspecting the address.	A route is more sophisticated and intelligent device as it can read IP address and direct the packets to another network with specified IP address. Moreover routers can built address tables that helps in routing decisions.
5.	At least single network is required to connect.	At least single network is required to connect.	Router needs at least two networks to connect.
6.	Hub is cheaper as compared to switch and router.	Switch is an expensive device than hub.	Router is a relatively much more expensive device than hub and switch.
7.	Speed of original hub 10Mbps and modern internet hub is 100Mbps.	maximum speed is 10Mbps to 100Mbps.	maximum speed for wireless is 1-10 Mbps and maximum speed for wired connections is 100 Mbps.
8.	Hubs are used in LANs.	Switch is used in LANs.	Routers are used in LANs, MANs and WANs.

FDMA	TDMA	CDMA
Stands for frequency division Multiple Access.	Stands for Time Division Multiple Access.	Stands for code Division Multiple Access.
Shares a single BW among multiple stations by dividing it into subchannels. • Divides the spectrum into multiple frequency channels.	• Divides the time into slots.	• Assigns a unique code to each user.
• Each user is allocated to a unique frequency channel. Users can access the channel simultaneously but not shared it.	• Each user is allocated to one or more time slots. Users share the same frequency but transmit in different time slots. Only one user is transmit in a given time slot.	• Users can transmit simultaneously using the entire spectrum. Signals are distinguished by their unique codes.
No need of any codeword.	No need of any codeword.	Need.
Organization as Synchronization isn't required.	Required	not required.
Data rate is low	medium	high.
Mode of data transfer is continuous signal	signal in bursts.	digital signal.

Parameters	OSI Model	TCP/IP Model
Full Form	Open Systems Interconnection.	Transmission control protocol/ Internet protocol.
Layers	It has 7 layers.	It has 5 layers. or 4 layers.
Usage	It is low in usage.	It is mostly used.
Approach	It is vertically approached	It is horizontally approached.
Delivery	Delivary of the package is guaranted in OSI Model.	is not guaranted.
Replacement	Replacement of tools & changes can easily be done in this model.	is not easy.
Reliability	It is less reliable than TCP/IP Model.	It is more reliable than OSI model.
	Supports connectionless & connection oriented communication in the network layer	only
Developed by	ISO (International Standard Organization)	ARPANET (Advanced Research Project Agency Network.
	Reference Model	Implementation of OSI.
	Has separate session & presentation layer	combines the session & presentation layers in the network layer.