Chapter 1 - INTRODUCTION

→ computer Network is a collection of autonomous computers interconnected by a single technology.

→ Two computers are said to be interconnected if they are able to exchange information.

→ Networks come in many sizes, shapes and forms.

→ The internet is not a single network but a network of networks. (No. of networks are connected with each other and it forms the internet).

Uses of computer networks :-

i) Access to Information
ii) Person - to - person communication
iii) eCommerce
iv) Entertainment
v) Internet of Things (IOT)

i) Access to Information :- Access to Information comes in many forms. A common method of accessing information through the internet using a web browser which allows a user to retrieve information from various websites.

Information on the internet is accessed using a client - server model where a client requests information from a server that hosts information

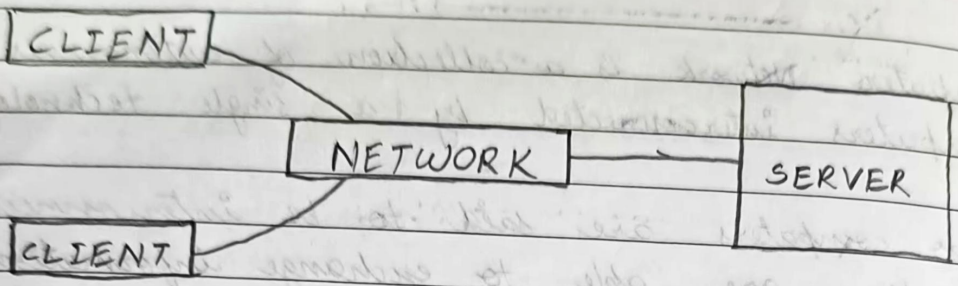
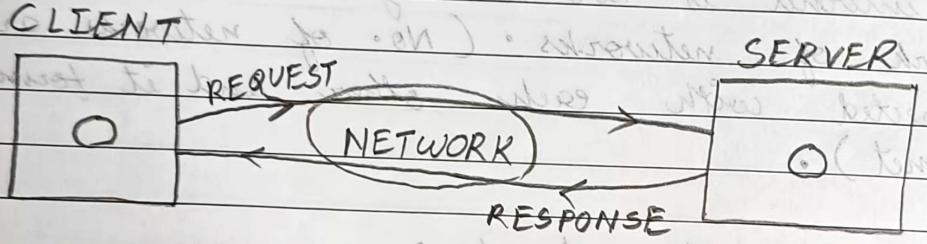


Fig :- Client - Server Model.



In client - server model, two processes are involved :- one on the client machine and one on the server machine.

Communication takes the form of the client process sending a message over the network to the server process.

The client process wait for a reply message when the server process gets the request, it performs the requested work and sends back a reply.

ii) Person - to - Person Communication :- Another type of person to person communication, sometimes known as peer to peer communication.

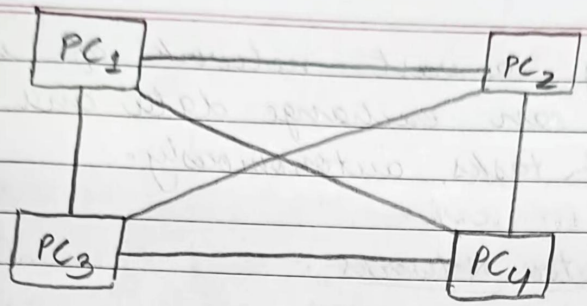


Fig:- Peer-to-Peer communication

In peer-to-peer communication, individuals who form the group can communicate with others in the group.

In peer-to-peer system there are no fixed clients and servers.

iii) Electronic commerce (eCommerce):-
Electronic commerce are of different forms:-

→ Business-to-consumers – B2C → ordering books online
→ Business-to-business – B2B → Car manufacturer ordering parts from supplier.
→ Government-to-Consumer – G2C → Government tax system.
→ Peer-to-Peer – P2P → File sharing.

iv) Entertainment :- Distribution of music, radio, Television programs & movies over the internet.

v) Internet of Things (IoT):- Internet of things refers to the collective network of connected devices and the technology.
IoT enables these devices to communicate with each other and with other internet enabled

devices creating a vast network of interconnected devices that can exchange data and perform a variety of tasks autonomously.

Types of computer Networks :-

(1) Access Networks — (A) Broadband access networks
(B) Mobile & wireless Access networks

(2) Content provider networks.

(3) Transit Network

(4) Enterprise Network.

1 → Access Networks :- Networks we commonly use to access the internet.
Internet access provides home users with connectivity to remote computers.

i) Broadband access networks :- Broadband access is delivered to home through copper (telephone lines), coaxial cables / optical fiber

ii) Mobile and Wireless Access Networks :- Cellular networks operated by telephone companies are one familiar kind of wireless network.
Wireless hotspot based on the IEEE 802.11 standard are another kind of wireless networks for mobile devices.

For high performance, wired networks are always better.

2→ Content Provider Networks :- Networks that house the data & application we use everyday is known as content provider networks (Data center Networks).

Many internet services are now served from the cloud Modern data center networks have thousands or millions of servers in a single location.

Many popular internet services use a service known as content delivery network (CDN) to deliver the content around the world.
A CDN is a large collection of servers that are geographically distributed in such a way that content is placed as close as possible to the users that are requesting it.
Eg :- Google, Facebook, Netflix are the best example of content provider.

3 → Networks that connect Access Networks with Content provider Networks is known as Transit Networks

When the content provider and Internet Service Provider are not directly connected, they depend on a transit network to carry the traffic between them.
Transit Network typically charge both the Internet Service Provider and the content provider to establish a connection between them.

4→ Enterprise Networks :- Networks that we use on a campus, office building or other organisation is known as Enterprise Network.

For smaller companies, the computers maybe located in a single office. But in case of largers companies, the computers and employees maybe situated over different offices at different places.

Networks called virtual private networks (VPN) connect the individual networks at different location into one logical network.

Network technology from Local to Global :-

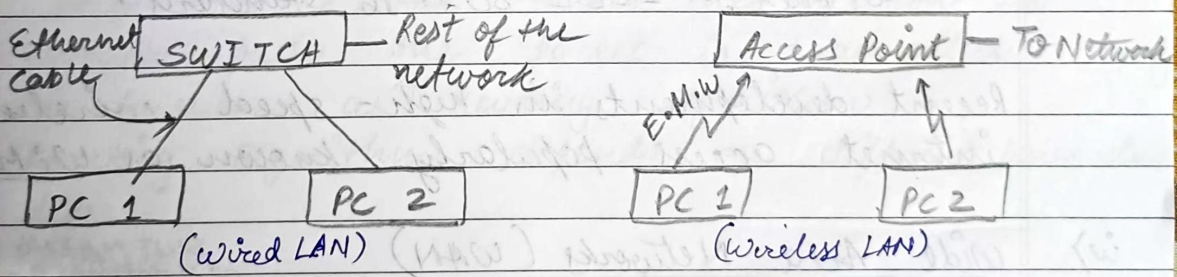
Classifying networks based on their scale :-

1 M	Square meter	PAN
10 M	Room	LAN
100 M	Building	
1 KM	Campus	
10 KM	City	MAN
100 KM	Country	WAN
1000 KM	Continent	
10000 KM	Planet	INTERNET

1- PAN → Personal Area Network
2- LAN → Local Area Network
3- MAN → Metropolitan Area Network
4- WAN → Wide Area Network
5- Home networks
6- Internetworks or internet

i) Personal Area Networks :-
Personal Area Network meant for one person.
Eg :- → Wireless headphones, mouse etc.
→ connection of smartwatch with phone.

ii) Local Area Networks :-
Interprocessor distance is around 10m to 1km
LAN are privately owned network within a single building / campus.
There are two types of LAN :- ① Wired LAN
② Wireless LAN.



Wireless LAN is also known as :- IEEE 802.11 standard.

Wired LAN use many different transmission technologies

Common Physical Media of transmission for wired LAN are :-
1- Twisted pair cable
2- Coaxial cable
3- Optical Fiber.

Speed :-
Wired LAN can run at speed around 100 MBPS to 40 GBPS.
Wireless LAN normally.

Wireless LAN normally use free space as medium of communication using Electromagnetic Waves.

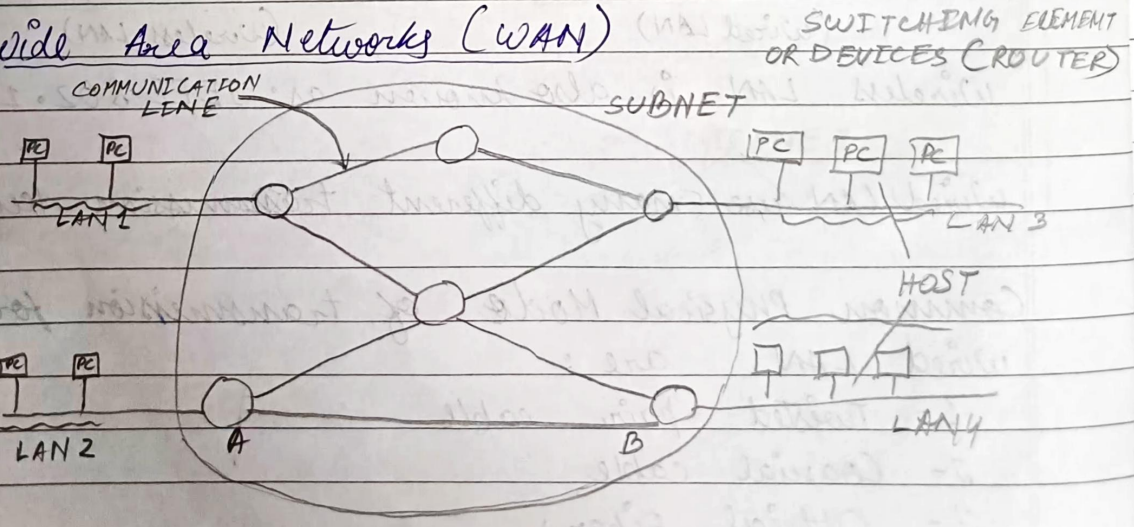
Speed :-
Wireless LAN can run at speed 11 MBPS to 7 GBPS

iii) Metropolitan Area Networks :- (MAN)
A metropolitan area network / MAN covers a city. The best known example of metropolitan area network is the cable television network available in many cities.

WiMax :- IEEE 802.16 Standard.

Recent developments in high-speed wireless internet access popularly known as WiMax.

iv) Wide Area Networks (WAN)



Components :-

i → LAN
ii → Switching elements / devices.
iii → Communication Line
iv → Host
v → Internet Service Provider

* Subnet :- It consist of i) Transmission line / communication line
ii) Switching Elements.

→ The Subnet is provided by Internet Service Provider.

→ If the host or local area networks are connected to the subnet, it forms the network.

Routing Algorithm :- There maybe many paths in the networks that connect the routers. How the network makes the decision in which path the packet is transmitted is known as Routing Algorithm.
Routing Algorithms depends on different parameters like :-

i) Distance
ii) Time of Transmission
iii) Number of Nodes.

Most recently the advanced version of the wide area network (SD-WAN) ⇒ Software-Defined Wide area networks.
SD-WAN controls the network using a combination of programmable switches and

some specific software program.

v) Home Networks :
The fundamental idea of Home Network is that in the future, most homes will be set up for networking & every device in the home will be capable of communicating with every other device.

vi) Internetworks or Internet :-
A collection of interconnected networks is called internetworks or internet.

→ The Internet connects content provider access networks, enterprise networks, home networks and many other networks to one another.

Q * Differentiate between Subnet, Networks and Internetworks.

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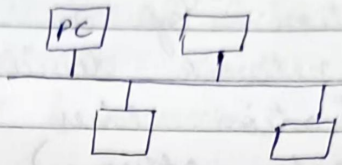
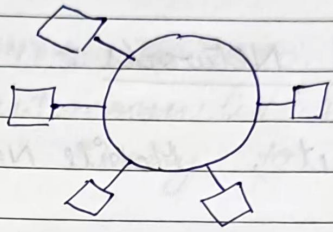
Network Topology :-

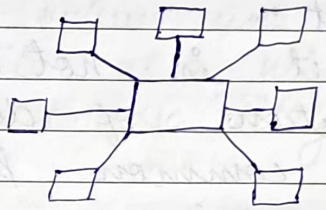
1- Bus Topology :-



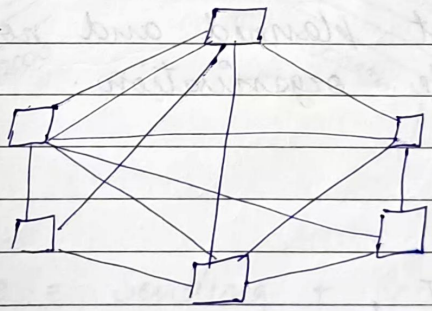
2- Ring Topology :-



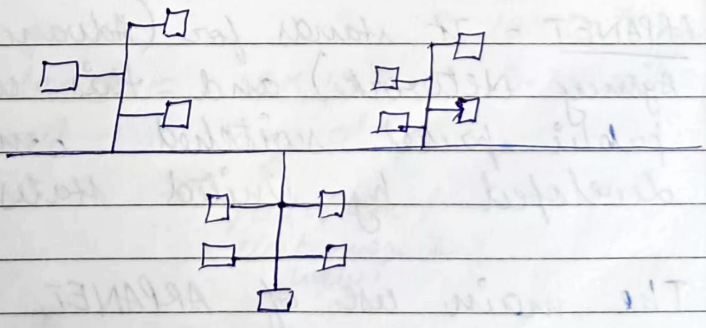
3- Star Topology :-



4- Mesh Topology :-



5- Tree Topology :-



Network topology is the diagrammatic representation of a network (how the different network devices, computers & communication lines are interconnected with each other.)

Example of Networks :-

The Internet, Mobile Networks, Wireless Networks (WiFi)

i) The Internet :-
The Internet is not a network but a vast collection of different networks that use common protocols and provide certain common services.

It was not planned and not controlled by any single organisation.

1- ARPANET
2- NSFNET
3- EUROPA NET,

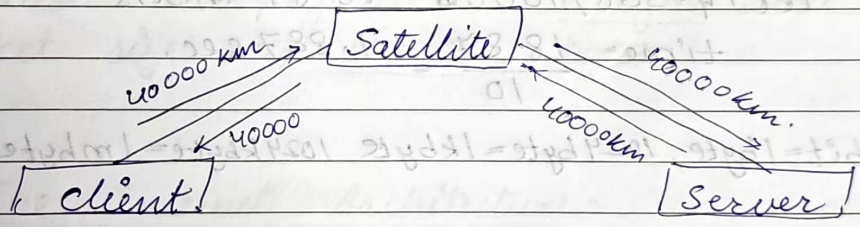
ARPANET - It stands for (Advanced Research Project Agency Network) and this was the first public-packet switched computer network developed by United States in 1969.

The main use of ARPANET was for academic and research purpose.

NSF NET :- National Science Foundation Network
It is developed by National Science Foundation in 1985 to replace ARPANET as the main network linking government & research facility.

During 1990s
EUROPANET, EBONY :- In 1990, in Europe, certain other interconnected networks like EuropaNet and Ebony to share their information.

Q.1:- A client server system uses a satellite network with the satellite at a height of 40000 Km. What is the best case delay in response to a request.



Total distance = Sending + Recieving
= 80000 + 80000 = 160000 km.
= 16×10^7 m.

Time = $\frac{\text{distance}}{\text{Speed}} = \frac{16 \times 10^7}{3 \times 10^8} = 5.3 \times 10^{-1}$ sec.

↑ speed of light / electromagnetic wave.

Q.2. An image of size 1024 x 768 pixels with 3 bytes /per pixel. Assume the image is uncompressed. how long does it take to transmit over a

i) 56 Kbps modem channel

ii) 10 Mbps channel

Ans:- No. of Bytes = 1024 x 768 x 3
= 2359296 bytes.
= 18874368 bits

i) Time in 56 Kbps ⇒

18874368/1000 = 18874.368 Kbits.

$$\text{time} = \frac{18874.368}{56} = 337.04 \text{ sec}$$

ii) 18874.368/10000 = 18.87 Mbits

$$\text{time} = \frac{18.87}{10} = 1.887 \text{ sec}$$

8bit = 1byte, 1024byte = 1kbyte 1024kbyte = 1mbyte

Q-3- Assume 6 devices are arranged in a Mesh Topology, how many cables are needed?

If N devices are connected in a Mesh topology then how many cables are needed?

Ans. No. of cables = No. of edges in complete graph

$$= \frac{n(n-1)}{2} = \frac{6 \times 5}{2} = 15$$

Q.4- A system has n-layer protocol. An application generate message of length 'M' bytes. At each of the layer, an 'h' byte header is added. Calculate what fraction of the network bandwidth is filled with headers?

Ans The fraction of each packet used by the protocol & headers is $\frac{nh}{(M+nh)}$

→ We have n layers of protocol, with h bytes added at each tier, for a total of nh header bytes.

Because the payload is M bytes, the total packet size is M + nh bytes

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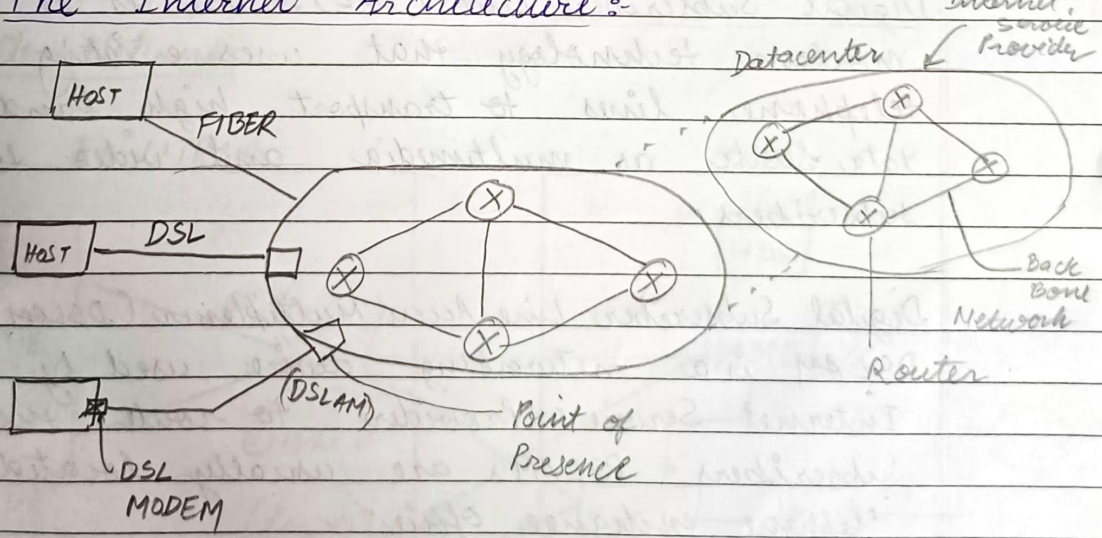
The Internet Architecture :-



A common method for connecting to the internet from home is to send signals over the cable television infrastructure.

The cable network sometimes called HFC (HFC :- Hybrid Fiber Coaxial Network)

Another option for connecting to the internet from home is known as FTTH (Fiber to Home)

Modem :- Modem represents Modulator and Demodulator.
Modem refers to any device that converts between digital bits and analog signal.
The device at the home is called a cable modem and the device at the cable head end is known as CMTS (cable Modem Termination System)

Digital Subscriber Line (DSL) :- DSL is a modem technology that uses existing telephone lines to transport high bandwidth data such as multimedia and video to the subscribers.

Digital Subscriber Line Access Multiplexer (DSLAM) :- DSLAM is a networking device used by Internet Service Providers to route their subscribers. DSLAM's are usually located at telephone exchange office.

Point of Presence (POP):- The location at which customer packets enter the ISP network is called Point of Presence.

ISP networks may be regional, national or international Transit network / Backbone Networks interconnect all the ISP networks by the help of transit network.

The packets are transmitted from one user to another user by the help of different network devices like modem, CMTS / router.

There are 4 levels in the Internet hierarchy :-

i) Customer IP networks
ii) Internet Service Provider :- Local ISP
iii) Regional Access Providers
iv) National Backbone Operators.

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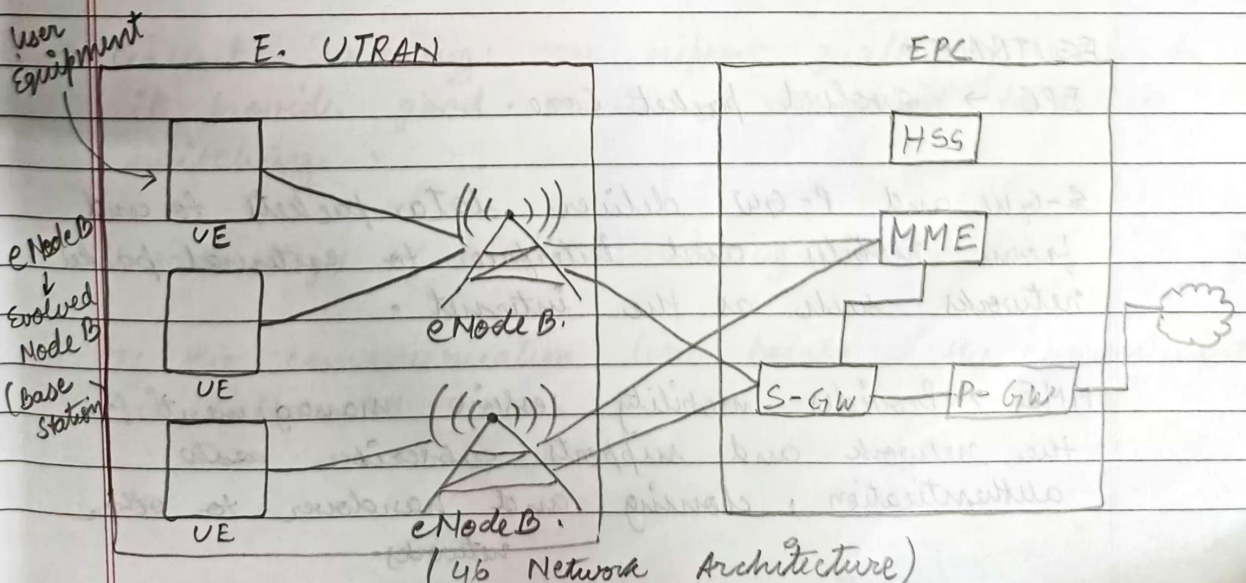
Mobile Networks :-



(4G Network Architecture)

E-UTRAN → Evolved UMTS Terrestrial Radio access Networks.

UMTS → Universal Mobile Telecommunication System.

S-GW → Serving Network Gateway.

P-GW → Packet Data Network Gateway.

MME → Mobility Management Entity.

HSS → Home Subscriber Server.

Theoritical data rate for 4G = 150 Mbps.
Theoritical data rate for 5G = 10 Gbps.

user Equipment :- Eg:- Mobile Phone / any device connected to 4G network

User equipment connected to base station and base station is also known as (enode B).
through electromagnetic wave. (microwave).

~~EUTRAN~~
EPC → Evolved packet Core.

S-GW and P-GW deliver data packets to and from mobiles and interface to external packet networks such as the internet.

MME → Provides mobility session management for the network and supports subscriber authentication, cloning and handover to other networks.

HSS → Provides the location of each subscriber as well as other profile information that is used for authentication and authorization.

In 4G network, packet switching normally used for transmitting the data or packets from one end to another end.

There are two types of switching :-

→ Circuit Switching and Packet switching (4G) :-

In Circuit Switching, first a permanent path is established between sender and reciever and all the packets are transmitted using the same path until the call is terminated.

In Packet Switching, every packet is routed independently of every other packet.

Advantages of Circuit Switching :-

→ Circuit Switching can support quality of service or it provide good service as compared to packet switching.

Disadvantages of Circuit Switching :-

→ If the communication line breaks, the communication is interrupted.

Advantages of Packet Switching :-

It overcomes the disadvantage of circuit switching.

Disadvantages of Packet Switching :-
There is a possibility that some of the packets maybe lost during transmission due to overflow of the packets at the router.

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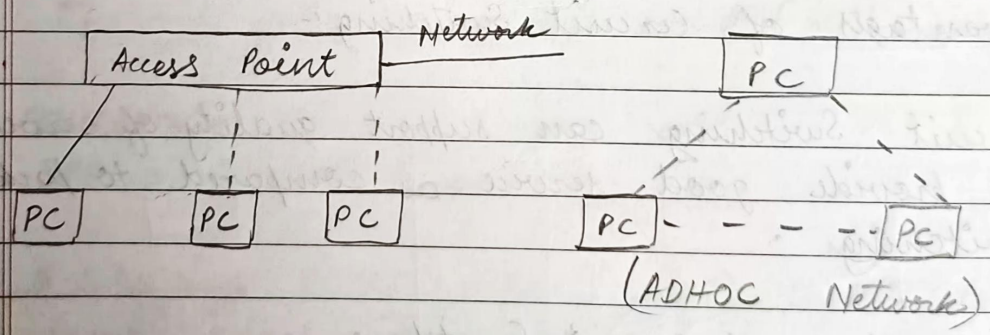
Wireless Networks (WiFi) - IEEE 802.11

→ Short Range radio transmitters and recievers are used to communicate.

Wireless Network normally works in 2 different mode :- ① In the presence of a base station
② In the absence of a base station.



NETWORK PROTOCOLS :-

i) Design Goals
ii) Protocol layering
iii) Connections and Reliability
iv) Service Primitives
v) Relationship of services and Protocols.

Protocol :- A protocol is a standard set of rules that allow electronic devices to communicate with each other.

i) Design Goals :-
- Reliability
- Resource Allocation
- Evolvability
- Security

→ Reliability :- The ability to recover from errors, faults or failures. (Error correction and Error detection mechanism is normally used to provide reliable service)

→ Resource Allocation :- Sharing access to a common/ limited resource. Many designs share network bandwidth dynamically and this design is called statistical multiplexing

→ Evolvability :- Incremental deployment of protocol improvements over time. Over time, networks grow larger and new designs that need to be connected to the existing network.

→ Security :- Defending the network from various type of attacks. Security provides confidentiality, authentication and integrity.

ii) Protocol Layering :-

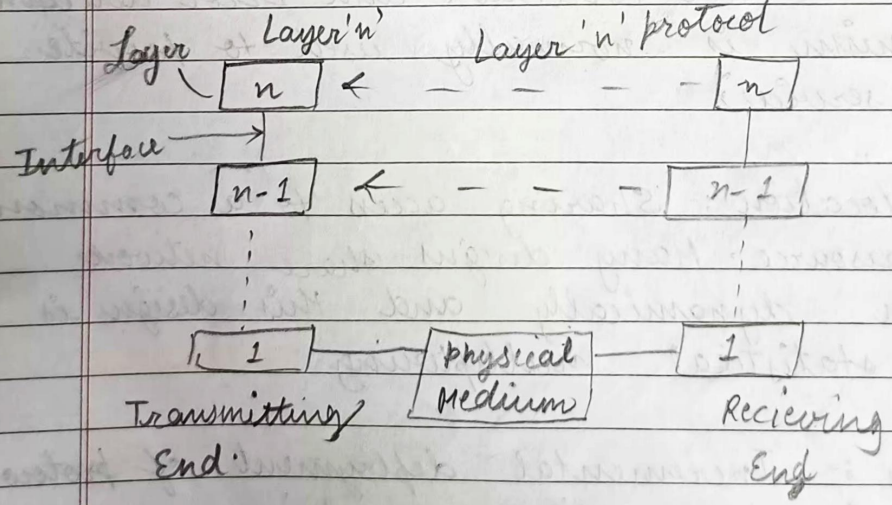
→ To reduce the design complexity, most networks are organised as a stacks of layers or ~~labels~~ levels.

→ The number of layers, the name of each layer, the content of each layer and the function of each layer differ from network to network.

→ The purpose of each layer is to offer certain services to the higher layer.

→ The protocols associated with layer N is known as layer-N protocol.

→ In reality no data are directly transferred from layer-N on one machine to layer-N on another machine.



A set of layers and protocols is called network architecture.

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ii) Connections and Reliability :-

→ Connection oriented service
→ Connectionless Service

Layers can offer to different types of service to the layer above them :- (mentioned above)
i) ~~Connection~~

* Connection oriented service is modelled after the telephone system.
In connection oriented service, the service user first establish a connection, then use the connection, then release the connection.

Advantage :- The order of the bits is preserved.

* Connectionless Service is modelled after the postal system.
In connectionless service, each message carries the full destination address and each one is routed through the system independent of all the others.

Disadvantage :- The order of the bits may not be preserved.

Connection oriented & connectionless service can be characterized by their reliability. (Reliable in the sense that they never loose data.

A reliable service is implemented by having the receiver acknowledge the reciept of each message.

The acknowledgement process introduces overhead and delays.

Connection oriented and connectionless service maybe reliable or unreliable type depending upon the application and use.

Six different type of Service

	SERVICE	Examples
Connection oriented	1 Reliable message system	Sequence of pages
	2 Reliable byte stream	Movie download
	3 Unreliable connection	Voice over IP
Connectionless	4 Unreliable Datagram	Electronic junk mail
	5 Acknowledgement datagram	Text message
	6 Request - Response	Database query

iv) Service Primitives :-

→ A service is formally specified by a set of primitives (operations) available to a user process to access the service.

→ These primitives tell the service to perform some action

→ The set of primitives available depends on the nature of the service being provided.

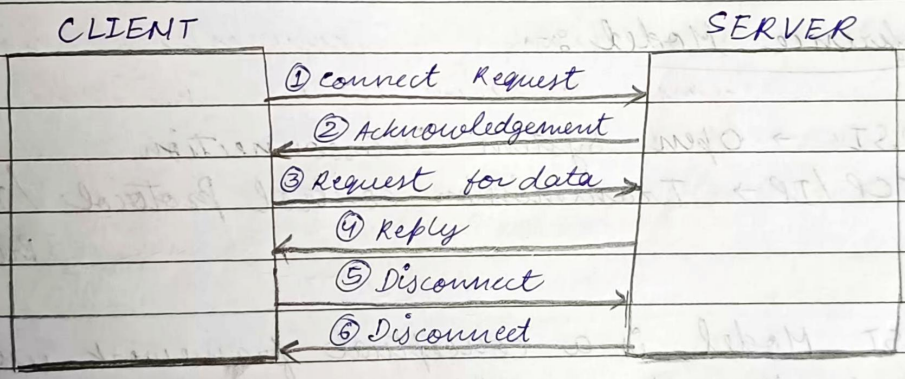
→ The primitives / connection oriented service are different from connectionless service.

Eg:- ① Five service primitives for implementing a simple connection-oriented service :-

→ Listen
→ Connect
→ Receive
→ Send
→ Disconnect

Eg:- ② Packets sent in a simple client-server interaction on a connection-oriented network.

→ Connect Request
→ Acknowledgement
→ Request for Data
→ Reply
→ Disconnect



Q. Give some real-life example of connection-oriented & connectionless services and write down what are the primitives used in this process.

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The relationship of services to protocols :-

A service is a set of primitives / operations that a layer provides to the layer above it.
A service relates to an interface between two layers with the lower layer being the service provider and the upper layer being the service user.

A protocol is a set of rules that are exchanged by the peer entities within a layer

Entities use protocols to implement their service.

Reference Model :-

i → OSI → Open System Interconnection
ii → TCP/IP → Transmission control Protocol / Internet Protocol

* OSI Model is a conceptual framework used to describe the functions of a networking system.

* TCP/IP Model is a set of communication protocols used to interconnect network devices on the Internet.

* OSI Model gives guidelines on how communication needs to be done whereas TCP/IP protocol standards on which the internet was developed.

So, TCP/IP is a more practical model

Note:-
In OSI reference model :- 7 layers
In TCP/IP reference model :- 4 layers

OSI Reference Model :-

The principles that were applied to arrive at the seven layers are :-

i) A layer should be created where a different function is needed.

ii) Each layer should perform a well-defined function.

iii) The function of each layer should be chosen based on internationally standarized protocols.

iv) The layer boundaries should be chosen to minimize the information flow across the interfaces.

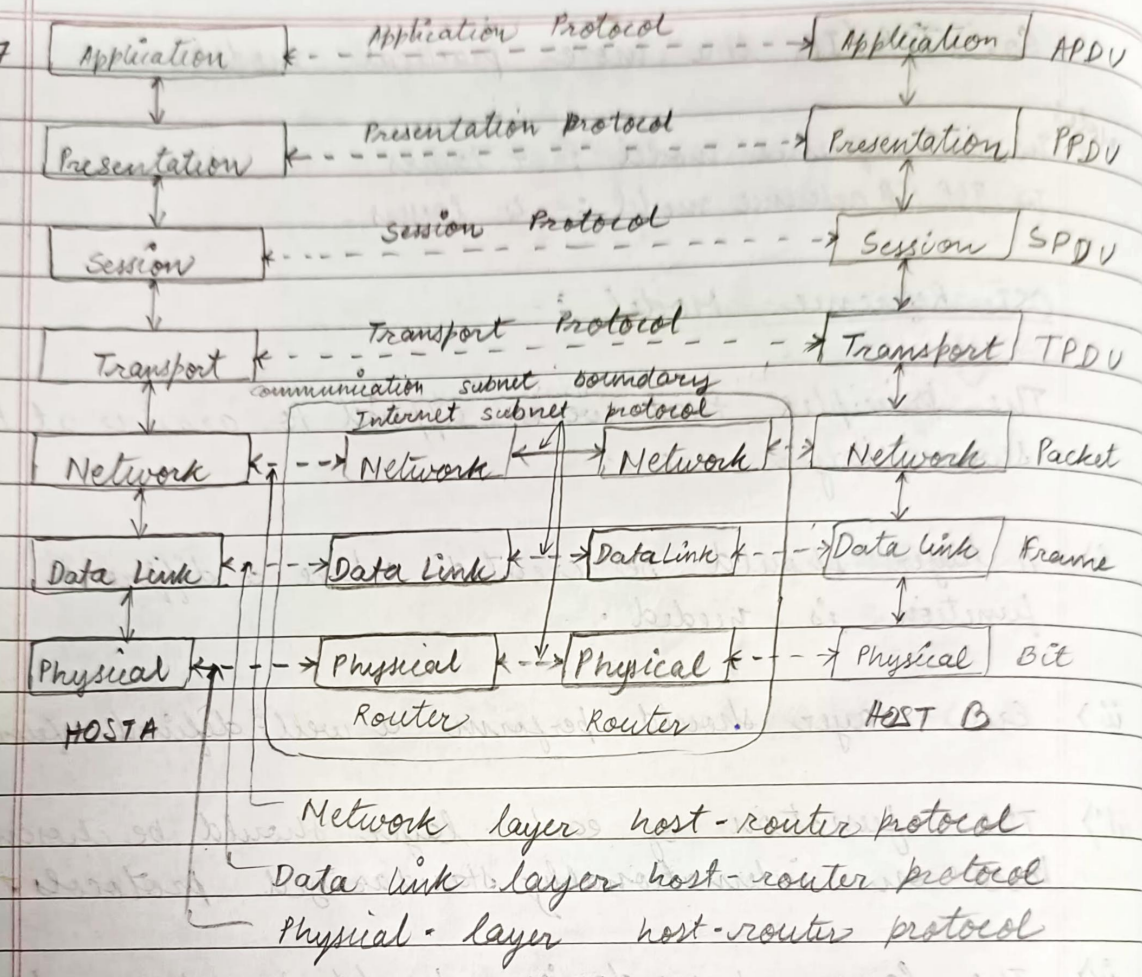


Fig 1.32 → OSI Reference model

7 Layers of OSI Reference Model

1- Physical Layer
2- Datalink Layer
3- Network Layer
4- Transport Layer
5- Session Layer
6- Presentation Layer
7- Application Layer.

Application Layer :-

It enables the user to access network resources.

Services :- ① File Transfer
② Mail Transfer
③ Directory services

Presentation Layer :-

It is concerned with the syntax and semantics of the information exchanged between the system.

Services :- ① Translating
② Encryption and Decryption
③ Compression

Session Layer :-

It establishes, maintains and synchronizes the interaction among communicating devices.

Services :- ① Synchronization
② Type of communication
→ Half Duplex
→ Full Duplex
→ Two way communication

Transport Layer :-

It is responsible for process to process delivery of entire message.

Services :- ① Port addressing
② segmentation and reassembly
③ connection control
④ End - to - end flow control
⑤ Error control

Network Layer:-

It is responsible for delivery of data from the original source to the destination network.

Services :- ① Routing
② Logical Addressing

Datalink Layer:-

It is responsible for moving data from one node to another node.

Services :- ① Framing
② Physical Addressing
③ Flow Control
④ Error Control
⑤ Access Control

Physical Layer:-

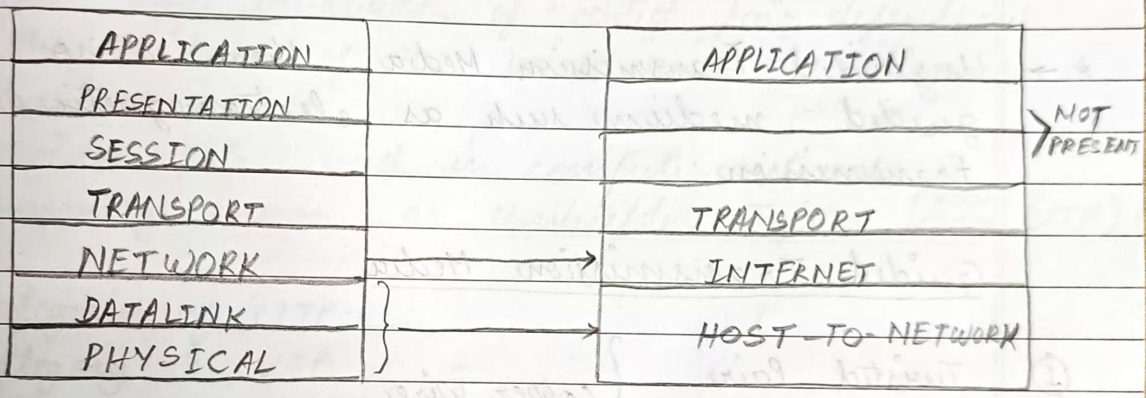
It is responsible for transmitting bits over a medium. It also provides electrical and mechanical specification.

Services :- ① Physical Characteristics of the Medium
② Representation of Bits
③ Data Rates
④ Synchronization of Bits
⑤ Line Configeration
⑥ Physical Topology

TCP/IP Reference Model :-

The main aim behind the development of TCP/IP reference model is to support / interconnect different types of network.

Another major goal is to ~~keep~~ provide uninterruptable service if some of the machines / transmission lines b/w transmitting & recieving end, were suddenly put out of operation.



The reference model used in this book:-

→ Physical Layer
→ Datalink Layer
→ Network Layer
→ Transport Layer
→ Application Layer

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Chapter 2 - THE PHYSICAL LAYER

Transmission Media → Guided Transmission Media
Transmission Media → Unguided Transmission Media

* → In Guided Transmission media, the electrical signals / light signals guided from source to destination by the help of copper wire or optical fiber.

* → Unguided Transmission Media, there is no guided medium such as electromagnetic wave transmission.

Guided Transmission Media

1. Twisted Pair
2. Coaxial Cable
3. Optical Fiber

} copper wire

Each Guided Transmission media has its own characteristics in terms of i) frequency
ii) Bandwidth
iii) Delay
iv) Cost
v) Installation
vi) Maintenance

1. **Twisted Pair** :- A twisted pair consist of two insulated copper wires around 1 mm thick. The wires are twisted together in a helical

form.

→ To avoid interference with one another, twisting is required.

→ When the wires are twisted, the wave from different twist cancel out so the wires radiate less effectively and interference is reduced.
Eg:- Telephone system.

→ Twisted pair can be used for transmitting analog / digital signals.

→ The ~~bade~~ bandwidth of twisted pair depends on the thickness of the wire and the distance travelled

→ Twisted pair used in computer network is generally known as Unshielded Twisted ~~Cable~~ pair (UTP)

Categories of UTP:-

1 → Category 3 UTP
2 → Category 5 UTP
3 → Category 6 UTP
4 → Category 7 UTP

In category 5, the number of twist per cm is more as compared to category 3.

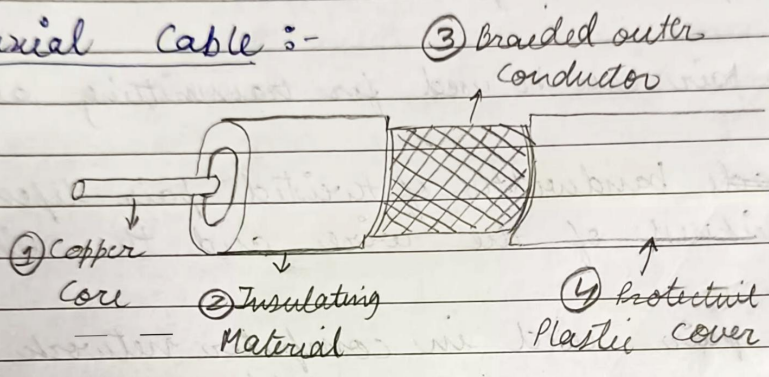
In category 3 UTP, the bandwidth is 16 MHz
In category 5 UTP, the bandwidth is 100 MHz
In category 6 UTP, the bandwidth is 250 MHz
In category 7 UTP, the bandwidth is 600 MHz

If the bandwidth is more, then the achievable data rate is also more.

Category 5 UTP → Datarate → 100 Mbps to 1 Gbps

Category 6 & 7 → Datarate → Upto 10 Gbps

② Coaxial Cable :-



It is used for digital and analog transmission

Coaxial Cable is of two types:-

i) 50 Ω cable → used for digital transmission

ii) 75 Ω cable → used for analog transmission and cable T.V.

The bandwidth of coaxial cable depends on cable quality, length and signal to noise ratio of the data signal.

For efficient communication, signal to noise ratio is high.

Bandwidth of coaxial cable is around 6 GHz

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POWER LINES:-

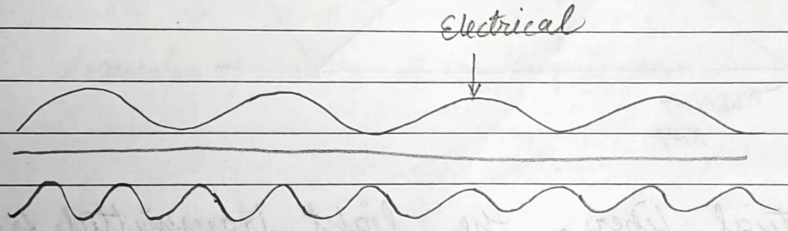
→ Power lines have been used by electrical companies for low rate communication.

→ Power lines deliver electrical power to houses.

→ Power lines maybe used for high rate communicat[n] both inside the home as local area network and outside the home for broadband internet access.

→ In case of power line communication, a low frequency signal mixed with a high frequency signal and transmitted.

→ At the receiver end, by the help of a suitable communication device, original signal can be generated.



FIBER OPTICS:-

With the current fiber technology, the bandwidth of fiber optics is around 50,000 Gbps (50 Tbps). The bandwidth is very high as compared to twisted pair & coaxial cable.

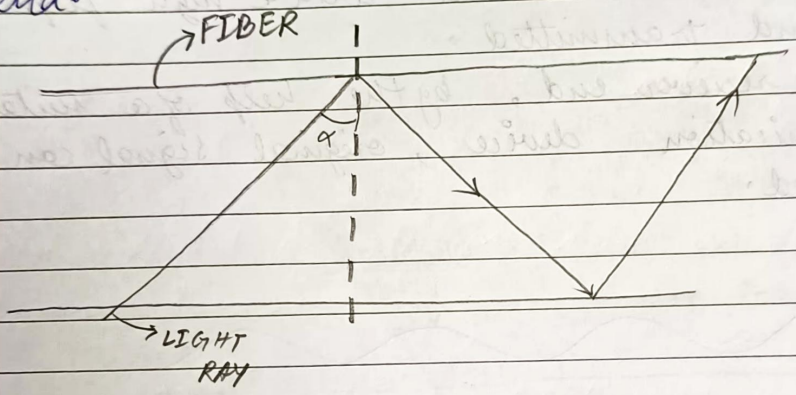
Optical Transmission System has 3 components:-

1. Light Source
2. Transmission Medium (optical fiber)
3. Detector

The presence of light source is equal to 1, the absence of light source is equal to 0.

The detector generates an electrical pulse when light falls on it.

By attaching a light source to one end of an optical fiber and a detector to the other, we have a unidirectional data transmission system that accepts an electrical signal, converts and transmit it by light pulse and then reconvert the output to an electrical signal at the receiving end.



In optical fiber, the light transmitted from one end of the fiber to the other end, by total internal reflection.

Critical angle = θ_c
Let the angle of incidence θ_c

If the angle of incidence θ_i is more than or equal to the critical angle θ_c, total internal reflection takes place otherwise refraction takes place.

$$\theta_i \geq \theta_c$$

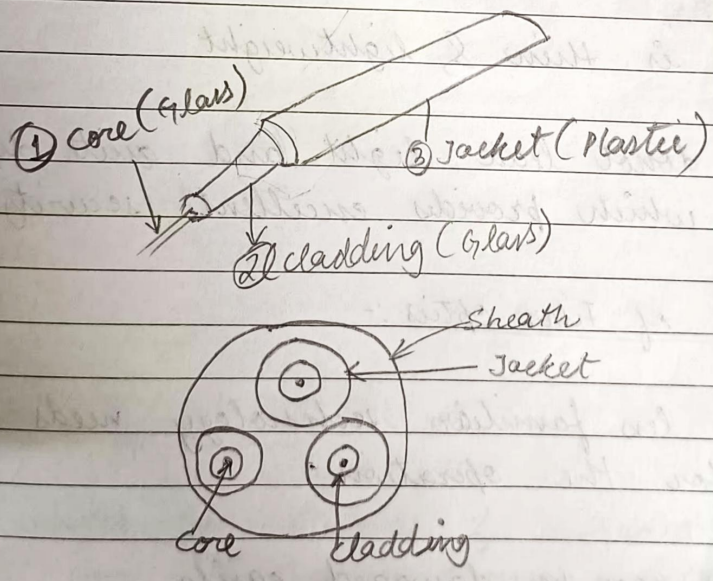
There are two types of optical fiber :-

→ Multi Mode fiber → (More than one signal is transmitted)
→ Single Mode fiber → (only one signal is transmitted in a straight line)

Parallel, not costly, diameter of core :- 50 microns.

Single mode fiber is costly as compared to multimode fiber.

Single mode fiber can transmit data 100 Gbps for 100 km without amplification
(Normally used for longer distances)
⇓
diameter of core :- 8 to 10 microns.



Two kinds of light source are typically used for signalling :-

i) Light Emitting Diode
ii) Semiconductor Laser.

The recieving end of an optical fiber consist of a photodiode which gives off an electrical pulse when light falls on it.

14/10/23

Comparison of Fiber optics with copper Wire

Advantage of Fiber optics :-

i) Bandwidth of fiber optics have larger bandwidth as compared to copper wire

ii) Low attenuation :- less number of repeaters are required which reduce the cost of installation

iii) Not affected by electromagnetic interference or power surges.

iv) Fiber optics is thin & lightweight

v) Fiber optics donot leak light and quite difficult to tap, which provides excellent security.

Disadvantage of Fiber optics :-

i) Fiber is a less familiar technology needs expertise for the operation.

ii) Fiber optics can be damaged easily

iii) Optical transmission is undirectional.

iv) Fiber interface cost more than electrical interface

4) Interface cost is more as c

Wireless Transmission Media

In wireless transmission, the signal is transmitted by the help of electromagnetic wave.

Electromagnetic wave is characterized by different parameters like frequency & wavelength.

The speed of electromagnetic wave is equivalent to the speed of light i.e. 3×10^8 m/s.

Speed of the signal in copper wire or optical fiber is around 2/3rd the speed of light i.e :- 2×10^8 m/s.

The electromagnetic wave are ~~character~~ classified according to their frequency band.

i) Radio Wave
ii) Micro Wave
iii) Infrared
iv) Visible
v) UV
vi) X-ray
vii) γ-ray

The radio, micro wave & Infrared are normally used for electronic communication.

If the signal frequency is increasing, signal power is also increasing.

UV, x-ray & γ-ray are not used for communication due to health hazards (also due to less penetrating power due to any obstacle)

Radio Transmission:-
frequency :- 10^4 to 10^8 Hz

Radio waves are easy to generate. Can travel longer distances and can easily penetrate obstacles, so they are widely used for communication both indoors and outdoors.

Major disadvantage of radio transmission is the interference of electrical equipment is more.

Microwave Transmission :-
frequency :- above 100 MHz
(10^8 to 10^{11} Hz)

unlike radio waves, microwaves donot pass through buildings well.

Microwave communication is widely used for long distance telephone communication, mobile phones and television distribution.

Infrared Wave Transmission :-
frequency :- 10^{12} to 10^{14} Hz

Widely used for short range communication like remote control.

Relation between speed of light, frequency & wavelength :-

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

→ For effective transmission & reception, the length of the antenna should be comparable with the wavelength of the signal.

16/10/23

From Waveform to Bits :-

① The Theoritical Basis of data communication :-

$g(t)$ → periodic signal with period 'T'

Fourier series representation of $g(t)$:

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

$$a_n = \frac{2}{T}\int_0^T g(t) \sin(2\pi n f t)\, dt$$

$$b_n = \frac{2}{T}\int_0^T g(t) \cos(2\pi n f t)\, dt$$

$$c_n = \frac{2}{T}\int_0^T g(t)\, dt$$

Periodic signal :- If any signal repeats its behaviour after certain interval is known as periodic signal and that interval is known as period.

Any periodic signal with period 't' can be represented by :-

$$g(t) = \frac{1}{2}C + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

[Sum of ∞ no. of sine and cosine terms]

$n \rightarrow n^{th}$ harmonic.

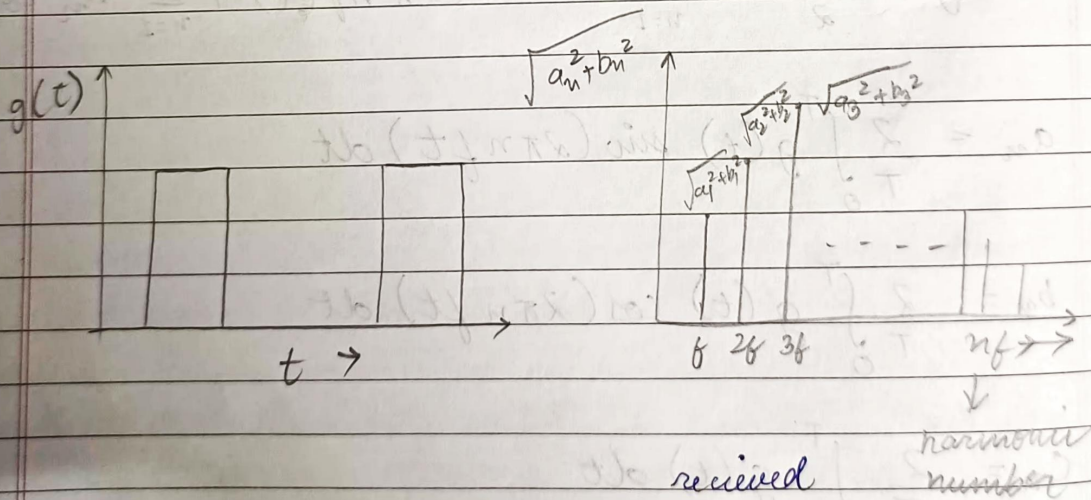
At n^{th} harmonic, the frequency is equal to nf and $f = \frac{1}{t}$

Spectral Amplitude $= \sqrt{a_n^2 + b_n^2}$ (r.m.s value)

↓

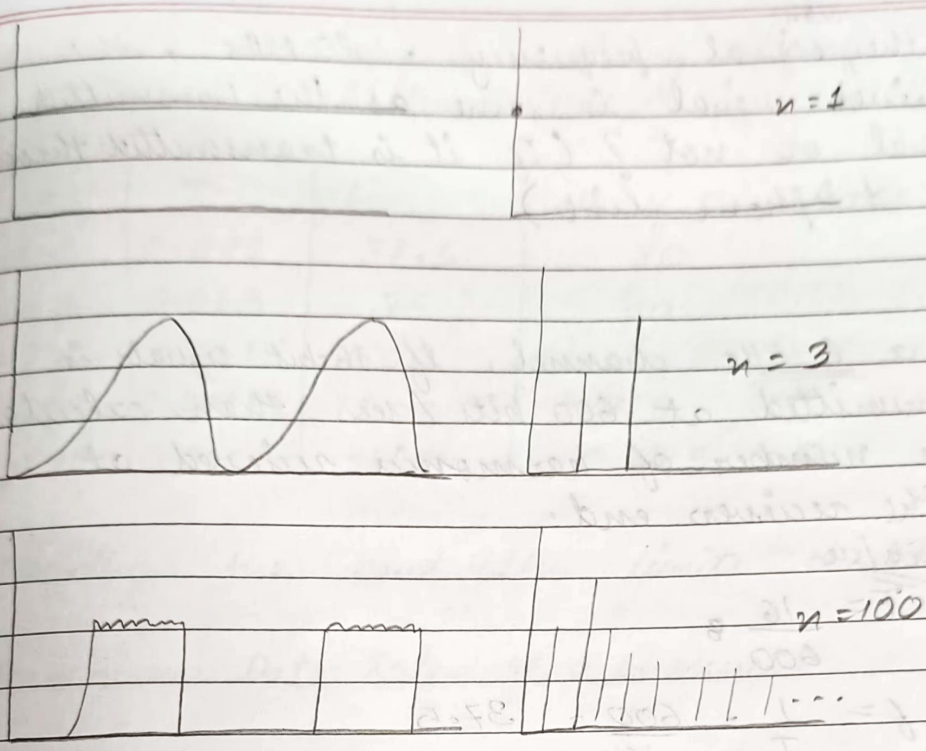
Root mean square

Any signal consists of infinite no. of harmonics



received

★ If the number of harmonics, at the receiver end is very large, then the received signal is equivalent to transmitted signal.



Due to band limited nature of any channel, the higher harmonics normally drop during transmission.

All transmission facilities reduce different fourier components / harmonics by different amount, thus introducing distortion.

The range of frequency transmitted in a channel without being strongly attenuated, is called the bandwidth.

The bandwidth is a physical property of the transmission medium and usually depends on the construction, thickness & length of the medium.

A telephone wire has a bandwidth of around 1 MHz.

Q- If the max. signal frequency = 20 MHz, the received signal is same as the transmitted signal or not ? (If it is transmitted through a telephone line)

Q- In a 6 KHz channel, if 16-bit signal is transmitted at 600 bits / sec, then calculate the number of harmonics recieved at the reciever end.

a) 600 bits/sec

$$T = \frac{16}{600} \text{ s}$$

$$f = \frac{1}{T} = \frac{600}{16} = 37.5$$

$$\text{No. of harmonics} = \frac{\text{Bandwidth}}{\text{frequency}} = \frac{6000}{37.5}$$

$$= \boxed{160}$$

b) 96000 bits / sec.

$$T = \frac{16}{96000}$$

$$f = \frac{1}{T} = \frac{96000}{16} = 6000$$

$$\text{No. of harmonics} = \frac{6000}{6000} = (1)$$

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Bandwidth = 3000 Hz in ordinary telephone line.
8 bit signal is transmitted.

BPS	T	f	No. of Harmonics
300	0.026	37.5	80
600	0.013	75	40
4800	0.001	600	5
9600	0.00083	1200	2.5
38400	0.000208	4800	0.625 ≈ 0

→ Limiting the bandwidth limits the data rate.

* Maximum Data Rate of a Channel :-

① Noiseless Channel → Noise signal = 0
② Noisy Channel → S + N
(S: original signal, N: Noise signal)

SNR
[Signal to Noise Ratio] = $\frac{\text{Signal Power}}{\text{Noise Power}}$

Unitless

For noiseless channel, the signal to noise ratio is very large / infinite, as Noise Power = 0

SNR in dB (decibels) = $10 \log_{10}\left(\frac{S}{N}\right)$

i) Noiseless channel :-

Bandwidth of channel ↓ , No. of bits ↓

* Maximum Data Rate = $2 \times B.W \times b$
[NYQUIST THEOREM] = $2 B \log_2 V$ ← No. of levels

The data rate with same parameter of a noiseless channel is always more than the data rate of a noisy channel.

Eg :- The bandwidth of a noiseless channel is 3KHz transmitting a binary signal (2-level), then calculate what is the maximum data rate of a channel.

Ans Maximum Data Rate

$BW = 3\,KHz = 3000\,Hz$
$b = 1$ or $V = 2$ [for binary signal]

Max. data rate = $2 \times BW \times b = 2 \times 3000 \times 1$
$= 6000$ bps

$= 2 \times BW \times \log_2 2 = 2 \times 3000 \times 1$
$= 6000$ bps

Q. What is the maximum data rate in a noiseless 6 KHz channel transmitting 16-bit signal ?

~~2 x 6 x 16~~

Ans Maximum data rate = $2 \times 6000 \times 16 = 192,000$ bps

Q- Calculate SNR in dB i) if the SNR is 100
ii) if the SNR is 1000
iii) if the SNR is 10000

Ans

i) SNR in dB $= 10 \log_{10}(100) = 10 \times 2 = 20$ dB

ii) SNR in dB $= 10 \log_{10}(1000) = 10 \times 3 = 30$ dB

iii) SNR in dB $= 10 \log_{10}(10000) = 10 \times 4 = 40$ dB

ii) Noisy channel :-

* Maximum Data Rate $= B \cdot W \times \log_2\left(1 + \frac{S}{N}\right)$
[SHANNON's THEOREM] (Bandwidth) ↳ Normal value

Q- Calculate the maximum data rate of a channel with signal to noise ratio 10 dB and bandwidth of the channel = 3 KHz

10 dB $\Rightarrow$ SNR = 10

Maximum Data Rate $= 3000 \times \log_2(1 + 10)$

$= 3000 \times \log_2 11$ bps

If signal to noise ratio is 30 dB $\Rightarrow$ SNR = 1000

Maximum data Rate $= 3000 \times \log_2(1 + 1000)$
$= 3000 \times \log_2 1001$ bps.
≈ 30000 bps (approx)

Q- A binary signal is sent over a 3 KHz channel whose signal to noise ratio is 20 dB. What is the maximum data rate of the channel?

Ans:- Bandwidth = 3 KHz = 3000 Hz

SNR = 20 dB = 100

Maximum Data Rate = $3000 \times \log_2 (100+1)$

$= 3000 \times \log_2 101$ bps

Base band Transmission → Signal is directly transmitted to transmit signal
Base band Transmission is normally used ~~for~~ unguided transmission medium.

28/10/23

2- Passband Transmission

In wireless networks and radio transmissions. (wireless channel) it is not practical to send very low frequency signal because the size of the antenna needs to be comparable with signal wavelength.

For wireless network & radio transmissions, passband transmission is used.

Passband transmission used different modulation techniques.

Modulation is defined as the process of conversion of data into waves by adding information to a carrier signal.

[Modulation is required to change a low frequency band signal to a high frequency band signal by the help of carrier signal.]

Basic forms of Modulation :-

i) Amplitude modulation (AM) - Amplitude Shift Keying (ASK)

ii) Frequency modulation (FM) - Frequency Shift Keying (FSK)

iii) Phase modulation (PM) - Phase Shift Keying - (PSK)

$$x_c(t) = A \cos(2\pi f_c t + \theta_c)$$

Amplitude — frequency — phase

→ Amplitude modulation :- In amplitude modulation, two different amplitudes are used to represent 0 and 1.

→ Frequency modulation :- In frequency modulation, two different frequencies are used to represent 0 and 1.

→ Phase modulation - In phase modulation, two different phase shift (0°) & (180°) is used to represent 0 and 1.

Binary Signal :- 1 0 1 1 0

Amplitude Modulation Signal :- 1 0 1 1 0

Amplitude changes, F & θ constant.

1 → ⌇⌇⌇
0 → ⌇⌇⌇

Frequency Modulation Signal

1 → ⌇⌇⌇ 100MHz
0 → ⌇⌇⌇ 50MHz

1 0 1 1 0

Frequency Changes, A & θ constant

Phase Modulation Signal

1 0 1 1 0

1 → ⌇⌇
0 → ⌇⌇

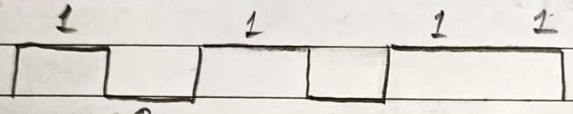
180° differe

Q- If 1 is represented by 2 cycle & 0 also 2 cycle, draw the waveform of phase modulated signal.

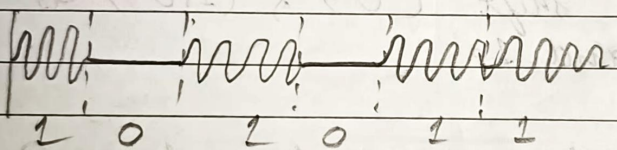
Eg:- Binary Signal → 10 10 11

Draw the waveform of : ① original signal
② AM signal
③ FM signal
④ PM signal

1-



2-



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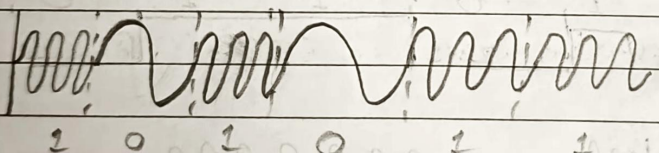

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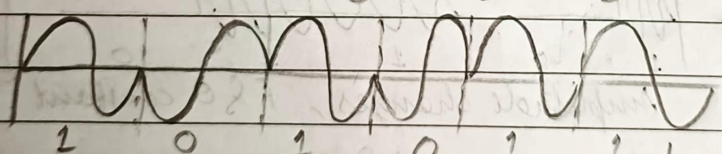
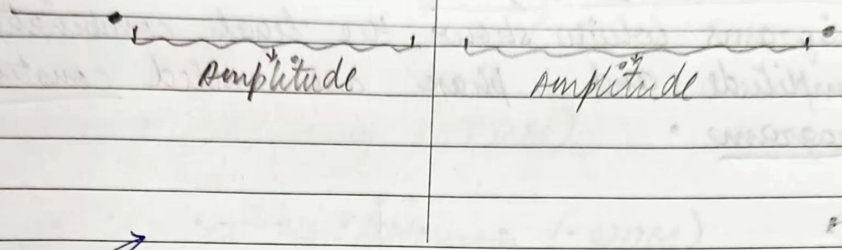


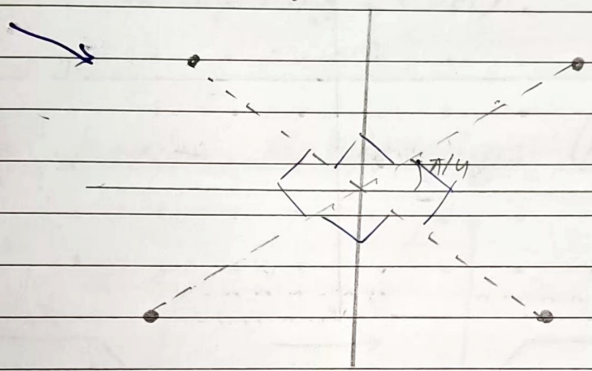
↳ Binary Phase Shift Key (BPSK)

In binary phase shifting, each symbol is represented by 1-bit.



BPSK
Binary Phase Shift Key.

Constellation Diagram



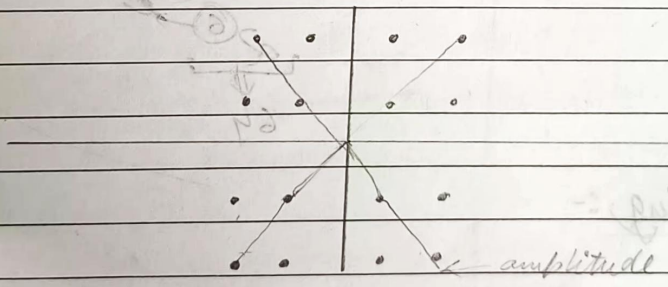
$\theta_1 = \frac{\pi}{4} = 45^\circ$

$\theta_2 = \frac{\pi}{2} + \frac{\pi}{4} = 135^\circ$

$\theta_3 = \pi + \frac{\pi}{4} = 225^\circ$

$\theta_4 = \frac{\pi}{2} + \pi + \frac{\pi}{4} = 315^\circ$

QPSK
Quadrature Phase Shift Key.



QAM-16
Quadrature Amplitude Modulation - 16
Combination of both Amplitude & Phase modulation

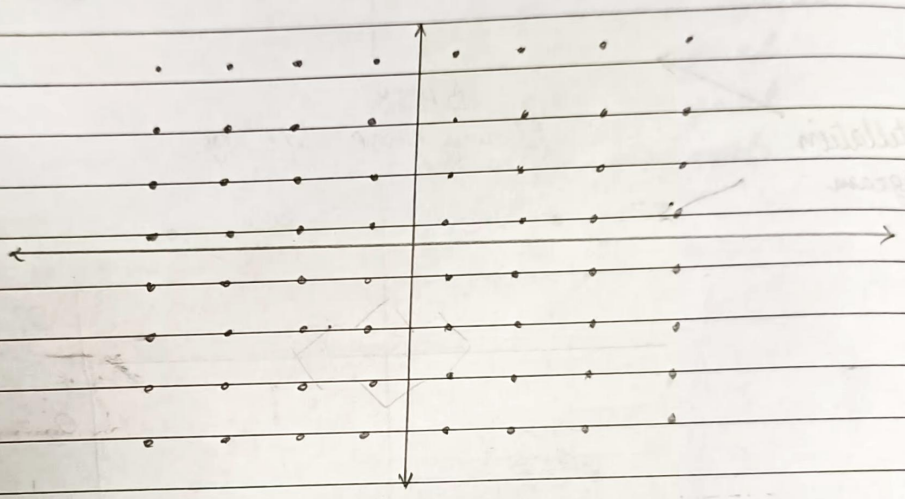
In QAM-16, 4 different amplitudes are there.

16 different combinations of amplitudes and phase.

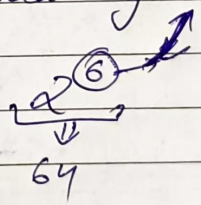
No. of Symbols = 16, Each Symbol = 4 bits

QAM-64 :- No. of symbols = 64

Constellation Diagram :-
Diagrams which show the legal combination of amplitude and phase are called constellation diagram.



64-combinations
Each symbol is represented by 6-bits



Multiplexing :-

Process by which a number of users can use a common channel.

i) Time Division Multiplexing
ii) Frequency Division Multiplexing.

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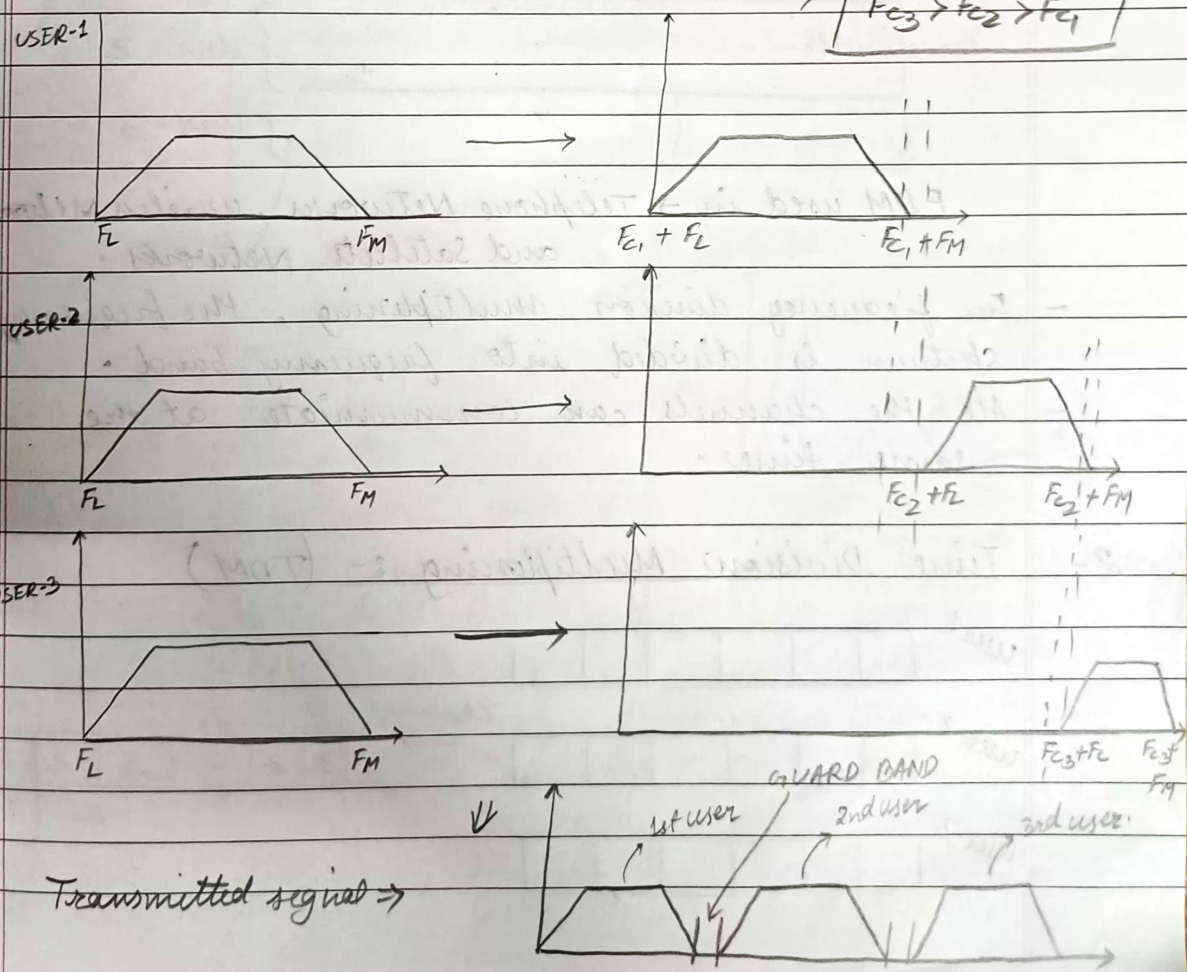
MULTIPLEXING

Process by which a number of users can use/share a common channel simultaneously.

1. Frequency Division Multiplexing (FDM)
2. Time Division Multiplexing (TDM)
3. Wavelength Division Multiplexing (WDM)
4. Code division multiplexing (CDM)

1- Frequency Division Multiplexing:- (FDM)

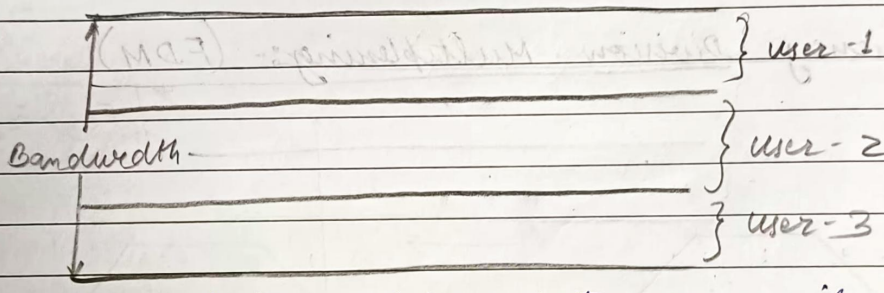
★ $F_{c_3} > F_{c_2} > F_{c_1}$



To separate one frequency band from another frequency band, guard band is used.

Bandwidth of Channel = (No. of users × Fq. band of each user) + ((No. of users - 1) × Guard Band)

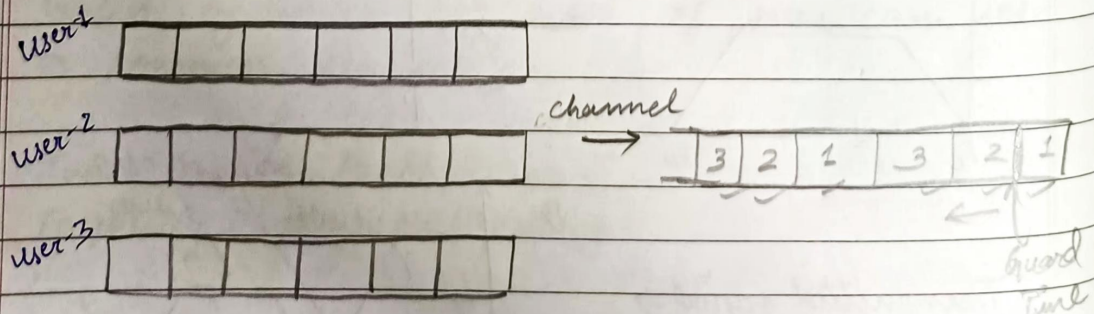
At the reciever end, by the help of a suitable filter, the individual signals of all the users can be generated.



FDM used in → Telephone Networks, Wireless Networks and Satellite Networks.

- In frequency division multiplexing, the frequency spectrum is divided into frequency band.
- All the channels can communicate at the same time.

2- Time Division Multiplexing :- (TDM)



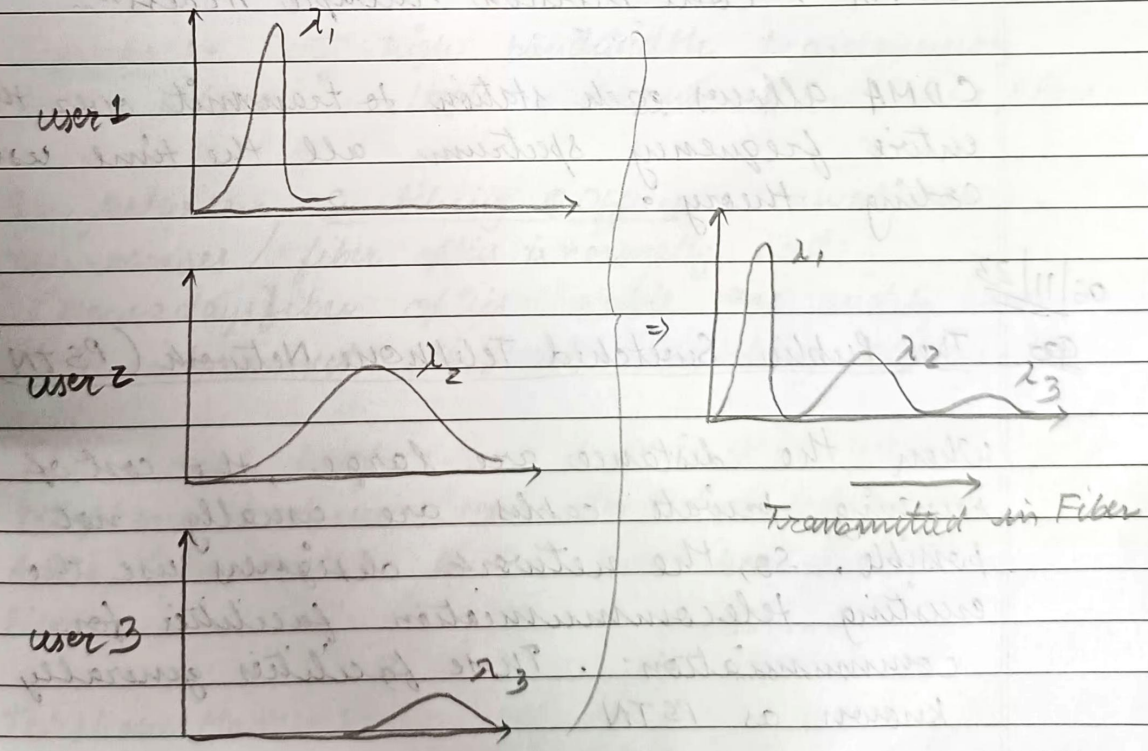
In Time Division Multiplexing, the users take turns in a round-robbin fashion. That means, each one periodically getting the entire bandwidth for a certain time interval.

Guard Time is ~~used~~ analogous to frequency guard band maybe used between two users to separate them.

TDM is used → Telephone & cellular Networks

3- Wavelength Division Multiplexing :- (WDM)

Wavelength Division Multiplexing normally used in fiber-optic communications.



i) For fiber optic channel, a variation of frequency division multiplexing is used and is called WDM or wavelength division multiplexing.

ii) Many fibers come together at an optical combiner each with its energy present at a different wavelength.

iii) At the reciever end, the individual wavelength can be separated by the help of a suitable splitter.

4- Code Division Multiplexing :- (CDM)

CDMA → Code Division Multiple Access.

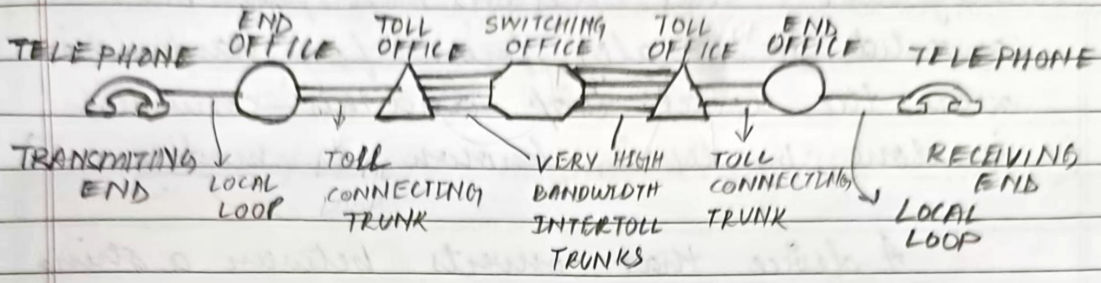
CDMA allows each station to transmit over the entire frequency spectrum all the time using coding theory.

06/11/23

The Public Switched Telephone Network (PSTN) :-

When the distance are large, the cost of running private cables are usually not possible. So, the network designers use the existing telecommunication facilities for communication. These facilities generally known as PSTN

Structure of Telephone System :-



Telephone system consist of three major component :-

1- Local Loop
2- Trunks
3- Switching office.

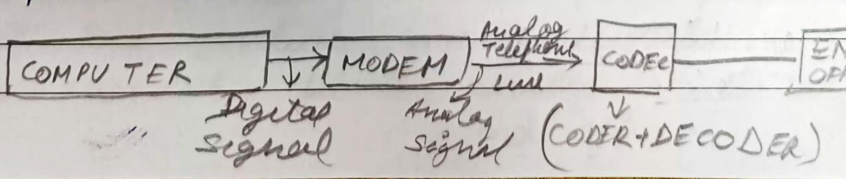
Local Loop :- consist of copper wire which connects the telephone to the nearest office (end office)

Trunks :- very high bandwidth transmission line where multiple transmission takes place.

Between Switching Offices, coaxial cables, microwaves / fiber optics is normally used.
(Nowadays fiber optics cable are widely used to interconnect different switching offices.)

* The Local Loop :-
1- Telephone Modem → (Modulator + Demodulator)
2- ADSL (Asymmetric digital Subscriber Line)
3- Fiber

Telephone Modem :-



When computer send digital data over an analog line, the data must first be converted to analog form for transmission over the local loop and this conversion is done by device known as modem.

A device that converts between a string of digital bits & analog signal that represent the bits.

Codec consist of A/D converter and D/A converter.

Locally Logically the modem is inserted between the digital computer & analog telephone system.

MODEM	STANDARD
V.32	9600 bps
V.32 bis	14,400 bps
V.34	28,800 bps
V.34 bis	33,600 bps
V.90	56 Kbps
V.92	56 Kbps.

The bandwidth of a normal telephone line is 4KHz (4000 Hz)

Digital Subscriber Line :-

Network technology that provides broadband (Highspeed) internet connections over conventional telephone lines.

Most popular → Asymmetric DSL (ADSL)

Fiber :-

Conventional telephone networks cannot transmit data at high rates. So, the coaxial cable & twisted pair can be replaced by optical fiber for high data rate (Fiber to the Home - FTTH)

↓

Uploading & Downloading wavelength are different.

08/11/23

Trunks & Multiplexing :-

→ A trunk is a high bandwidth communication / transmission line such as wire / optical fiber designed to carry multiple signals simultaneously.

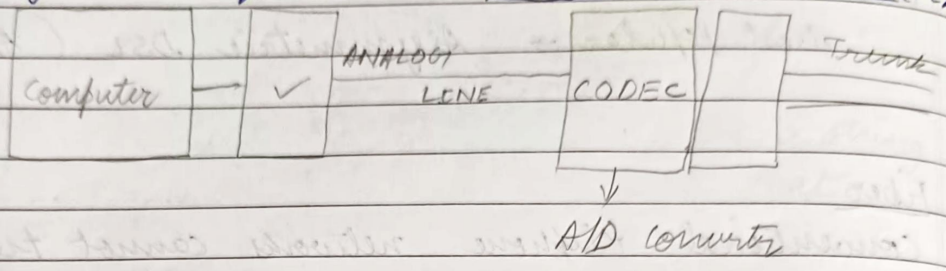
→ It is possible with multiplexing techniques like TDM, WDM, FDM & CDM

Digitizing voice signals :-

Time division multiplexing can only be used for digital data and the local loop produce analog signals

Since TDM can only be used for digital data and local loop produce analog signals, a conversion is needed from analog to digital in the end office.

The analog signals are digitized in the end office by a device known as CODEC (coder + decoder) using a technique called Pulse Code Modulation (PCM)



For a normal telephone line, the bandwidth is 4 KHz.

Samples / sec = 2x 4000 samples / sec = 8000 samples / sec.

↓

Nyquist Sampling Theorem.

For each sample = 1/8000
= 0.000125 sec
= 125 micro seconds

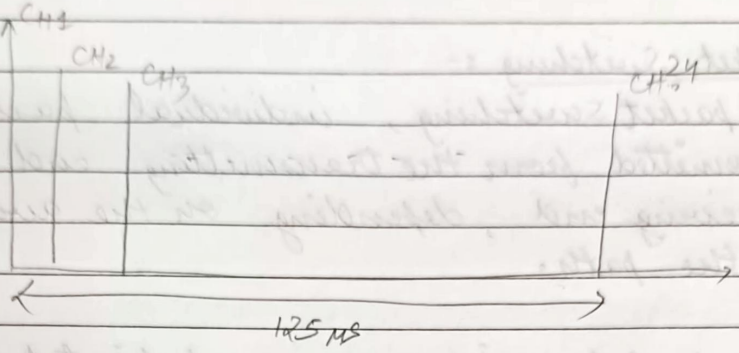
Q- If the normal telephone line, 8 bit data is used. What is the data rate?

Max data rate = 2x 4000 x 8
= 64 kbps.

T- Carrier :-
Multiplexing Digital signals on the phone network

Eg- T1 - Carrier :- T1 carrier consist of 24 voice signals / channels multiplexed together

If each sample is represented by 8-bits,
Total number of bits = $24 \times 8 = 192$ bits



If one bit is used for frame synchronisation,
Total no. of bits in a frame = 192 + 1 = 193 bits

∴ Bandwidth = $\frac{193}{125\mu s}$ = 1.5844 Mbps

T2- 4x T1 channels → 6.176 Mbps
T3- 7x T2 channels → 44.735 Mbps
T4- 6x T3 channels → 274.175 Mbps.

Switching :-
There are two types of switching :-
i) Circuit Switching
ii) Packet switching

Circuit Switching :-
① An important property of circuit switching is to setup an end-to-end path before any data can be sent.

② Once a call has been setup, a dedicated path

between both end exist and will continue to exist until the call is finished.

Packet Switching :-

(1) In packet switching, individual packets are transmitted from the transmitting end to the receiving end depending on the avalability of the path.

(2) In packet switching, no dedicated path being setup in advance.

		Circuit Switch	Packet Switch
1-	Call Setup :-	Yes	NO
2-	Dedicated Physical Path:-	Yes	NO
3-	Follows the same route	Yes	NO
4-	Packets arrive in order	Yes	NO
5-	Bandwidth	Fixed	Variable
6-	Wasted B/W	Yes	NO
7-	Store and forward	NO	Yes.

CHAPTER-3
THE DATA LINK LAYER

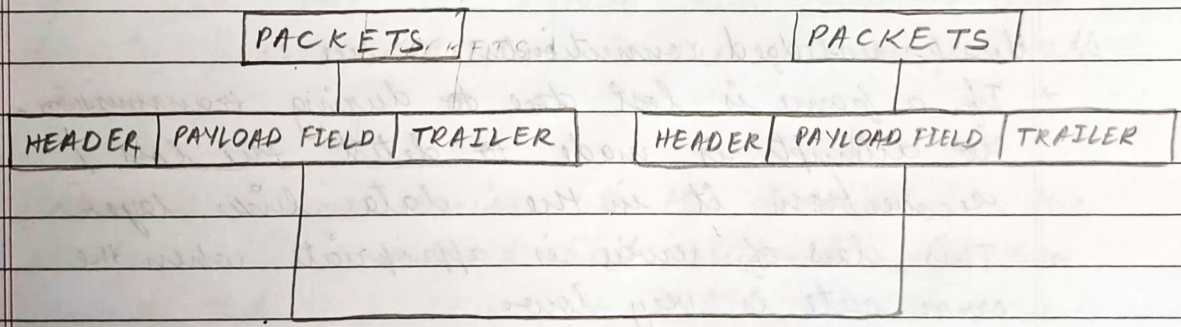
Datalink Layer design issues :- The data link layer has a number of functions (i) → providing a well defined service interface to the network layer.

ii → Framing sequence of bytes as self contained segments

iii → Detecting and correcting transmission errors.

iv → Regulating the flow of data between senders and recievers.

The data link layer takes the packets it gets from the network layer and convert them into frames for transmission.



Payload field normally contain the packet and the header and trailer normally carry the address and some extra bits for error control.

① Service provided to the network layer :-

The principal service is transferring data from the network layer on the source machine to the network layer on the destination machine.

The job of the datalink layer is to transmit the bits to the destination machine

The data link layer can be designed to offer various services :-

i) Unacknowledged connectionless Service.
ii) Acknowledged connectionless Service
iii) Acknowledged Connection-oriented Service

i) Unacknowledged connectionless service :-
→ If a frame is lost during transmission, no attempt is made to detect the loss / recover from it in the data-link layer.
→ This class of service is appropriate when the error rate is very low.
→ It is also appropriate for real-time traffic
→ Most local area networks use this type of service

ii) Acknowledged Connectionless Service :-
→ This service is useful over unreliable channels
→

iii) Acknowledged connection-oriented service

→ The source & destination machine establish a connection before any data is transferred.

→ Provide the network layer with the equivalent of a reliable bit stream.

(2) Framing :-

→ The physical layer accepts a raw bit-stream & attempt to deliver it to the destination.

→ These bit-stream is not guaranteed to be error-free. It is upto the data link layer to detect and if necessary, correct errors.

→ The usual approach is for the data link layer to break the bit stream and converted into discrete frames and compute the checksum for each frame.

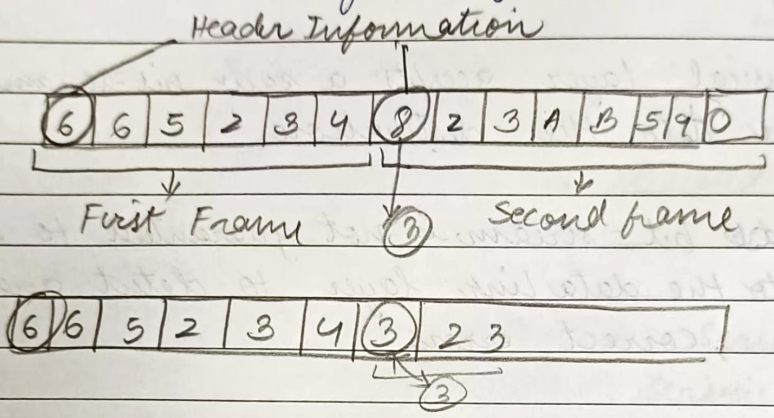
→ When a frame arrives at the destination, the checksum is recomputed and compared with the transmitted checksum to detect whether there is any error during transmission or not.

Framing Methods:-

i) Byte-count / character count
ii) Flag bytes with byte stuffing.
iii) Flag bits with bit stuffing.
iv) Physical layer coding violation

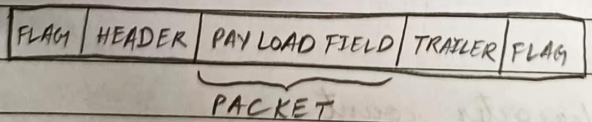
i) Byte count / character count :- This method uses a field in the header to specify the number of characters in the frame.

→ When the datalink layer at the destination sees the character count, it knows how many characters follow and where the end of the frame is.



The trouble with this algorithm is that if the header value change to a different value due to transmission error, the received frame detected at the receiver end are different from the transmitted frame.

ii) Flag Byte with Byte stuffing.



In this method, frame start & end with special bytes called a flag byte known as flag.

The header contain the source & destination address of the frame.

Payload Field :- It contains the message to be delivered.

Trailer :- contains the error detection & error correction bits.

Size of each flag = 1 byte.

The Flag is used to detect the beginning & end of each frame.

* In byte stuffing, a special byte called the escape character (ESC) is stuffed before every byte in the message with the same pattern as the flag byte.

If the escape sequence is found in the message byte, then another escape byte is stuffed before it.

Eg:- FLAG - 10 10 10 10
ESC - 11110000

PACKET / Original Message -

i) 111 011 00 10100000
ii) 10 10 10 10 11111111
iii) 10 10 10 10 11 11 11 11 10101010
iv) 10111111 11110000 01010101 10101010

Ans :-

i) | 10101010 | Header | 11101100 10100000 | Trailer | 10101010

ii) | 10101010 | Header | 11110000 | 10101010 11111111 | T | 10101010

ESC

↓

Because the part of message matches with flag.

iii) | FLAG | Header | 11110000 | 10101010 | 11111111 |
ESC
| 11110000 | 10101010 | Trailer | 10101010 |
ESC

ii) | F | H | | ESC | | | ESC | |

Q-1 | A | FLAG | B | → | A | ESC | FLAG | B |

2- | A | ESC | B | → | A | ESC | ESC | B |

3- | A | ESC | FLAG | B | → | A | ESC | ESC | ESC | FLAG | B |

4- | A | ESC | ESC | B | → | A | ESC | ESC | ESC | ESC | B |

5- | A | FLAG | FLAG | B | → | A | ESC | FLAG | ESC | FLAG | B |

Q- If the received frame is :-

| FLAG | H | | ESC | FLAG | | | ESC | ESC | | T | FLAG |

Find out the transmitted message:

Ans:- | | FLAG | | | ESC | | |

→ This byte-stuffing scheme is used in point-to-point protocol.

→ A major disadvantage of this framing method is that it uses 8-bit characters.
Eg:- UNICODE uses 16-bit characters.

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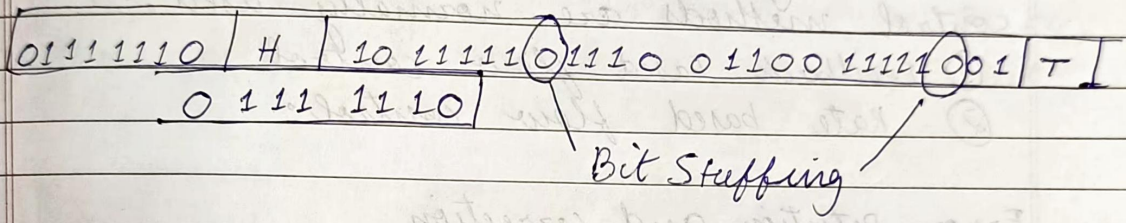
iii) Flag Bits with Bit Stuffing :-

→ Each frame begins and ends with a flag byte 01111110
→ If data encounters 5 consecutive one, it shift '0' bit into the data.

Eg.

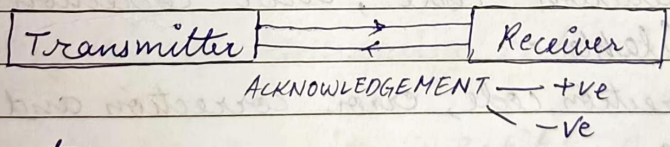
If original data is 10 11111 111011 00 111101 Then find out the transmitting frame using flag bit stuffing.



Error control and flow control :-

Error Control :-

Make sure all frames are delivered to the network layer to the destination and in proper order. The usual way to ensure reliable delivery is to provide the sender with some feedback.



Parameters :-

① Feedback → +ve acknowledgement, -ve acknowledgement
② Timer → If the frame is not received within a timeframe, the sender will retransmit the frame
③ Sequence → Assigns sequence number to outgoing frames to avoid multiple reception of frames.

Flow Control :-
Another design is what to do when sender transmit frames faster than the reciever can accept frames. This situation can easily occur when the sender is running on a fast computer & the reciver is running on a slow computer. Even if the transmission is error free, the reciver will simply be unable to handle the frames and start loosing some of the frames. Two flow control methods are normally used :-

1. Feedback based flow control
2. Rate based flow control.

Error Detection and correction
Error detection and correction algorithms are divided into two types :- (1) Error Detecting code.
(2) Error Correcting code.

Errors are of two types :-
(1) Single bit error
(2) Burst error

→ In error detection code, error correction facility is not available.
→ In error correction code, error correction and detection is available.
→ Hamming Distance :- Used to check how many bits differ between two code words. XOR operator is used to calculate the hamming Distance :-

Eg :-

T →	1	1	1	1	1	1	1	1
R →	1	0	1	0	1	1	1	1
Hamming Distance →	0	1	0	1	0	0	0	0

→ Error detection code is used when error rate is low, reliable channel. Error correction code is used when error rate is high.

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classmate
Date
Page

1. Error Correction code - (Hamming code) :-

M - No. of bits in message or data
K - length of check bits or syndrome word.

$$2^K - 1 \geq M + K$$

Step-1
Calculation of number of check bits

→ If the length of the data is 8, 16, 32, 64, then find out the length of check bit.

M	K
8	4
16	5

$2^K - 1 \geq 8 + k$

$\Rightarrow 2^4 - 1 \geq 8 + 4$ ✓

$2^K - 1 \geq M + k$

$2^5 - 1 \geq 16 + 5$ ✓

→ The length of hamming code is (M+K).

Let the message bits is 8-bit :- $D_8\ D_7\ D_6\ D_5\ D_4\ D_3\ D_2\ D_1$
& check bits :- $C_4\ C_3\ C_2\ C_1$

Step-2
Now, represent check bits inside the message bits using the rule 2^n.

Pos^n of check bits in 2^n ← i.e. 1, 2, 4, 8
pos^n

12	11	10	9	8	7	6	5	4	3	2	1
D_8	D_7	D_6	D_5	C_4	D_4	D_3	D_2	C_3	D_1	C_2	C_1
1100	1011	1010	1001	1000	0111	0110	0101	0100	0011	0010	0001

Step-3

Calculation of check bits from original message (calculation of $C_1 - C_4$ based on $D_1 - D_8$)

$C_1 = D_1 \oplus D_2 \oplus D_4 \oplus D_5 \oplus D_7$ (1st bit 1)

$C_2 = D_1 \oplus D_3 \oplus D_4 \oplus D_6 \oplus D_7$ (2nd bit 1)

$C_3 = D_2 \oplus D_3 \oplus D_4 \oplus D_8$ (3rd bit 1)

$C_4 = D_5 \oplus D_6 \oplus D_7 \oplus D_8$ (4th bit 1)

Q: In the original data bit 00111001, calculate the transmitted data using hamming code

D_8	D_7	D_6	D_5	C_4	D_4	D_3	D_2	C_3	D_1	C_2	C_1
0	0	1	1	0	1	0	0	1	1	1	1

↳ Hamming code.

Transmitted check bits

$C_1 = 1$

$C_2 = 1$

$C_3 = 1$

$C_4 = 0$

Q- Let the 3rd bit of the transmitted data change to 1. Calculate Hamming code and check bits

D_8	D_7	D_6	D_5	C_4	D_4	D_3	D_2	C_3	D_1	C_2	C_1
0	0	1	1	0	1	1	0	0	1	0	1

Received check bits

$C_1 = 1$
$C_2 = 0$
$C_3 = 0$
$C_4 = 0$

C_4	C_3	C_2	C_1	
0	1	1	1	– corrected
⊕ 0	0	0	1	– wrong.
0	1	1	0	$= (6)^{th}$ position of the sequence.

↓
Syndrome Word.

↓
i.e. D_3
↓
error.

Eg- original data is 01010111

i) Find out the transmitted frame using hamming code

D_8	D_7	D_6	D_5	C_4	D_4	D_3	D_2	C_3	D_1	C_2	C_1
0	1	0	1	0	0	1	1	0	1	1	0

Transmitted check bit = $C_1 = 0$
$C_2 = 1$
$C_3 = 0$
$C_4 = 0$

ii) If the received data is 01010101,
→ Check if there is any error
→ Find out position of error.

D_8	D_7	D_6	D_5	C_4	D_4	D_3	D_2	C_3	D_1	C_2	C_1
0	1	0	1	0	0	1	0	1	1	1	1

Received check Bit =

$C_1 = 1$

$C_2 = 1$

$C_3 = 1$

$C_4 = 0$

Syndrome word ⇒

0 0 1 0

0 1 1 1

0 1 0 1 = (5)th pos^n.

i.e. D_2

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② Error Detecting Code

i) Parity check
- Simple parity check
- Two dimensional Parity check

ii) Cyclic Redundancy Check (CRC)

- Simple Parity check :-

Eg:- Odd parity :- (odd no. of 1)

0	1 0 1 0 1 0 1 1 1 1 1 0 1

↓ parity check.

Even parity :- (Even no. of 1)

1	1 0 1 0 1 0 1 1 1 1 1 0 1

- **Two dimensional Parity check :-**

→ Represent the original data in the form of a matrix by dividing the original data into different segments.

→ Check the parity row-wise and column wise.

→ Concatenate the data in row-wise.

Eg:- 10101011 11111100 00110011 11110001

Two dimensional Parity check (Even parity is used)

Even parity

	1	0	1	0	1	0	1	1
	1	1	1	1	1	1	0	0
	0	0	1	1	0	0	1	1
	1	1	1	1	0	0	0	1
	1	0	0	1	0	1	0	1

↳ Parity check (Row-wise)

↳ Parity check (column-wise)

Concatenate ⇒ 10101011 11111100 00110011 11110001 10010101

- **Cyclic Redundancy check :- (CRC)**

Polynomial code or CRC are based on bit strings, represented in the form of polynomial with coefficient 0 and 1.

Eg → 1 0 1 1 ⇒ $1 \times x^0 + 1 \times x^1 + 0 \times x^2 + 1 \times x^3$

⇒ $x^3 + x + 1$

→ CRC is based on binary division.

→ In CRC all the arithmetic operations follows Modulo 2 arithmetic.

↳ Addition & subtraction is same

⇓

XOR operation.

Eg:-

```
  10   10   10      101010
+ 11   11   11    - 111111
  01   01   01      010101
```

(same (XOR))

Q- Take 2 no :- 10 → 1010

12 → 1100

0110 ⇒ (6)

→ CRC code consist of two important parameters.

i) Original Message

ii) Generator polynomial :- $G(x)$

⇓

[It is known at transmitting & recieving end]

→ In CRC, a sequence of redundant bit / Extra check bits are appended to the end of data so that the resulting data becomes divisible by predetermined binary number. ($G(x)$)

→ At the destination, the incoming data is

divisible by the same number. If the remainder is zero, the data unit is assumed to be correct and accepted. If the remainder is not zero, the received data is not same as transmitted data; So the receiver will request to retransmit the data.

Algorithm :-

Step 1:-
Append ~~zero bits~~ 'r' zero bits to original data.
↳ Degree of G(x)

$G(x) = x^3 + 1$

1 0 0 0 0 0 0

↳ Append 3 zeros.

1 0 0 0 0 0 0 0 0 0.

Step 2:-
Divide the bit string corresponding to G(x) using Modulo 2 arithmetic.

$x^3 + 1 \rightarrow 1001$

```
1001 | 10 10 000 000
       1001
       -----
       00110 0
         1001
         ----
         01010
          1001
          ----
          00110 0
            1001
            ----
            01010
             1001
             ----
             0011  → Remainder
```

- Step 3:-
subtract the remainder from the bit string (which is generated from step 1) using Modulo 2 arithmetic.

⇒ 1010 000 000
011
1010000011
↓
CRC

Eg:- If the transmitted (original) message is your last 2 digit of Regd. no. + 9, then find out the CRC using polynomial generator $G(x) = x^2 + 1$ (↳ 101). Also verify the output.

Message = 66 + 9 = 75
↓
1001011

Step 1:- append 2 zeroes ⇒ 100101100

Step 2:- $x^2 + 1 = 1 \times x^0 + 0 \times x^1 + 1 \times x^2$
= 101

```
101 | 100 1011 |
      101
      ---
      0011 0
       101
       ---
       0111
        101
        ---
        0101
         101
         ---
          0
```

Remainder = 0
↓
(correct)

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Elementary Data Link Protocols :-

Elementary Data Link Protocols is normally used for flow control and error control.

Data Link Protocols :-

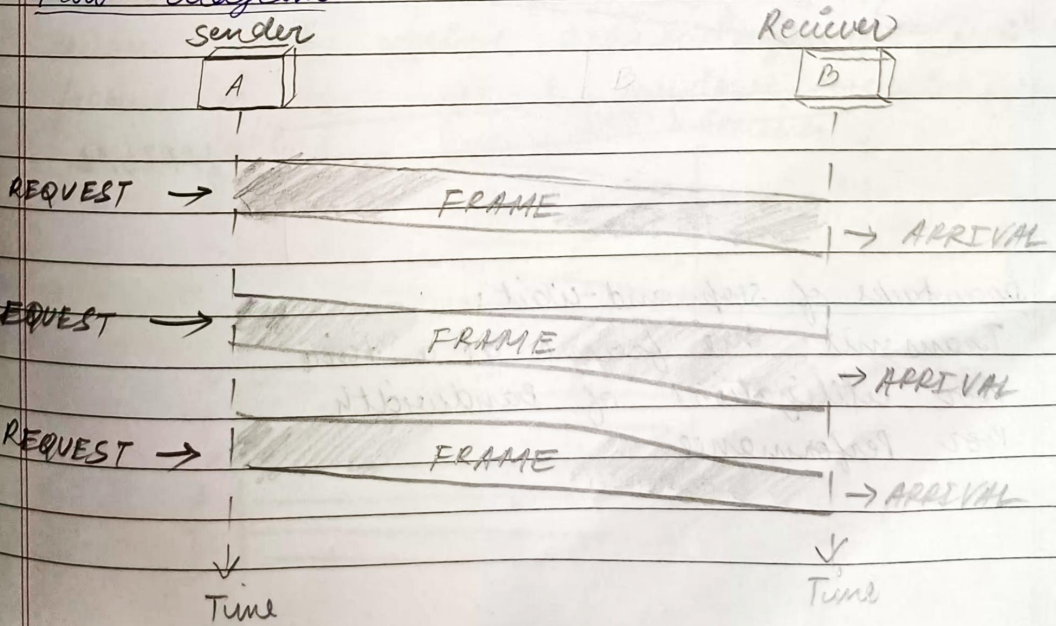
- Noiseless channels → • Simplex
  - Stop-and-wait
- Noisy channels → • Sliding window protocol

Sliding Window Protocol :- i) one bit sliding window protocol
ii) Go-back-N Protocol
iii) Selective repeat protocol

An Unrestricted Simplex Protocol :-

→ Has no flow or error control

Flow diagram :-



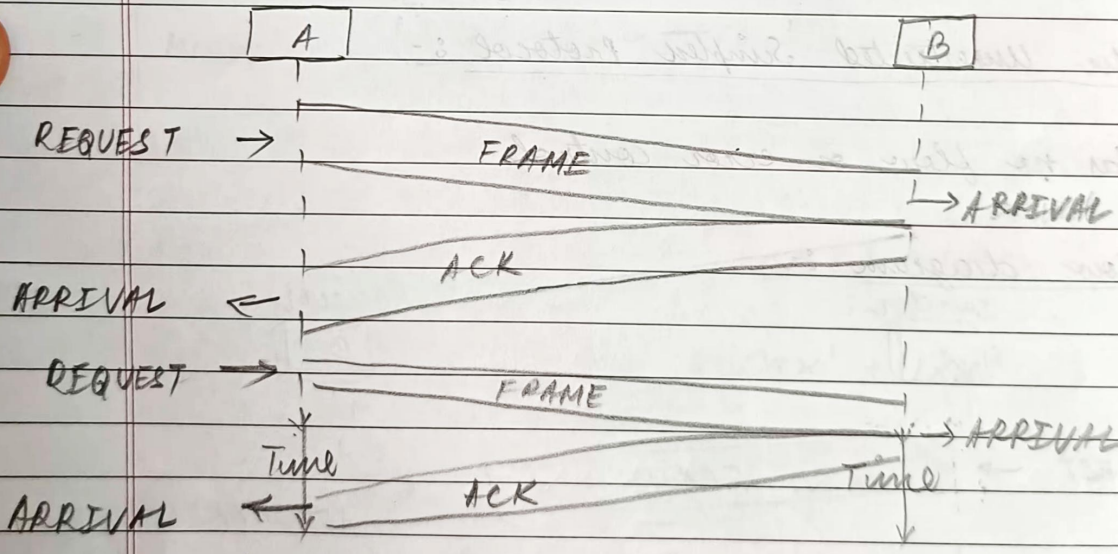
→ It is assumed that both sender & receiver are always ready for data processing and both of them have infinite Buffer.

→ Since this protocol is totally unrealistic, it is also known as Utopian Simplex Protocol

Simplex Stop-and-Wait protocol:-

→ It provides unidirectional data transmission with flow control facilities but without error control facility.

Flow Diagram



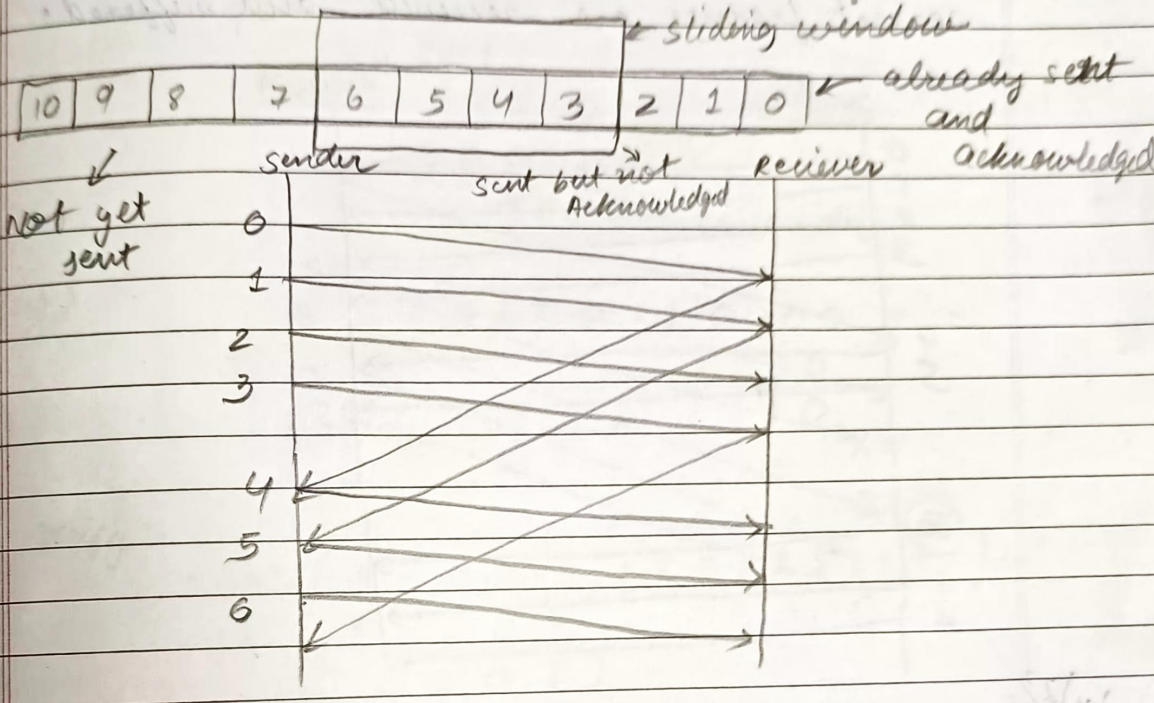
Drawbacks of Stop-and-Wait:-

- Transmit one frame at a time
- Poor utilization of Bandwidth
- Poor Performance

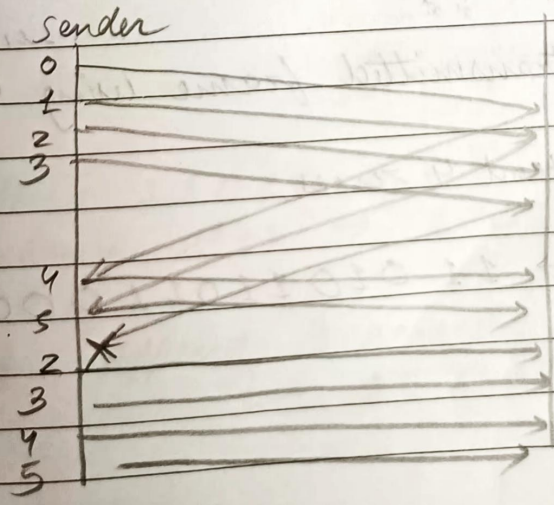
Sliding Window Protocol :-

→ Sends multiple frames at a time.

→ Number of frames to be sent is based on window size.

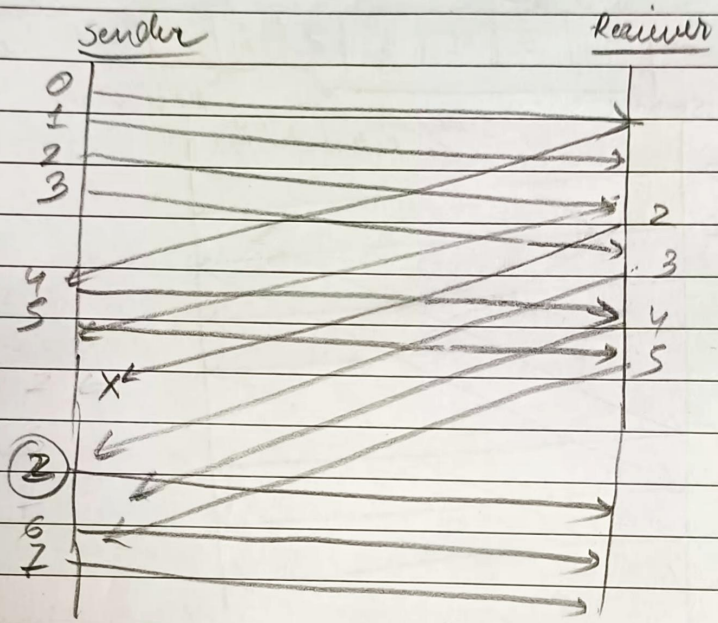


→ Go-Back-N :- If the acknowledgement of a frame not received within an agreed upon time period or receiver send negative acknowledgement (NAK), all frames in the current window are transmitted



Selective Repeat Protocol :-

In selective repeat protocol, only the erroneous or lost frames are retransmitted, while correct frames are received and buffered.



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Example :-

FRAME : 1 1 0 1 0 1 1 0 1 1

GENERATOR : 1 0 0 1 1 → $x^4 + x + 1$

(x^4 x^1 x^0)

Determine the transmitted frame using CRC.

Step-1 x^4 → append 4 zeroes

→ 1 1 0 1 0 1 1 0 1 1 0 0 0 0

Step 2

```
10011 | 1 1 0 1 0 1 1 0 1 1 0 0 0 0 )
        1 0 0 1 1
        ---------
          1 0 0 1 1
          ---------
            1 0 0 1 1
            ---------
              0 1 0 1 1 0
                1 0 0 1 1
                ---------
                  1 0 1 0 0
                    1 0 0 1 1
                    ---------
                      0 1 1 0
```

→ remainder

Step 3

```
  1 1 0 1 0 1 1 0 1 1 0 0 0 0
⊕                     1 1 1 0
-------------------------------
1 1 0 1 0 1 1 0 1 1 1 1 1 0
```

Verify :-

```
10011 | 1 1 0 1 0 1 1 0 1 1 1 1 1 0 )
        1 0 0 1 1
        ---------
          1 0 0 1 1
          ---------
            1 0 0 1 1
            ---------
              0 1 0 1 1 1
                1 0 0 1 1
                ---------
                  1 0 0 1 1
                  ---------
                    1 0 0 1 1
                    ---------
                      0 0 ✓
                        0
                      -----
                      0 ✓
```

Q. FRAME - 1101011
Generator - x^3+1 → 1001

Step 1 : Append 3 zeroes
↳ 1101011000

Q2 a) Station A needs to send a message consisting of 9 packets to station B using a sliding window (window size is 3). and go-back-N error control strategy. If every 5th packets that 'A' transmit get lost, then what is the number of packets that 'A' will transmit for sending the message to B? (No acknowledgement lost from receiver to sender.)

b) Repeat the same question for selective repeat error control strategy.

Ans-1 → Step 2

```
1001 | 1101011000 )
       1001
       ----
        1000
        1001
        ----
         1110
         1001
         ----
          1110
          1001
          ----
           1110
           1001
           ----
            0111  → Remainder.
```

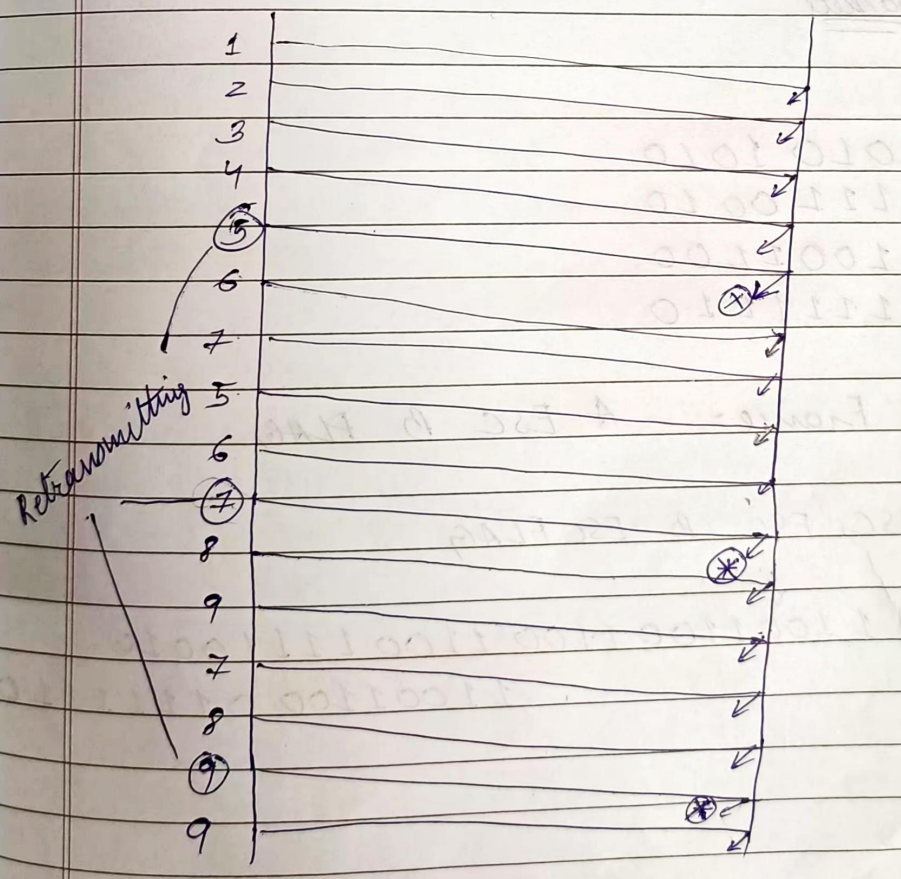
Step-3

```
  1101011000
+       0111
  ----------
  1101011111
```

```
1001 | 11010111 11 |
       1001
       1000
       1001
          111
          1001
          1101
          1001
           100 1
           1001
              0 ✓
```

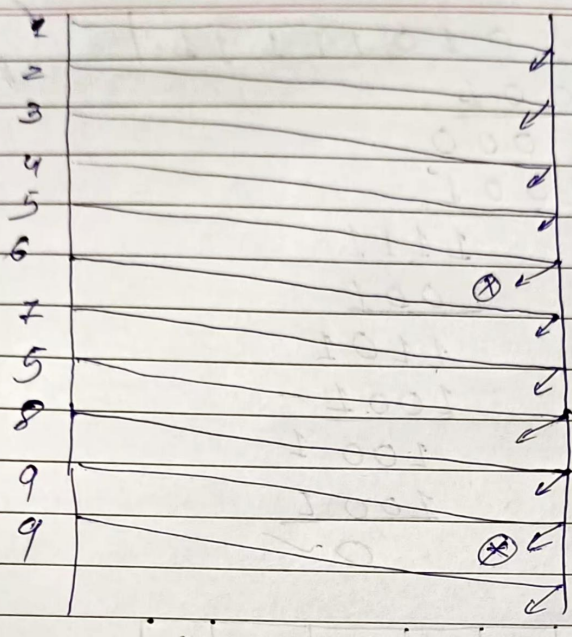
Ans 2

9	8	7	6	5	4	3	2	1



No. of packets transmitted = 16.

ii)



11 packets

Q A → 1010 1010
B → 1111 0010
ESC → 1100 1100
FLAG → 0111 1110

Original Frame = A ESC B FLAG.

Ans :- A ESC ESC B ESC FLAG

10101010 11001100 11001100 11001111 10010

11001100 01111110

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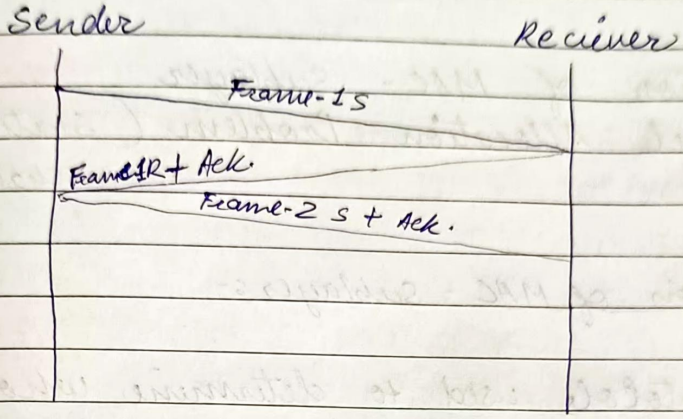
Improving Efficiency - Piggy Backing :-



CHAPTER 4- MEDIUM ACCESS CONTROL SUBLAYER (MAC - SUBLAYER)

i) Definition of MAC - Sublayer
ii) Channel Allocation Problem (Static & Dynamic Channel Allocation)

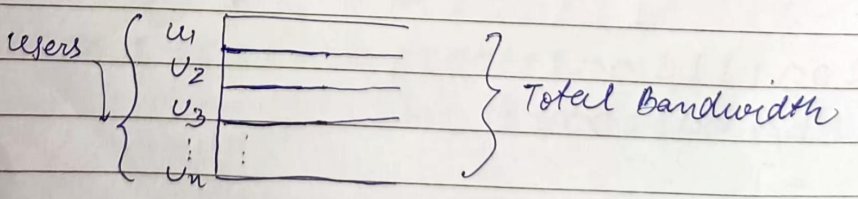
Definition of MAC - Sublayer :-

- The protocols used to determine who goes next on a multi-access channel belong to a sub-layer of the datalink layer called the MAC - sublayer.

- The MAC Sublayer is especially important in Local Area Network.
- The MAC sublayer is the bottom part of the datalink layer.

Channel Allocation Problem :-

i → Static Channel Allocation →
The traditional way of allocating a single channel is frequency division multiplexing.



If there are n - users, the bandwidth is divided into n equal parts and each user being assigned one part.

→ Since each user has a private frequency band, there is no interference between users.

Disadvantages :-

→ When the no. of users is large & continously varying, the static allocation is not suitable.

→ Wastage of bandwidth.

ii → Dynamic Channel Allocation :-

In Dynamic channel Allocation, frequency bands are not permanently assigned to the users. Channels are allotted to users dynamically as needed

Advantage :-

→ This allocation scheme optimizes bandwidth use and results in faster transmission.

Multiple Access Protocols :-

ALOHA :-

i) Pure ALOHA

ii) Slotted ALOHA

ALOHA :- It is developed in 1970 to solve the channel allocation problem.

The two types differ with respect to whether time is divided into discrete slots into which all frames must fit.

Problems on Ch - 3 :-

Q.1 Suppose an 8-bit data word stored in memory is :- 11000010 . Using the hamming algorithm, determine what check bits should be stored in memory with the data word.

12	11	10	9	8	7	6	5	4	3	2	1
D_8	D_7	D_6	D_5	C_4	D_4	D_3	D_2	C_3	D_1	C_2	C_1
1	1	0	0	0	0	0	1	0	0	1	0

$C_1 = 0$
$C_2 = 1$
$C_3 = 0$
$C_4 = 0$

Q.2 For the 8-bit word 00111001, the check bits should be 0111. Suppose when the word is transmitted & check bits are calculated at the receiving end is 1101. then what is the data word originally transmitted.

Ans. Correct Check Bit → 0111
1101
1010 → (10)
↓
Syndrome word

↓
10th pos^n error.
↓
00011001 (corrected) ✓

Q.3 How many check bits are needed if the hamming error correction code is used to detect single-bit error in a 1024 bit data word.

$$2^k - 1 \geq M + K$$

$$2^{11} - 1 \geq 1024 + 11$$

$k = 11$ ✓

Q.4 What is the maximum overhead in byte stuffing algorithm?

Maximum overhead in a byte-stuffing algorithm is $2n$, where n is the number of bytes in the payload.