Unit 3: Physical Layer and its Design Issues
[7 Hrs.]

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3.1 Introduction, Design Issues and Duties of Physical Layer

Physical layer co-ordinates the functions required to transmit a bit stream over a physical medium. It deals with the mechanical and electrical specifications of the interface and transmission medium.

The lowest layer of the OSI reference model is the physical layer. It is responsible for the actual physical connection between the devices. The physical layer contains information in the form of bits. It is responsible for transmitting individual bits from one node to the next.

Functions of physical layer :

Data Rate - This layer defines the rate of transmission which is the number of bits per second.
Interface - The physical layer defines the transmission interface between devices and transmission medium.
Representation of Bits - Data in this layer consist of stream of bits. The bits must be encoded into signals for transmission.It defines the type of encoding i.e.how 0's and 1's are changed to signals.
Line configuration - This layer connects devices with the medium either it can be point to point configuration or Multipoint configuration.
Transmission Modes - Physical layer defines the direction of transmission between two devices such as Simplex, Half duplex, Full duplex.
Topologies - Devices must be connected through any topologies either it can be Mesh, Star, Bus And Ring.

Design Issues in Physical Layer :

The physical layer is basically concerned with transmitting raw bits over a communication channel.

Mainly the design issues here deal with electrical, mechanical, timing interfaces, and the physical transmission medium, which lies below the physical layer.

Design issue has to do with making sure that when 1 bit send from one side, it is received 1 bit by other side also not as a 0 bit.

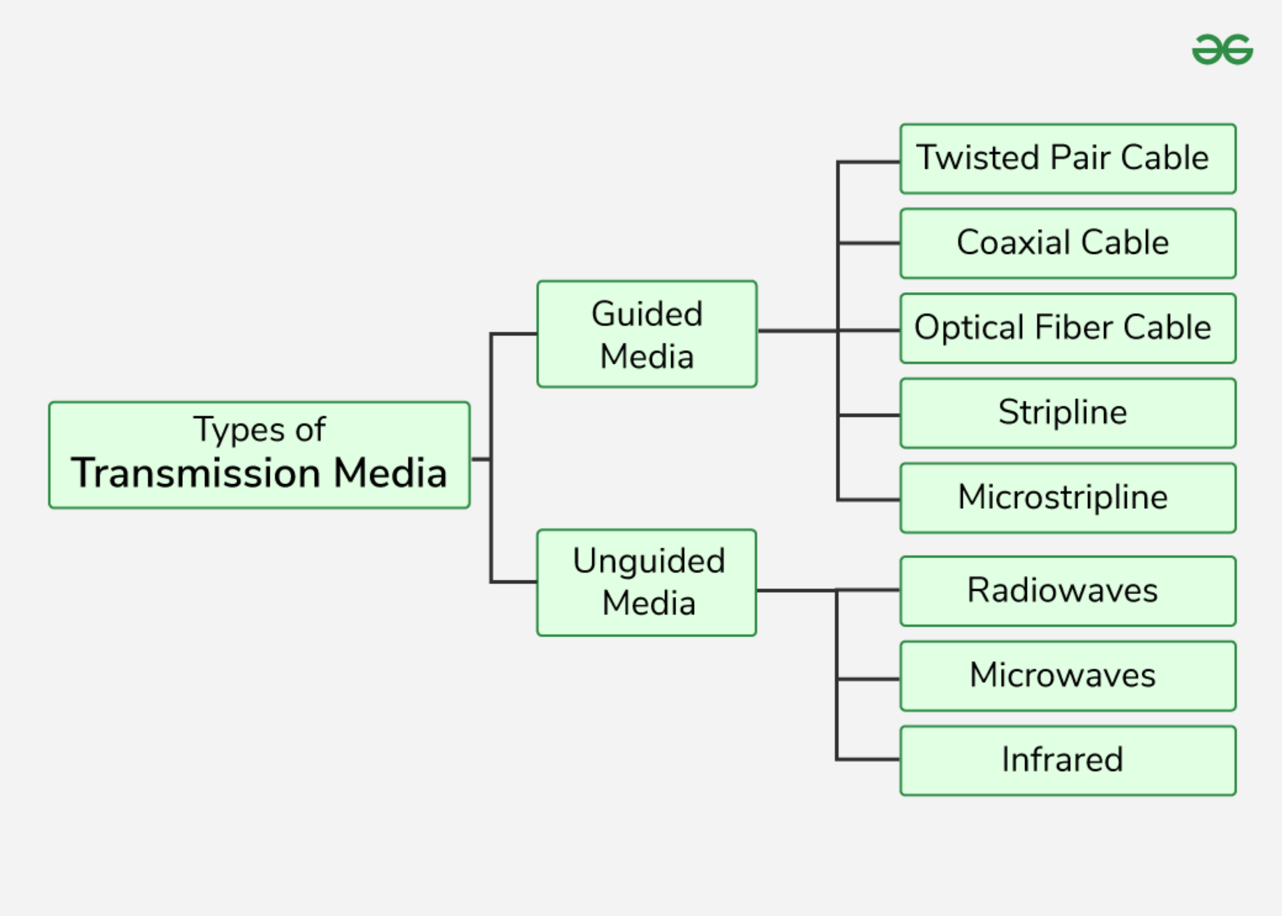
3.2 Transmission Media: Guided (Twisted Pair, Coaxial Cable, Optical Fiber), Unguided (Radio Wave, Microwave Infrared and Satellite)

Transmission media is the physical medium through which data is transmitted from one device to another within a network. These media can be wired or wireless. The choice of medium depends on factors like distance, speed, and interference.

A transmission media is a physical path between the transmitter and the receiver i.e. it is the path along which data is sent from one device to another. Transmission Media is broadly classified into the following types:

1. Guided Media

Guided Media is also referred to as Wired or Bounded transmission media. Signals being transmitted are directed and confined in a narrow pathway by using physical links.



There are 3 major types of Guided Media:

1.Fiber Optical Cable

Fiber Optical Cable uses the concept of total internal reflection of light through a core made up of glass. The core is surrounded by a less dense glass or plastic covering called the coating. It is used for the transmission of large volumes of data. The cable can be unidirectional or bidirectional. The WDM (Wavelength Division Multiplexer) supports two modes, namely unidirectional and bidirectional mode.

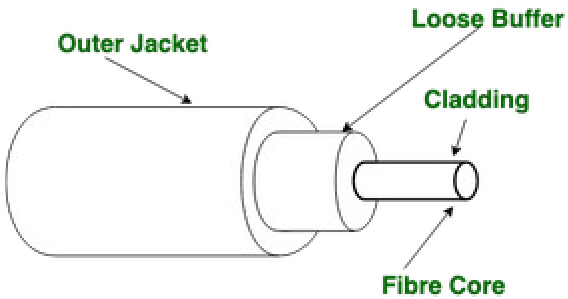
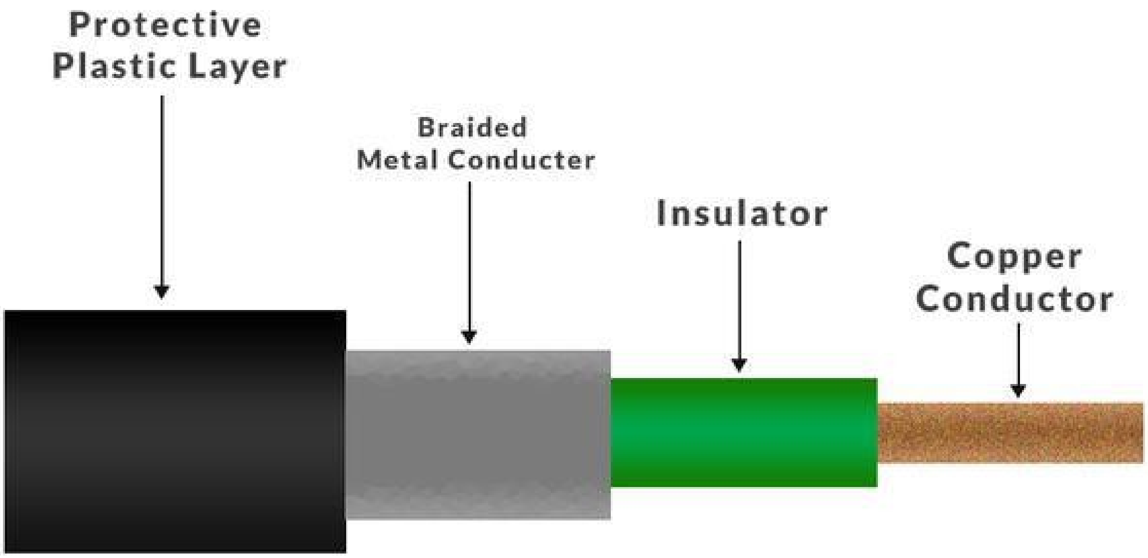


Figure of Optical Fibre Cable

2. Coaxial Cable

Coaxial cable has an outer plastic covering containing an insulation layer made of PVC or Teflon and 2 parallel conductors each having a separate insulated protection cover. The coaxial cable transmits information in two modes: Baseband mode(dedicated cable bandwidth) and Broadband mode(cable bandwidth is split into separate ranges). Cable TVs and analog television networks widely use Coaxial cables.



3.Twisted Pair Cable

It consists of 2 separately insulated conductor wires twisted about each other. Generally, several such pairs are bundled together in a protective sheath. They are the most widely used Transmission Media. Twisted Pair is of two types:

Unshielded Twisted Pair (UTP): UTP consists of two insulated copper wires twisted around one another. This type of cable has the ability to block interference and does not depend on a physical shield for this purpose. It is used for telephonic applications.

Shielded Twisted Pair (STP): Shielded Twisted Pair (STP) cable consists of a special jacket (a copper braid covering or a foil shield) to block external interference. It is used in fast data rate Ethernet and in voice and data channels of telephone lines.

2.Unguided Media

It is also referred to as Wireless or Unbounded transmission media. No physical medium is required for the transmission of electromagnetic signals.

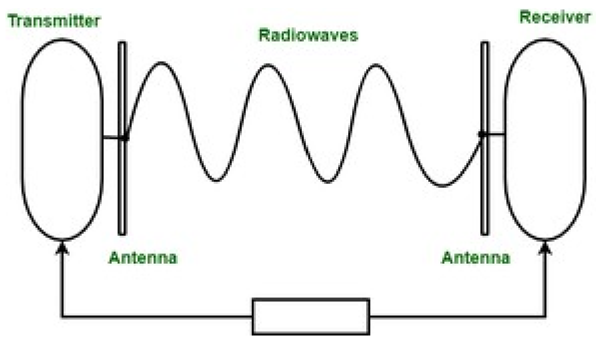
There are 3 types of Signals transmitted through unguided media:

1.Radio Waves

Radio waves are easy to generate and can penetrate through buildings. The sending and receiving antennas need not be aligned. Frequency Range:3KHz - 1GHz. AM and FM radios and cordless phones use Radio waves for transmission.

Types of Radio Waves:
- Short Wave: AM Radio
- VHF (Very High Frequency): FM Radio/TV
- UHF (Ultra High Frequency): TV

Radio Wave Components:
- Transmitter: Responsible for encoding the signal.
- Receiver: Responsible for decoding the signal.



2.Microwaves

It is a line of sight transmission i.e. the sending and receiving antennas need to be properly aligned with each other. The distance covered by the signal is directly proportional to the height of the antenna. Frequency Range:1GHz - 300GHz. Micro waves are majorly used for mobile phone communication and television distribution.

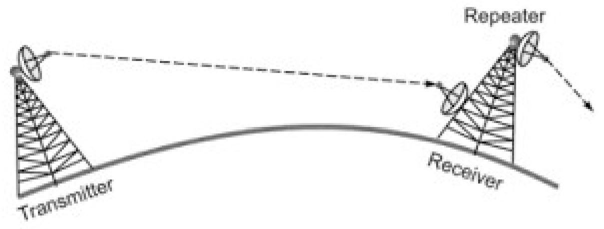
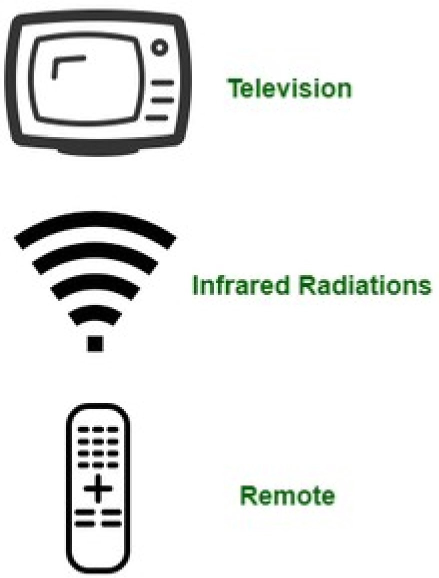


Fig: Microwave Transmission

3.Infrared

Infrared waves are used for very short distance communication. They cannot penetrate through obstacles. This prevents interference between systems. Frequency Range:300GHz - 400THz. It is used in TV remotes, wireless mouse, keyboard, printer, etc.



3.3 Ethernet Cable Standards

Ethernet cable standards define the physical and electrical characteristics of cables used in local area networks (LANs). These standards, primarily from IEEE and ISO, categorize cables by performance (e.g., Cat5e, Cat6, Cat6a, Cat8) and ensure compatibility between network devices.

Common Ethernet Standards and their characteristics:

Cat5e (Category 5e): Supports data transfer rates up to 1000 Mbps (1 Gbps) and bandwidth of 100 MHz.

Cat6 (Category 6): Offers higher performance than Cat5e, with data transfer rates up to 10 Gbps over shorter distances, and a bandwidth of 250 MHz.

Cat8 (Category 8): Designed for data centers, supporting data transfer rates up to 40 Gbps and bandwidth of 2000 MHz, typically with RJ45 connectors.

3.4 Ethernet, Fast-Ethernet and Giga- Ethernet

Ethernet
Speed: 10 Mbps
Standard: IEEE 802.3
Cable: Twisted pair (Cat3), coaxial (older)
Maximum cable length: 100 meters
Connector: RJ-45
Topology: Star or bus
Use: Basic LANs and home networks

Fast Ethernet
Speed: 100 Mbps
Standard: IEEE 802.3u
Cable: Twisted pair (Cat5), fiber
Maximum cable length: 100 meters
Connector: RJ-45
Topology: Star
Use: Office LANs with more speed than regular Ethernet
Backward compatible with Ethernet

Gigabit Ethernet
Speed: 1000 Mbps (1 Gbps)
Standard: IEEE 802.3ab (copper), 802.3z (fiber)
Cable: Twisted pair (Cat5e, Cat6), or fiber
Maximum cable length: 100 meters
Connector: RJ-45
Topology: Star
Use: High-speed LANs, data centers, fast data transfer
Backward compatible with Fast Ethernet and Ethernet

3.5 IEEE 802.11 (Wi-Fi) and IEEE 802.15.1(Bluetooth) Standards

IEEE 802.11 (Wi-Fi)

This is a wireless communication standard used to create wireless local area networks (WLANs).
It allows devices like laptops, smartphones, and routers to connect to the internet wirelessly.
Operates mainly on 2.4 GHz and 5 GHz frequency bands.
It supports different versions like 802.11a, b, g, n, ac, ax — each with different speed and range.

Wi-Fi is used for medium to high-speed wireless internet access in homes, offices, and public places.

IEEE 802.15.1 (Bluetooth)

This is a wireless standard designed for short-range communication between devices.
It connects devices like smartphones, headphones, keyboards, mice, and smartwatches.
Operates in the 2.4 GHz frequency band (same as Wi-Fi but with different technology).
Bluetooth is focused on low power and short-distance data exchange, usually within 10 meters.
It is ideal for personal area networks (PANs), not for internet access like Wi-Fi.

3.6 Signals

Signals are used to carry data from one device to another over a transmission medium like cables or air (wireless).
There are mainly two types of signals:

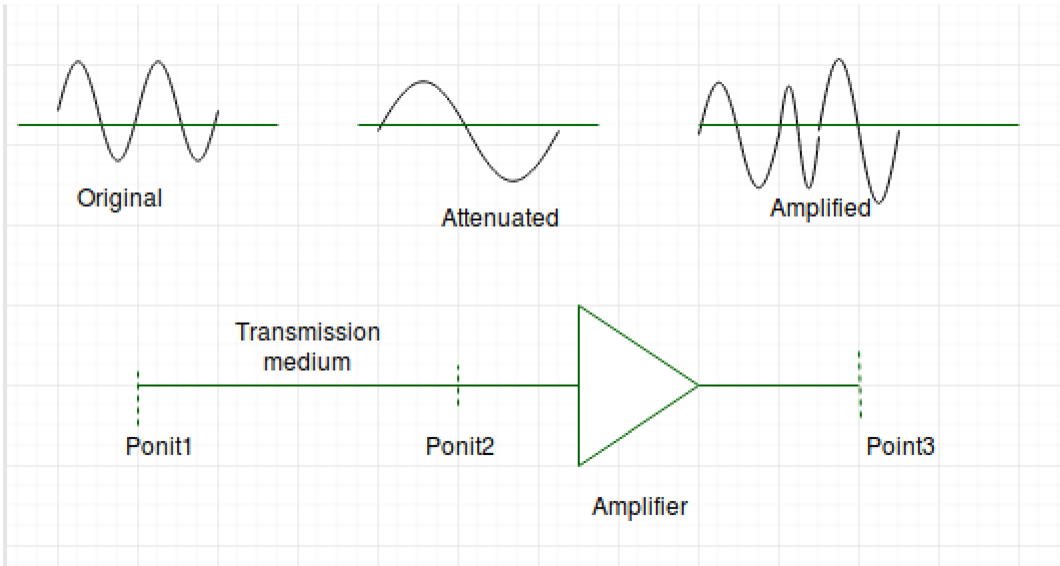
+Analog Signal
An analog signal is continuous and varies smoothly over time.
It can take any value in a range.
Examples: human voice, radio waves.

+Digital Signal
A digital signal is discrete and has only two levels: 0 and 1 (binary).
It is used in computers and digital communication systems.
Examples: data sent through a computer network.

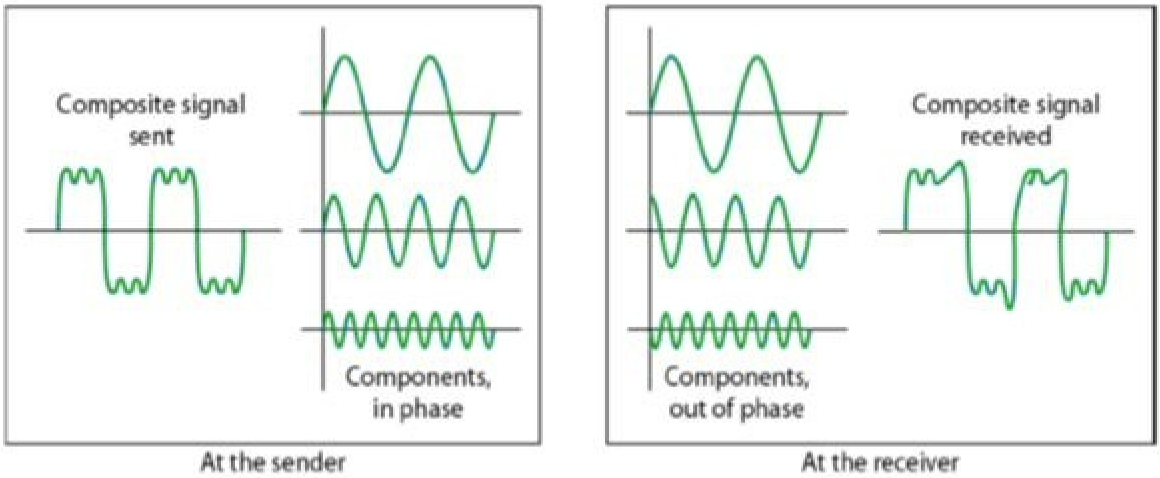
3.7 Transmission Impairment: Attenuation, Distortion and Noise

Transmission Impairment means the signal gets weaker or distorted as it travels through the transmission medium (like cables or air). It affects the quality of data communication.

Attenuation - It means loss of energy. The strength of signal decreases with increasing distance which causes loss of energy in overcoming resistance of medium. This is also known as attenuated signal. Amplifiers are used to amplify the attenuated signal which gives the original signal back and compensate for this loss.



Distortion - It means changes in the form or shape of the signal. This is generally seen in composite signals made up with different frequencies. Each frequency component has its own propagation speed travelling through a medium. And thats why it delay in arriving at the final destination Every component arrive at different time which leads to distortion. Therefore, they have different phases at receiver end from what they had at senders end.

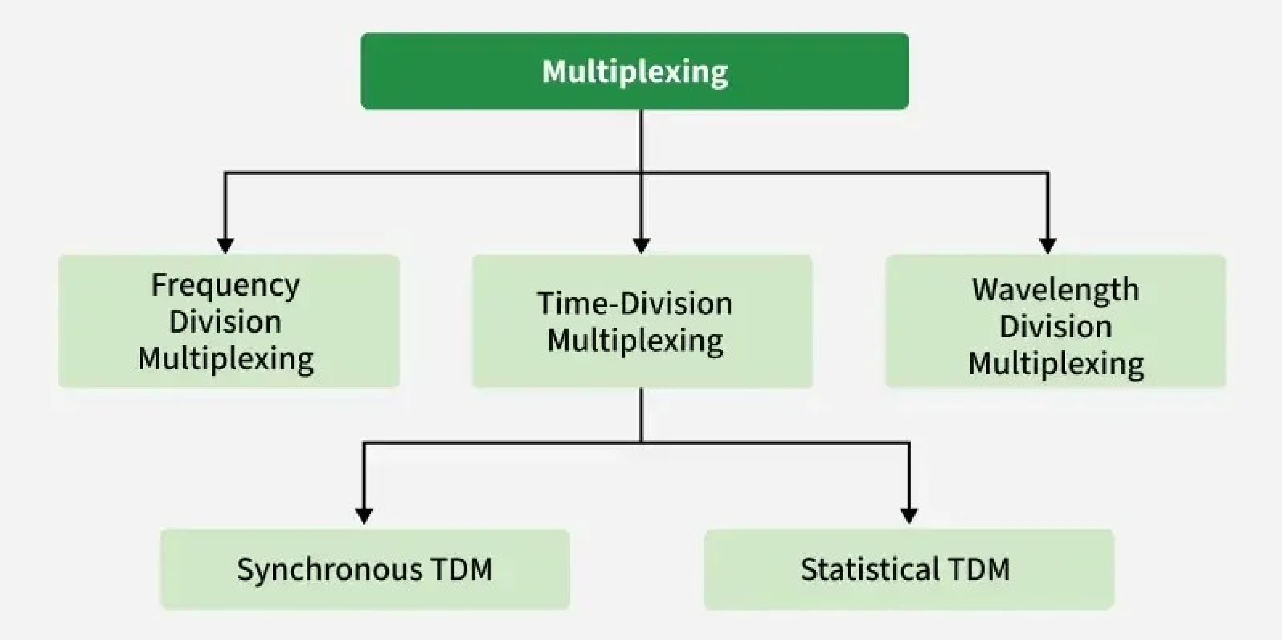


Noise - The random or unwanted signal that mixes up with the original signal is called noise. There are several types of noise such as induced noise, crosstalk noise, thermal noise and impulse noise which may corrupt the signal.

3.8 Multiplexing: TDM, FDM and WDM

Multiplexing is the sharing of a medium or bandwidth. It is the process in which multiple signals coming from multiple sources are combined and transmitted over single communication/physical line.

Types of Multiplexing



Frequency Division Multiplexing

Frequency division multiplexing is defined as a type of multiplexing where the bandwidth of a single physical medium is divided into a number of smaller, independent frequency channels.

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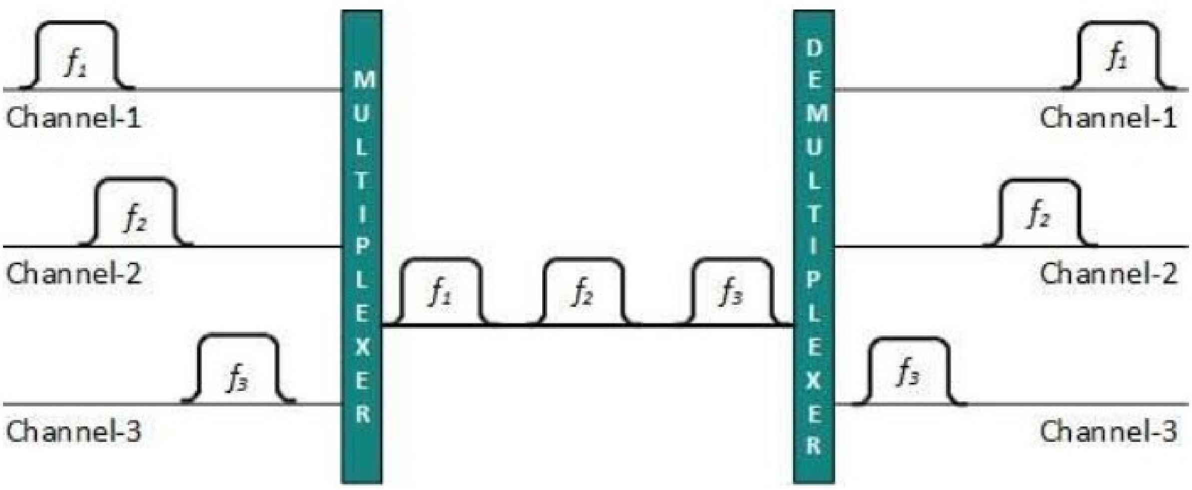
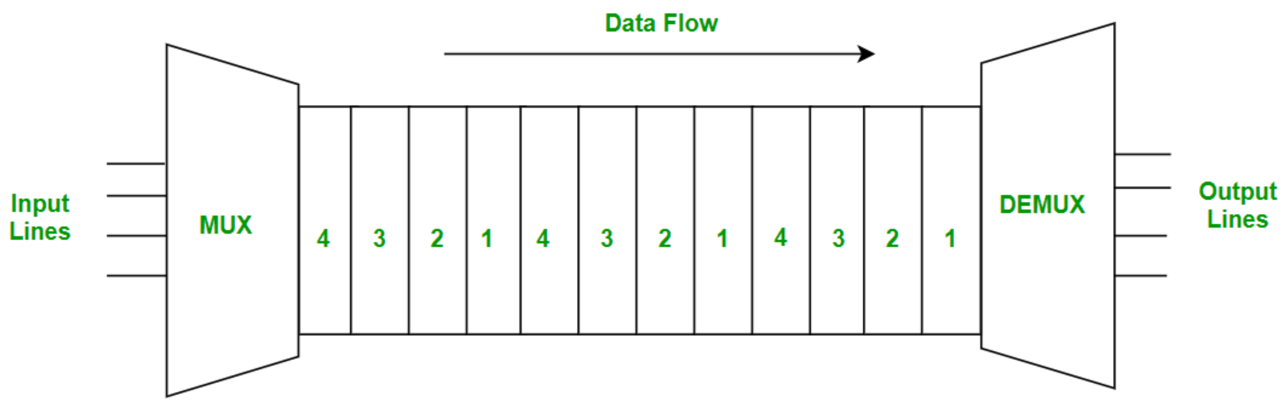


In order to prevent the inter-channel cross talk, unused strips of bandwidth must be placed between each channel. These unused strips between each channel are known as guard bands. Guard band is a frequency which is not used by either channel.
Frequency Division Multiplexing is used in radio and television transmission.

Time Division Multiplexing

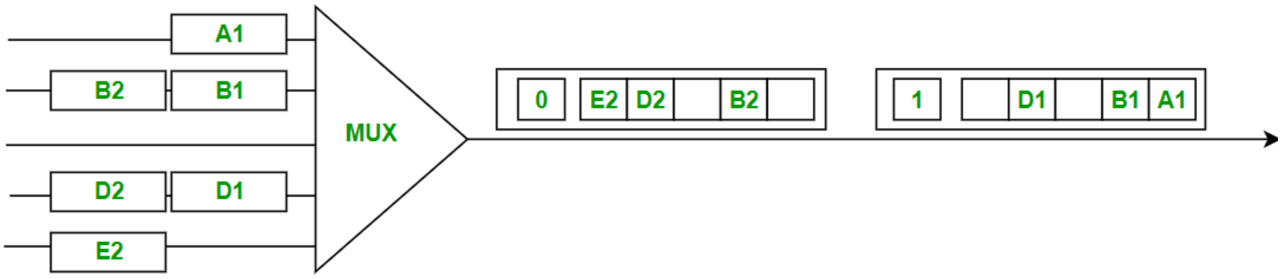
Time-division multiplexing is multiplexing wherein FDM, instead of sharing a portion of the bandwidth in the form of channels, in TDM, time is shared. Each connection occupies a portion of time in the link. In Time Division Multiplexing, all signals operate with the same frequency (bandwidth) at different times.



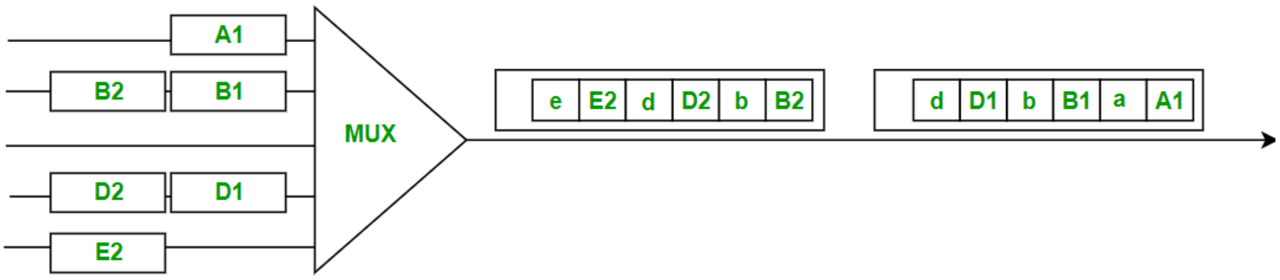
There are two types of Time Division Multiplexing :

- Synchronous Time Division Multiplexing
- Statistical (or Asynchronous) Time Division Multiplexing

Synchronous TDM : Synchronous TDM is a type of Time Division Multiplexing where the input frame already has a slot in the output frame. Time slots are grouped into frames. One frame consists of one cycle of time slots. Synchronous TDM is not efficient because if the input frame has no data to send, a slot remains empty in the output frame. In this, we need to mention the synchronous bit at the beginning of each frame.



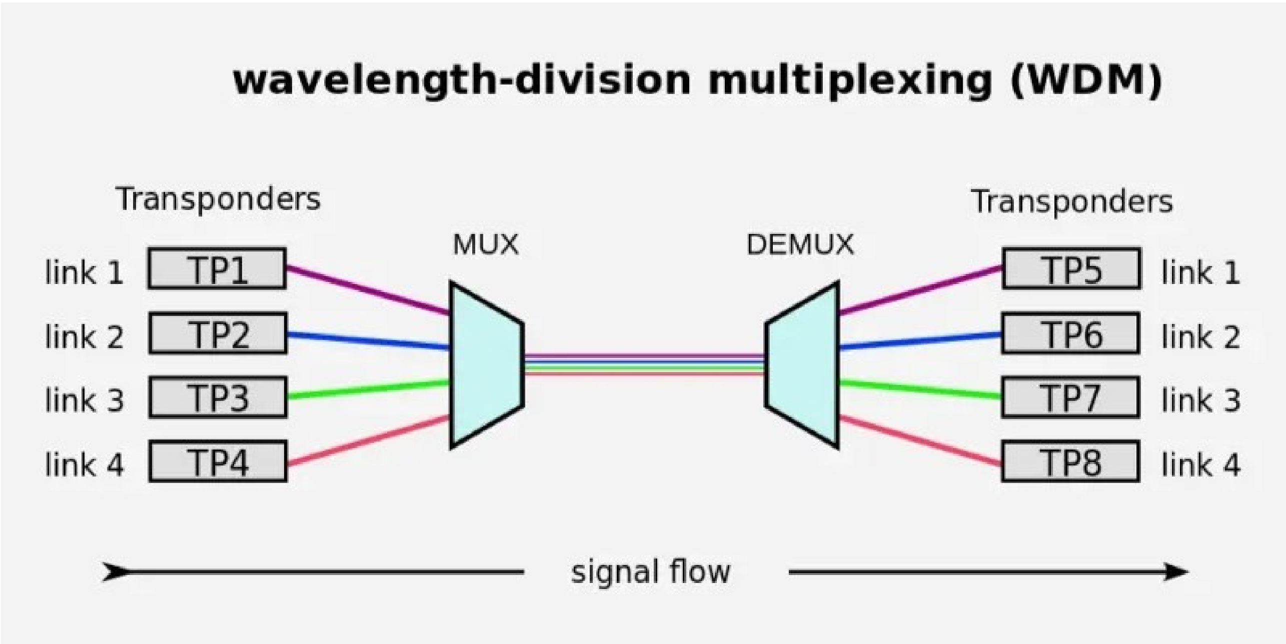
Statistical TDM: Statistical TDM is a type of Time Division Multiplexing where the output frame collects data from the input frame till it is full not leaving an empty slot like in Synchronous TDM. In this, we need to include the address of each particular data in the slot that is being sent to the output frame.



Wavelength Division Multiplexing

Wavelength Division Multiplexing (WDM) is a multiplexing technology used to increase the capacity of optical fiber by transmitting multiple optical signals simultaneously over a single optical fiber, each with a different wavelength. Each signal is carried on a different wavelength of light, and the resulting signals are combined onto a single optical fiber for transmission.

At the receiving end, the signals are separated by their wavelengths, demultiplexed and routed to their respective destinations. It is used in telecommunications, cable TV, ISPs, and data centers for high-speed, long-distance data transmission.



WDM can be divided into two categories:

Dense Wavelength Division Multiplexing (DWDM) is used to multiplex a large number of optical signals onto a single fiber, typically up to 80 channels with a spacing of 0.8 nm or less between the channels.

Coarse Wavelength Division Multiplexing (CWDM) is used for lower-capacity applications, typically up to 18 channels with a spacing of 20 nm between the channels.

3.9 Switching: Circuit Switching, Message Switching, Packet Switching, Virtual Circuit Switching

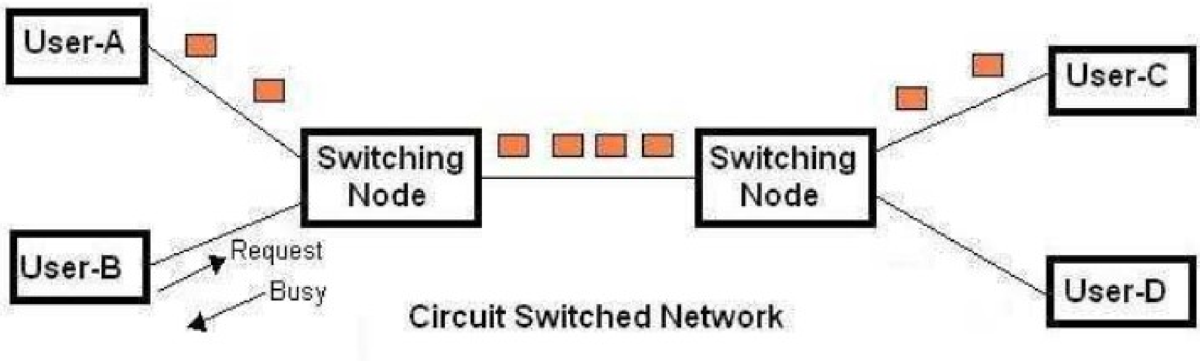
Switching

Switching is process to forward packets coming in from one port to a port leading towards the destination. In large networks there might be multiple paths linking sender and receiver. Information may be switched as it travels through various communication channels.

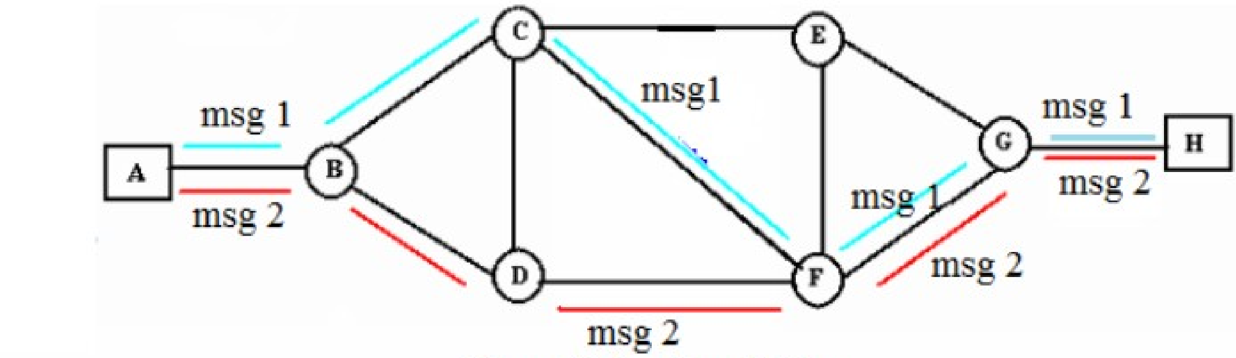
A switch is a dedicated piece of computer hardware that facilitates the process of switching i.e.incoming data packets and transferring them to their destination.

Circuit Switching: In this type of switching, a connection is established between the source and destination beforehand. This connection receives the complete bandwidth of the network until the data is transferred completely.

This approach is better than message switching as it does not involve sending data to the entire network, instead of its destination only. Telephone is the best suitable example of circuit switching.

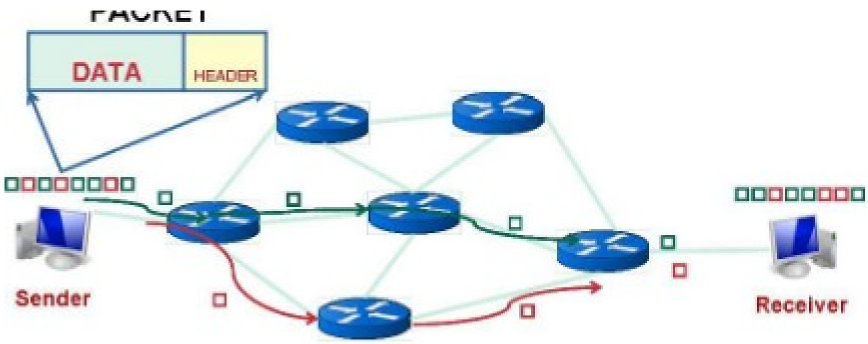


Message Switching: This is an older switching technique that has become obsolete. In message switching technique, the entire data block/message is forwarded across the entire network thus, making it highly inefficient.



Diag of Circuit switching

Packet Switching: This technique requires the data to be broken down into smaller components, data frames, or packets. These data frames are then transferred to their destinations according to the available resources in the network at a particular time.
This switching type is used in modern computers and even the Internet. Here, each data frame contains additional information about the destination and other information required for proper transfer through network components. Packets are stored and forwarded according to their priority to provide quality of service.



Virtual-Circuit Packet Switching: In Virtual-Circuit Packet switching, a logical connection between the source and destination is made before transmitting any data. These logical connections are called virtual circuits. Each data frame follows these logical paths and provides a reliable way of transmitting data with less chance of data loss.

Circuit Switching	Packet Switching
Physical path exist between source and destination	No physical path
All packets use same path	Packets travel independently
Reserve the entire bandwidth in advance	Does not reserve
Bandwidth Wastage	No Bandwidth wastage
No store and forward transmission	Support store and forward transmission

3.10 Network Performance: Bandwidth, Throughput, Latency, Bandwidth-Delay Product, Jitter

The performance of a network pertains to the measure of service quality of a network as perceived by the user. There are different ways to measure the performance of a network, depending upon the nature and design of the network.

Parameters for Measuring Network Performance

- Bandwidth
- Latency (Delay)
- Bandwidth - Delay Product
- Throughput
- Jitter

BANDWIDTH

Bandwidth refers to the range of component frequencies that is contained in a signal. Bandwidth is the difference between highest and lowest of the frequency range used for signaling In the case of digital devices, the bandwidth is measured in bits per second(bps) or bytes per second. In the case of analog devices, the bandwidth is measured in cycles per second, or Hertz (Hz).
"Bandwidth" means "Capacity".
More bandwidth does not mean more speed.

Bandwidth in Hertz: It is the range of frequencies contained in a composite signal or the range of frequencies a channel can pass.

Bandwidth in Bits per Seconds: It refers to the number of bits per second that a channel, a link, or rather a network can transmit.

LATENCY

In a network, during the process of data communication, latency(also known as delay) is defined as the total time taken for a complete message to arrive at the destination, starting with the time when the first bit of the message is sent out from the source and ending with the time when the last bit of the message is delivered at the destination. The network connections where small delays occur are called "Low-Latency-Networks" and the network connections which suffer from long delays are known as "High-Latency-Networks".

High latency leads to the creation of bottlenecks in any network communication. It stops the data from taking full advantage of the network pipe and conclusively decreases the bandwidth of the communicating network. The effect of the latency on a network's bandwidth can be temporary or never-ending depending on the source of the delays. Latency is also known as a ping rate and is measured in milliseconds(ms).

In simpler terms latency may be defined as the time required to successfully send a packet across a network.

It is measured in many ways like a round trip, one-way, etc.

Latency = Propagation Time + Transmission Time + Queuing Time + Processing Delay

THROUGHPUT

Throughput is the number of messages successfully transmitted per unit time. It is controlled by available bandwidth, the available signal-to-noise ratio, and hardware limitations. The maximum throughput of a network may be consequently higher than the actual throughput achieved in everyday consumption. Throughput is an actual measurement of how fast we can send data.

JITTER

Jitter is another performance issue related to the delay. In technical terms, jitter is a "packet delay variance". It can simply mean that jitter is considered a problem when different packets of data face different delays in a network and the data at the receiver application is time-sensitive, i.e. audio or video data. Jitter is measured in milliseconds(ms). It is defined as an interference in the normal order of sending data packets.

The major causes of jitter are electromagnetic interference(EMI) and crosstalk between signals.

Jitter is harmful and causes network congestion and packet loss. Congestion is like a traffic jam on the highway.In congestion, all the packets come to a junction at the same time. Nothing can get loaded.

The second negative effect is packet loss. When packets arrive at unexpected intervals, the receiving system is not able to process the information, which leads to missing information also called "packet loss".

Bandwidth-Delay Product (BDP)

The Bandwidth-Delay Product (BDP) is a measure of the amount of data (in bits) that can be in transit in a network at any given time.

It is calculated as:
BDP=Bandwidth×Propagation Delay

Where,

Bandwidth = Data rate of the link (in bits per second, bps)

Propagation Delay = Time it takes for a signal to travel from sender to receiver (in seconds)
The result of BDP is in bits.