5.0 DATA TRANSMISSION AND MODULATION

5.1 Data Transmission

Data transmission refers to the process of sending digital data from one device to another through a communication channel or medium. This process typically involves converting digital data into electrical, optical, or radio signals for transmission over physical mediums such as cables, fiber optics, or electromagnetic signals in wireless networks. Data transmission can occur over short distances (e.g., within a computer network) or long distances (e.g., across the internet). It involves various techniques and protocols to ensure reliable and efficient communication between sender and receiver devices.

Types of Data Transmission

The basic data transmission types tell us which *direction* data moves between sender and receiver. These are:

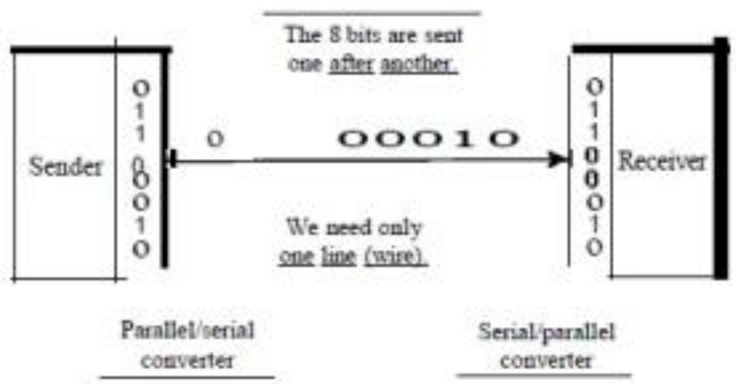
- Simplex Data Transmission
    - data is only sent in one direction from sender to receiver
- Half-Duplex Data Transmission
    - connections can transmit both ways, but not simultaneously.
- Full-Duplex Data Transmission
    - connections transmit data both ways at the same time, this is the most common type found in computer networks.

What are Serial and Parallel Transmission?

There are two ways of grouping bits of data and sending them across a network. Serial transmission means bits are sent sequentially, whereas parallel transmission sends data packets simultaneously.

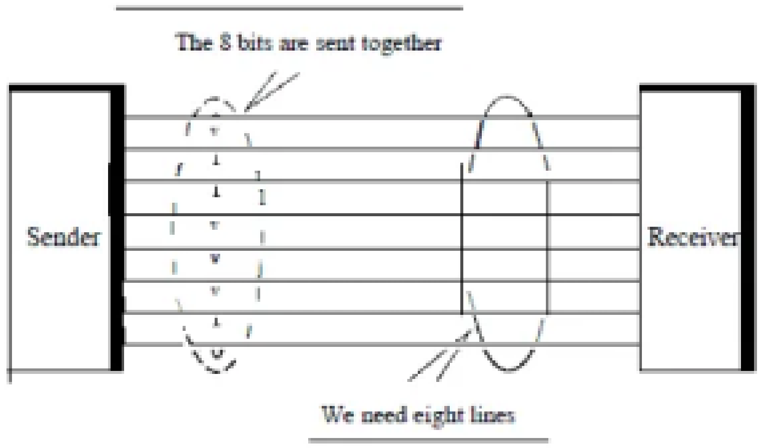
Serial Data Transmission

In serial data transmission, each bit is sent one after the other in sequence. This is the type of data transmission method devices use to communicate over a network.
Since the sending or receiving devices will use parallel transmission internally, converters (serial to parallel and parallel to serial) are used at the interface point between the device and the line.



Parallel Transmission

In parallel transmission, binary data is grouped into bits. The number of groups corresponds to the number of threads between the sender and receiver, and the groups are transmitted simultaneously.



This method allows for groups of bits (bytes) to be transmitted faster than serial transmission. However, because separate lines are required for each bit, building infrastructure this way would be costly.

That's why we mostly see parallel transmission within devices, like computer processors, for example. The communication between an API like RDDand the Spark codebase is another example of parallel transmission.

Note that Parallel transmission always happens in synchronicity with the system clock. ***Serial transmission, though, can be subdivided into three further groups*** based on the synchronization of the sending and receiving device.

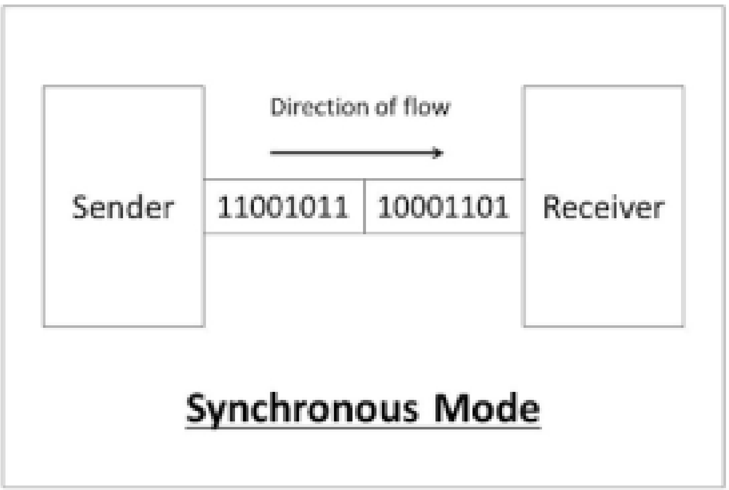
What are Synchronous and Asynchronous and Isochronous Transmission?

When data is sent at a synchronized rhythm, defined by the system clock, we call it synchronous transmission. Some types of data, like live video streams, need highly synchronized data feeds that arrive constantly. Other types can be sent asynchronously.

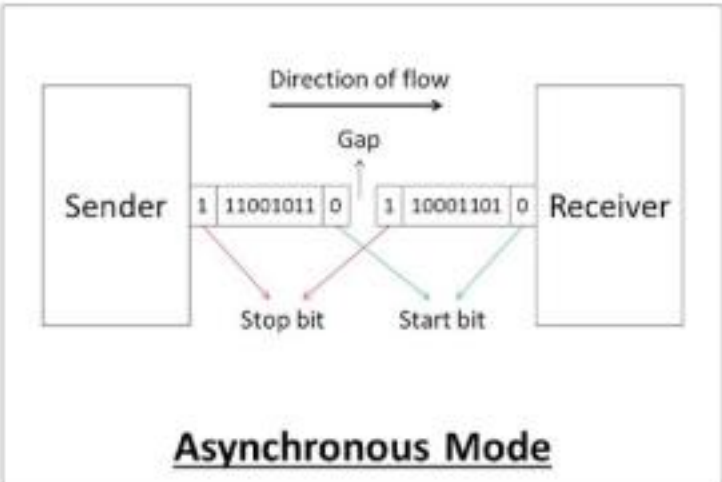
Synchronous

In synchronous transmissions, data is sent in frames. These are long continuous strings of uninterrupted binary data. The receiving device counts the bits of binary data, using the synchronicity between devices (defined in the data layer) to count the length of a byte.

Since data is sent as a constant stream, synchronous transmission allows for high transfer speeds. This kind of transmission is used for high-speed connections between modern computer networks



Asynchronous
This method sends bytes with an additional “start” and “stop” bit at the beginning and end. That means the receiving device knows the length of a byte without synchronizing with the transmitter.
By counting the start and stop bits, the receiver can resynchronize the data stream at the byte level each time a new signal is received. This method is often used for low-speed transmissions, such as the input data from your keyboard or sporadic data from business microservices.



Isochronous
When an image or audio signal needs to be broadcast at a specific frame rate, uninterrupted, then synchronous and asynchronous transmission both fall short. The entire bit stream needs to be synchronized and sent at a constant rate with no gaps between frames.
This is where Isochronous transmission is used. You might see this in a digital TV broadcast signal, or a live streaming service.

So when it comes to data transmission in computer networks, we define modes by the *direction of data flow*, the *number of simultaneous bits* being sent, and the *synchronicity of devices*.

- **Direction** – Simplex, Half-duplex, Full duplex
- **Number of simultaneous bits** – Serial or Parallel
- **Synchronicity** – Synchronous, Asynchronous, Isochronous

Each method has its uses. A network and each of its parts could use every kind of transmission at some stage.

5.2 Modulation

Data modulation, or simply modulation, is a process in which digital data is encoded onto an analog carrier signal for transmission over a communication channel. This process allows digital information to be transmitted efficiently through analog transmission mediums such as radio waves, optical fibers, or copper wires.

Modulation is essential in data transmission because it allows digital information to be transmitted efficiently over analog channels while mitigating the effects of noise and interference. At the receiver end, demodulation is performed to extract the original digital data from the modulated carrier signal.

There are several types of modulation techniques used in data transmission:

Amplitude Modulation (AM): In AM, the amplitude of the carrier signal is varied in proportion to the digital data being transmitted. The presence or absence of digital bits is represented by changes in the amplitude of the carrier signal.

Frequency Modulation (FM): In FM, the frequency of the carrier signal is varied based on the digital data. Changes in frequency correspond to changes in the digital signal.

Phase Modulation (PM): In PM, the phase of the carrier signal is altered to represent digital data. Changes in phase indicate changes in the digital signal.

Quadrature Amplitude Modulation (QAM): QAM is a more complex modulation technique that combines both amplitude and phase modulation. It allows for higher data rates by encoding multiple bits per symbol.

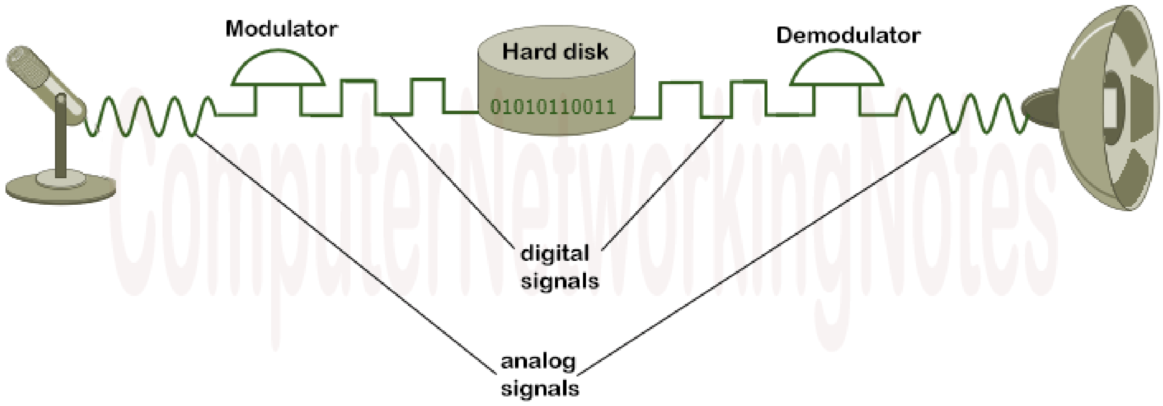
Importance of Data Modulation

Data modulation is a process that converts analog signals into digital signals and digital signals into analog signals. Computers store and process data in digital format. Data modulation allows computers to store and process analog signals.

Example: Recording and playing an Audio Clip

When you record and play an audio clip, the following happens.
You use a microphone to record the audio clip. The microphone sends your voice to the computer. Since the human voice consists of analog signals, the computer converts the received voice into digital signals before processing and storing them onto the hard disk.

When the recorded clip is played, the computer reads digital signals from the hard disk and converts them into analog signals before sending them to the speaker.

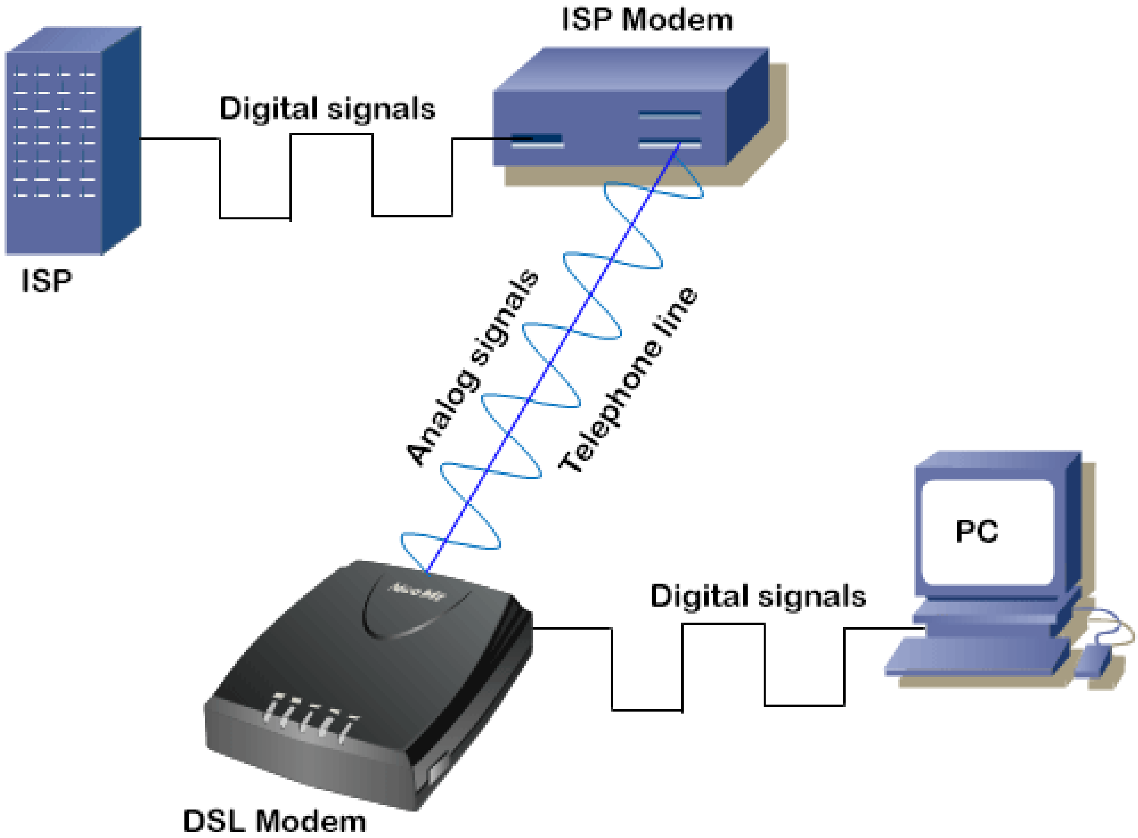


Modulators and demodulators are devices or chips or components that convert analog signals into digital signals and digital signals into analog signals, respectively.

Data modulation is not only used within the computer, but it is also used outside the computer. It allows computers to send digital signals on a media that can only carry analog signals. It converts signals in such a way that they become suitable for transport on a communication path that is not designed to carry such signals.

For example, telephone lines are designed to carry analog signals. Through data modulation, the same telephone lines can also be used to provide the Internet facility. To provide the Internet facility through telephone lines, a device known as the modem is used. A modem can act as both a modulator and a demodulator.

A modem connects a computer to the ISP network via a telephone line. It modulates digital signals into analog signals at the transmitting end, then demodulates analog signals into digital signals at the receiving end.


ISP Modem
Digital signals
ISP
Analog signals
Telephone line
PC
Digital signals
DSL Modem

Types of Multiplexing in Data Communications

What is Multiplexing?

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 a single communication/physical line.

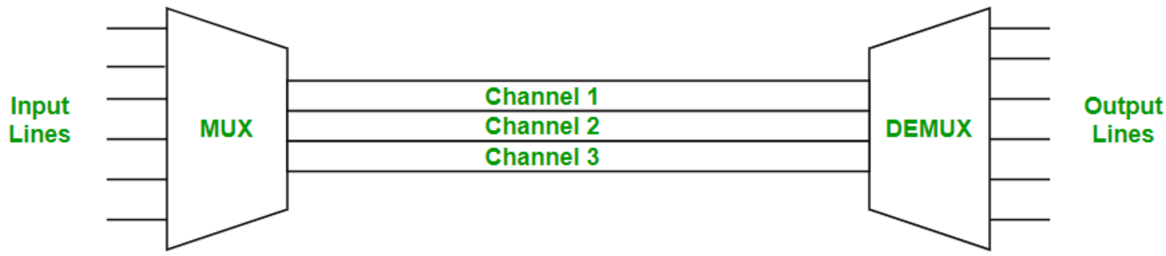
Types of Multiplexing

There are Five types of Multiplexing :

- Frequency Division Multiplexing (FDM)
- Time-Division Multiplexing (TDM)
- Wavelength Division Multiplexing (WDM)
- Code-division multiplexing (CDM)
- Space-division multiplexing (SDM):

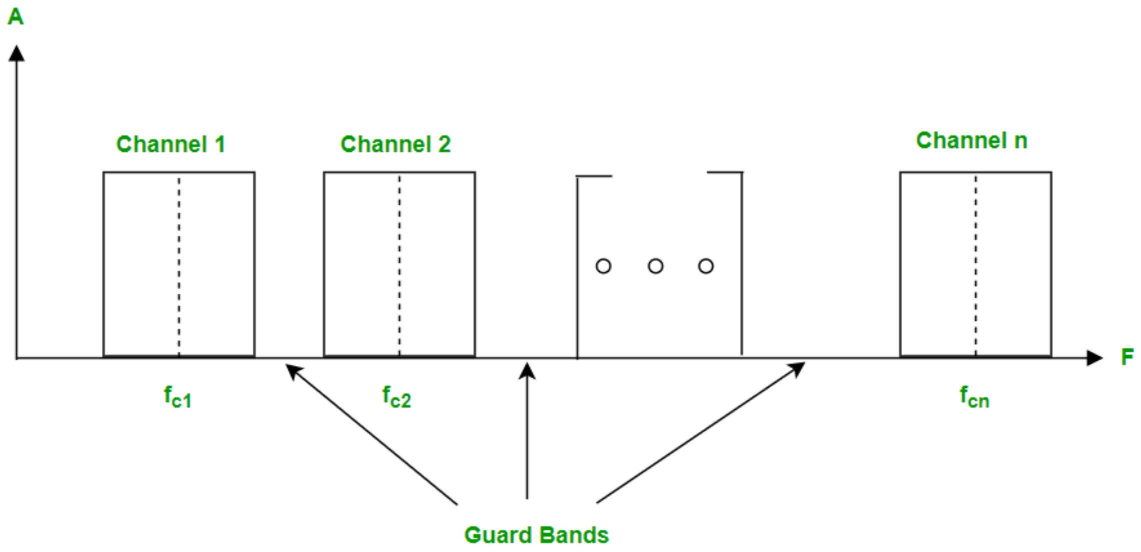
1. ***Frequency Division Multiplexing:***

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.



Frequency Division Multiplexing is used in radio and television transmission.

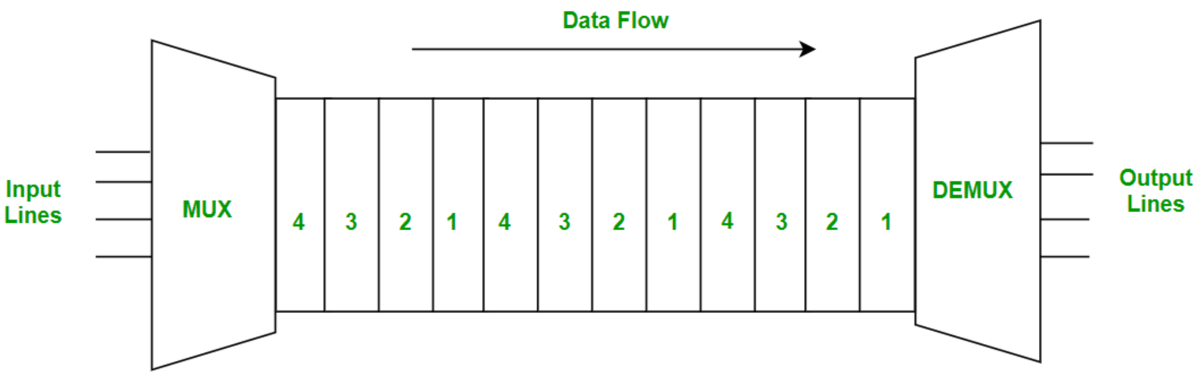
In FDM, we can observe a lot of inter-channel cross-talk, due to the fact that in this type of multiplexing the bandwidth is divided into frequency channels. In order to prevent the inter-channel cross talk, unused strips of bandwidth must be placed between each channel. These unused strips between each channel are known as guard bands.



2. Time Division Multiplexing

Time-division multiplexing is defined as a type of 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.



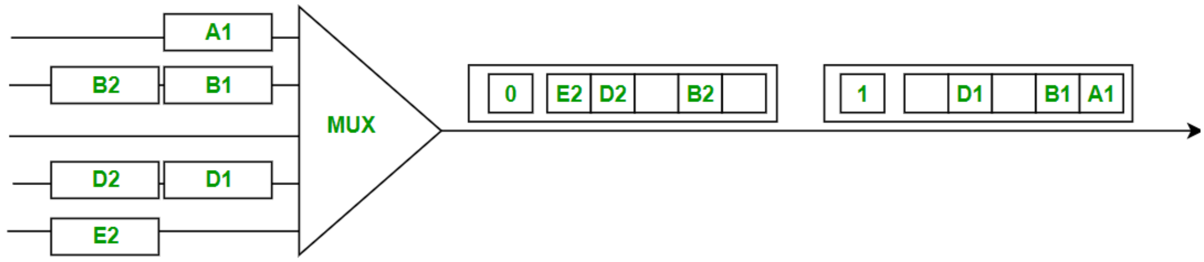
There are two types of Time Division Multiplexing :

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

a) 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.

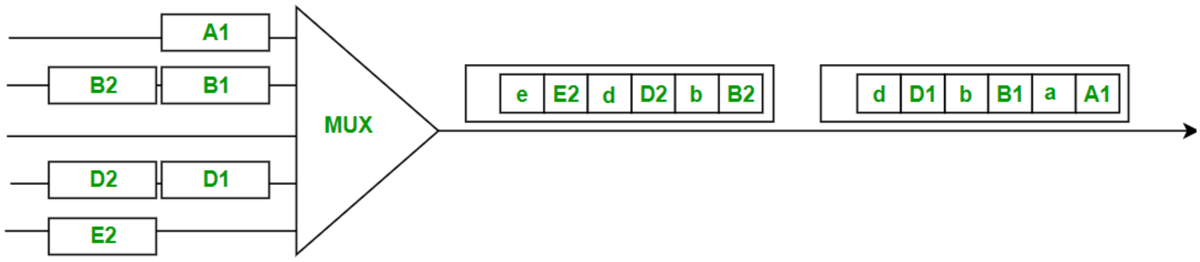
Synchronous TDM is not efficient because if the input frame has no data to send, a slot remains empty in the output frame.
In synchronous TDM, we need to mention the synchronous bit at the beginning of each frame.



b) 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 statistical TDM, we need to include the address of each particular data in the slot that is being sent to the output frame.



Statistical TDM is a more efficient type of time-division multiplexing as the channel capacity is fully utilized and improves the bandwidth efficiency.

3. 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.

WDM can be divided into two categories:

- Dense Wavelength Division Multiplexing (DWDM) and
- Coarse Wavelength Division Multiplexing (CWDM).

a) 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.

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

WDM has several advantages over other multiplexing technologies such as Time Division Multiplexing (TDM). WDM allows for higher data rates and capacity, lower power consumption, and reduced equipment complexity. WDM is also flexible, allowing for easy upgrades and expansions to existing networks.

WDM is used in a wide range of applications, including telecommunications, cable TV, internet service providers, and data centers. It enables the transmission of large amounts of data over long distances with high speed and efficiency.

Wavelength Division Multiplexing is used on fiber optics to increase the capacity of a single fiber. It is an analog multiplexing technique. Optical signals from the different sources are combined to form a wider band of light with the help of multiplexers. At the receiving end, the De-multiplexer separates the signals to transmit them to their respective destinations.

4. *Space-division multiplexing (SDM):*

Space Division Multiplexing (SDM) is a technique used in wireless communication systems to increase the capacity of the system by exploiting the physical separation of users.

In SDM, multiple antennas are used at both the transmitter and receiver ends to create parallel communication channels. These channels are independent of each other, which allows for multiple users to transmit data simultaneously in the same frequency band without interference. The capacity of the system can be increased by adding more antennas, which creates more independent channels.

SDM is commonly used in wireless communication systems such as cellular networks, Wi-Fi, and satellite communication systems. In cellular networks, SDM is used in the form of Multiple Input Multiple Output (MIMO) technology, which uses multiple antennas at both the transmitter and receiver ends to improve the quality and capacity of the communication link.

5. *Code-division multiplexing (CDM):*

Code division multiplexing (CDM) is a technique used in telecommunications to allow multiple users to transmit data simultaneously over a single communication channel. In CDM, each user is assigned a unique code that is used to modulate their signal. The modulated signals are then combined and transmitted over the same channel. At the receiving end, each user's signal is demodulated using their unique code to retrieve their original data.

In CDM, each user is assigned a unique spreading code that is used to spread the data signal. This spreading code is typically a binary sequence that is much longer than the original data signal. The spreading code is multiplied with the data signal to generate a spread spectrum signal that has a much wider bandwidth than the original data signal. The spread spectrum signals of all users are then combined and transmitted over the same channel.

At the receiving end, the received signal is multiplied with the same spreading code used at the transmitting end to dispread the signal. The resulting dispread signal is then demodulated to retrieve the original data signal. Because each user's data signal is spread using a unique code, it is possible to separate the signals of different users even though they are transmitted over the same channel.

CDM is commonly used in wireless communication systems such as cellular networks and satellite communication systems. It allows multiple users to share the same frequency band and increases the capacity of the communication channel. CDM also provides some level of security as the signals of different users are difficult to intercept or jam.