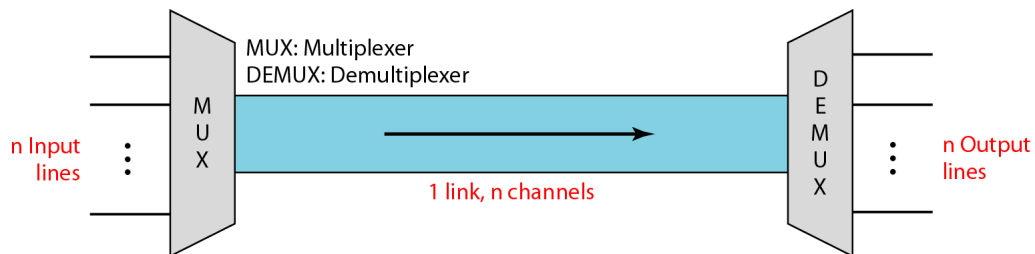


MODULE – IV

Multiplexing- Space Division Multiplexing-Frequency Division Multiplexing: Wave length Division Multiplexing - Time Division multiplexing: Characteristics, Digital Carrier system, SONET/SDH- Statistical time division multiplexing: Cable Modem - Code Division Multiplexing. Multiple Access- CDMA.

1. Multiplexing

- Multiplexing to refer to the combination of information streams from multiple sources for transmission over a **shared medium**.
- The aim is to share a scarce resource. For example, in telecommunications, several telephone calls may be carried using one wire.

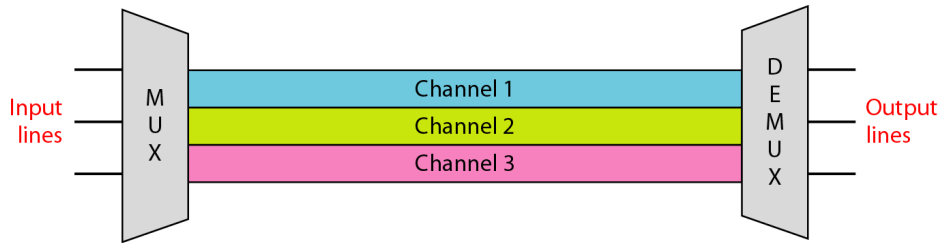


- each sender communicates with a single receiver
 - all pairs share a single transmission medium
 - multiplexor combines information from the senders for transmission in such a way that the demultiplexer can separate the information for receivers
- There are four basic approaches to multiplexing that each have a set of variations and implementations
 1. Frequency Division Multiplexing (FDM)
 2. Wavelength Division Multiplexing (WDM)
 3. Time Division Multiplexing (TDM)
 4. Code Division Multiplexing (CDM)
- TDM and FDM are widely used
 - WDM is a form of FDM used for optical fiber
 - CDM is a mathematical approach used in cell phone mechanisms

1.1 Frequency Division Multiplexing

- Frequency Division Multiplexing (FDM) Frequency-division multiplexing is a form of signal multiplexing which involves assigning non-overlapping frequency ranges to different signals or to each "user of a medium.
- FDM achieves the combining of several signals into one medium by sending signals in several distinct frequency ranges over a single medium.
- Frequency division multiplexing involves translation of the speech signal from the frequency band 300-3400 Hz to a higher frequency band. Each channel is translated to a different band and then all the channels are combined to form a frequency division multiplexed signal.

- In FDM, the speech channels are stacked at intervals of 4 kHz to provide a **guard band** between adjacent channels.



- FDM can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted.



- A demultiplexer applies a set of filters that each extract a small range of frequencies near one of the carrier frequencies

Advantage of FDM:

1. The senders can send signals continuously.
2. FDM support full duplex information flow
3. Works for analog signals too
4. Noise problem for analog communication has lesser effect
5. AM and FM radio broadcasting and Television broadcasting

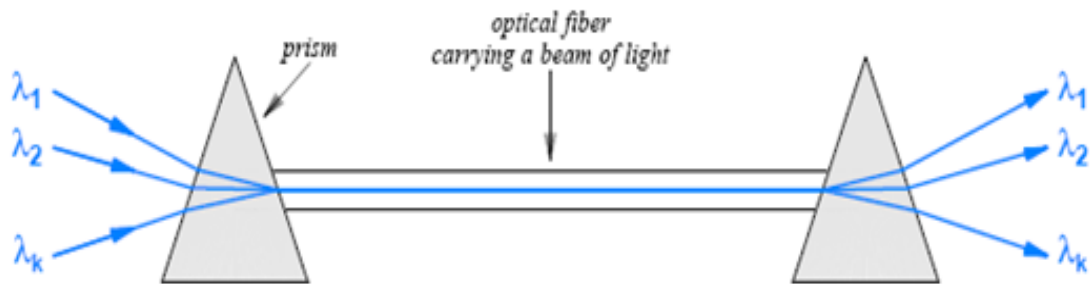
Disadvantage of FDM:

1. Separate frequency for each possible communication
2. Inflexible, one channel idle and other one busy
3. The initial cost is high
4. A problem for one user can sometimes affect others
5. Each user requires a precise carrier frequency.

1.2 Wavelength Division Multiplexing (WDM)

- WDM is an analog multiplexing technique to combine optical signals.
- Wavelength-division multiplexing (WDM) is designed to use the high-data-rate capability of fiber-optic cable.
- Also called Dense WDM (DWDM) to emphasize that many wavelengths of light can be employed.
- The inputs and outputs of such multiplexing are wavelengths of light denoted by the Greek letter λ , and informally called colors.

- Prisms form the basis of optical multiplexing and demultiplexing
 - o A multiplexer accepts beams of light of various wavelengths and uses a prism to combine them into a single beam
 - o A demultiplexer uses a prism to separate the wavelengths.



Advantages of WDM

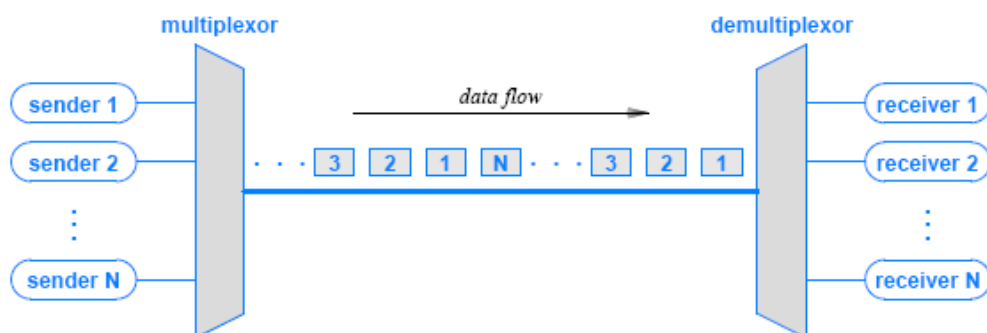
- 1) Speed: Works with low speed equipment
- 2) Transparency: WDM is transparent_ It does not depend on the protocol that has to be transmitted.
- 3) Scalable: It is scalable. Instead of switching to a new technology, a new channel can easily be added to existing channels.
- 4) Capacity Increment: It is easy for network providers to add additional capacity in a few days if customers need it.

Disadvantages of WDM

- 1) Complexity: Complex transmitters and receivers.
- 2) Reliability and Cost: They must be wide-band, which means they are more expensive and possibly less reliable.

1.3 Time Division Multiplexing

- Time-division multiplexing (TDM) is a digital process that allows several connections to share the high bandwidth of a line. Instead of sharing a portion of the bandwidth as in FDM, time is shared.
- Time Division Multiplexing is the process of dividing up one communication time slot into smaller time slots.



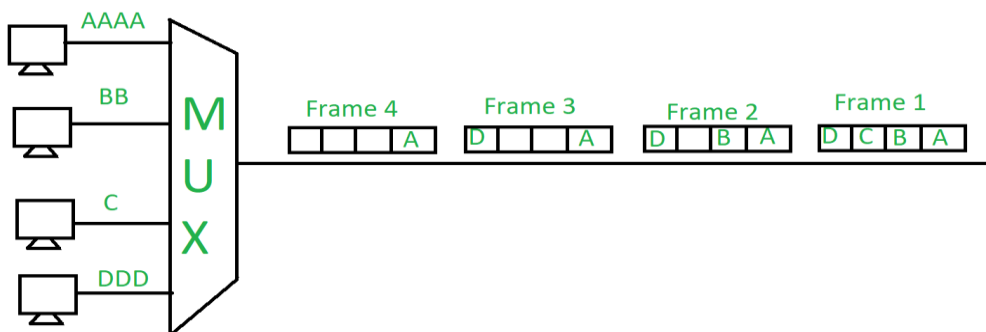
- Time Division Multiplexing (TDM) system, a single path and carrier frequency is used.
- TDM is a digital technology.
- Each user is assigned a unique time slot for their operation.
- A central switch or multiplexer goes from one user to the next in a specific predictable sequence and time.
- TDM system can be applied when the data rate capacity of the transmission medium is greater than the data rate required by the sending and receiving devices.
- TDM is more efficient than FDM, in that it does not require guard bands and it operates directly in digital form.
- In TDM, the transmission between the multiplexers is provided by a single high speed digital transmission line.

Types of Time Division Multiplexing It can be categories into two types:

- 1) Synchronous TDM
- 2) Asynchronous TDM

1.3.1 Synchronous TDM

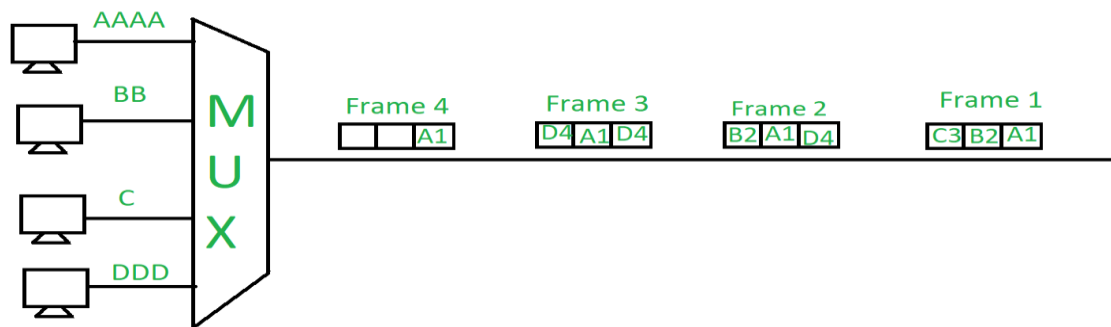
- Accepts input in a round-robin fashion
- Synchronous TDM works by the multiplexer giving exactly the-same amount of time to each device connected to it.



- This time slice is allocated even if a device has nothing to transmit.
- The use of Synchronous TDM does not guarantee maximum line usage and efficiency.
- T-1 and ISDN telephone lines are common examples of synchronous time division multiplexing.
- It is used for multiplexing digitized voice stream.

1.3.2 Asynchronous TDM

- Asynchronous Time-Division Multiplexing is a method of sending information that resembles normal TDM, except that time slots are allocated as needed dynamically rather than pre-assigned to specific transmitters.
- Asynchronous TDM is more intelligent and has better bandwidth efficiency than TDM.
- Good for low bandwidth lines
- Examples: used for LANs



Parameter	Synchronous TDM	Asynchronous TDM / Statistical TDM
Working	In Synchronous TDM data flow of each input connection is divided into units and each input occupies one output time slot.	In Statistical TDM slots are allotted dynamically. i.e. input line is given slots in output frame if and only if it has data to send.
No. of Slots	In Synchronous TDM no. of slots in each frame are equal to no. of input lines.	In Statistical TDM, No. of slots in each frame are less than the no. of input lines.
Buffers	Buffering is not done, frame is sent after a particular interval of time whether someone has data to send or not.	Buffering is done and only those inputs are given slots in output frame whose buffer contains data to send.
Addressing	Slots in Synchronous TDM carry data only and there is no need of addressing. Synchronization and pre assigned relationships between input and outputs that serve as an address.	Slots in Statistical TDM contain both data and address of the destination.
Synchronization	Synchronization bits are used at the beginning of each frame.	No synchronization bits are used
Capacity	Max. Bandwidth utilization if all inputs have data to send.	The capacity of link is normally is less than the sum of the capacity of each channel.
Data Separation	In Synchronous TDM de-multiplexer at receiving end decomposes each frame, discards framing bits and extracts data unit in turn. This extracted data unit from frame is then passed to destination device.	In Statistical TDM de-multiplexer at receiving end decomposes each frame by checking local address of each data unit. This extracted data unit from frame is then passed to destination device.

Advantages of TDM

- 1) The user gets full bandwidth of the channel in a particular time slot.
- 2) For bursty signals such as voice or speech TDMA gives maximum utilization of the channel.
- 3) Most suitable technique for digital transmission.
- 4) It does not require precise carrier matching at both end of the links.
- 5) Can expand the number of users on a system at a low cost.

Disadvantages of TDM

- 1) It is not much suitable for continuous signals.
- 2) Initial cost is high.
- 3) The noise problem for analog communication has greater effect.
- 4) Extra guard times are necessary.
- 5) Synchronization is necessary.

Difference between TDM and FDM

Time Division Multiplexing (TDM)	Frequency Division Multiplexing(FDM)
Total available time is divided into several users	Total frequency bands are divided into several users.
Transmission of two or more signals on the same path, but at different times.	A multiplex system for transmitting two or more signals over a common path by using a different frequency band for each signal.
TDM imply partitioning the bandwidth of the channel connecting two nodes into finite set of time slots	The signals multiplexed come from different sources/transmitters.
TDM is implemented using digital devices and circuits.	FDM is implemented using analog devices and circuits.
TDM system has relatively small inter-channel crosstalk which can be arrived by ensuring completely isolated and non-overlapping pulses indifferent time slots.	In FDM the non-linearities present in transmitter and receiver circuits produce intermodulation and harmonic distortion.

1.4 Code Division Multiplexing

- In code division multiplexing, every user can transmit over the entire frequency spectrum all the time.
- **CDM used in parts of the cellular telephone system and for some satellite communication**
- The specific version of CDM used in cell phones is known as **Code Division Multi-Access (CDMA)**
- CDM is achieved through application of **spread-spectrum techniques**.
- Spread spectrum techniques can be classified into two categories:
 - 1) Direct-Sequence
 - 2) Frequency hopping techniques.
- Generally, CDM is a frequency hopping spread spectrum techniques which allows utilization of full channel bandwidth for each user.
 - CDM does not rely on physical properties such as frequency or time
- CDM relies on an interesting mathematical idea - “values from **orthogonal vector spaces** can be combined and separated without interference”.

- Each sender is assigned a unique binary code C_i that is known as a **chip sequence**

- Chip sequences are selected to be orthogonal vectors (i.e., the dot product of any two chip sequences is zero).
- At any point in time, each sender has a value to transmit, V_i
- The senders each multiply $C_i \times V_i$ and transmit the results
 - The senders transmit at the same time
- and the values are added together
 - To extract value V_i , a receiver multiplies the sum by C_i

Consider an example

- To keep the example easy to understand, use a chip sequence that is only two bits long and data values that are four bits long.

Sender	Chip Sequence	Data Value
A	1 0	1 0 1 0
B	1 1	0 1 1 0

- The first step consists of converting the binary values into vectors that use -1 to represent 0:

$$C_1 = (1, -1) \quad V_1 = (1, -1, 1, -1) \quad C_2 = (1, 1) \quad V_2 = (-1, 1, 1, -1)$$

Multiplying $C_1 \times V_1$ and $C_2 \times V_2$ produces:

$$((1, -1), (-1, 1), (1, -1), (-1, 1)) \quad ((-1, -1), (1, 1), (1, 1), (-1, -1))$$

- If we think of the resulting values as a sequence of signal strengths to be transmitted at the same time, the resulting signal will be the sum of the two signals

$$\begin{array}{rcccccccc}
 & 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
 + & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 \\
 \hline
 & 0 & -2 & 0 & 2 & 2 & 0 & -2 & 0
 \end{array}$$

- A receiver treats the sequence as a vector
- Receiver 1 computes:

$$(1, -1) \cdot ((0, -2), (0, 2), (2, 0), (-2, 0))$$

to get:

$$((0+2), (0-2), (2+0), (-2+0))$$

- Interpreting the result as a sequence produces: (2 -2 2 -2)
- which becomes the binary value: (1 0 1 0) note that 1010 is the correct value of V_1
- Receiver 2 will extract V_2 from the same transmission

3. Digital Carrier System

- A carrier system is a telecommunications system that transmits information, such as the voice signals of a telephone call and the video signals of television etc.
- Carrier systems typically transmit multiple channels of communication simultaneously over the shared medium.

– A digital carrier system is a communication system that uses digital pulse rather than analog signals to encode information.

– Following are the digital carrier standards:

1. **T-carrier:** T-carrier system is entirely digital, using pulse code modulation (PCM) and time-division multiplexing (TDM).

The system uses four wires and provides duplex capability (two wires for receiving and two for sending at the same time).

T1 lines should be used for critical, high bandwidth applications. T1 lines are best when the sites being connected are close together (otherwise the cost is prohibitive).

2. **E-carrier:** E-carrier (European carrier) A hierarchy of standards for digital transmission, E-carrier is based on the original North America T-carrier digital carrier system, although the specifics are quite different with respect to signalling rates, framing convention, line coding technique, and PCM companding technique (A-law rather than μ -law). In many respects E-carrier is a considerable improvement over T-carrier.

For example, E-1 supports 30 DS-0 payload channels, compared with T1 at 24 channels, and the higher E-carrier levels build on that difference.

E-carrier also supports non-intrusive signalling and control through two channels reserved for such purposes.

As a result, E-carrier supports clear channel communication of a full 64Kbps per DS-0, compared to 56kbps data with T-carrier. The DS-0 (Digital Signal level Zero) is the fundamental building block of E-carrier, as it is with T-carrier and J-carrier, the Japanese version.

Through Time Division Multiplexing (TDM), E-carrier interleaves DS-0 channels at various signalling rates to create the services that comprise the European digital hierarchy.

3. **SONET/SDH:** The synchronous optical network (SONET) is a TDM standard for transmission over optical fibers in the terrestrial United States.

– Synchronous optical network (SONET) is a standard for optical telecommunications transport formulated by the Exchange Carriers Standards Association (ECSA) for the American National Standards Institute (ANSI), which sets industry standards in the U.S. for telecommunications and other industries.

– A similar standard, Synchronous Digital Hierarchy (SDH), is used in Europe by the International Telecommunication Union Telecommunication Standardization Sector (ITU-T). SONET equipment is generally used in North America, and SDH equipment is generally accepted everywhere else in the world.

– Both SONET and SDH are standards for a synchronous, fiber optic transport system. SONET, or synchronous optical network, is the North American standard.

– SDH is the similar standard used in Europe and rest of the world.

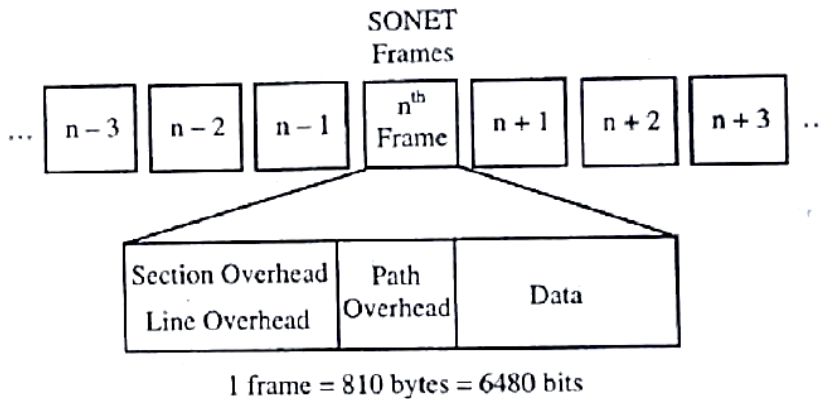
– SONET works at layer 1 (Physical).

– SONET/SDH's strength is in transporting delay-sensitive voice and video, but is also used for high speed data transport.

– SONET incorporates a continuous series of frames.

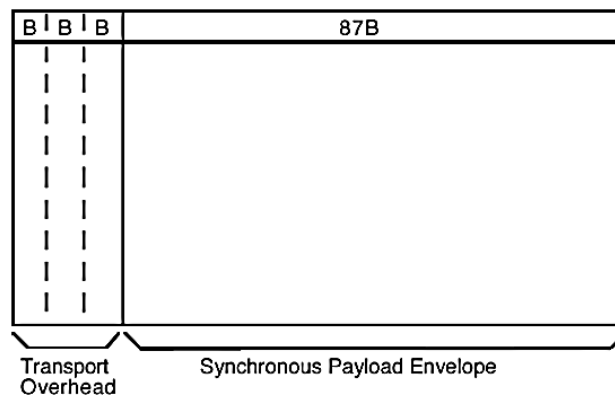
– SONET is used for high-speed data transmission. Telephone companies have traditionally used a lot of SONET but this may be giving way to other high-speed transmission services.

- SONET uses a basic transmission rate of synchronous transport signal-level 1 (STS-1) that is equivalent to 51.84 Mbps.



SONET STS-1 Frame Layout

- The frame format of the STS-1 signal is shown in below Figure.



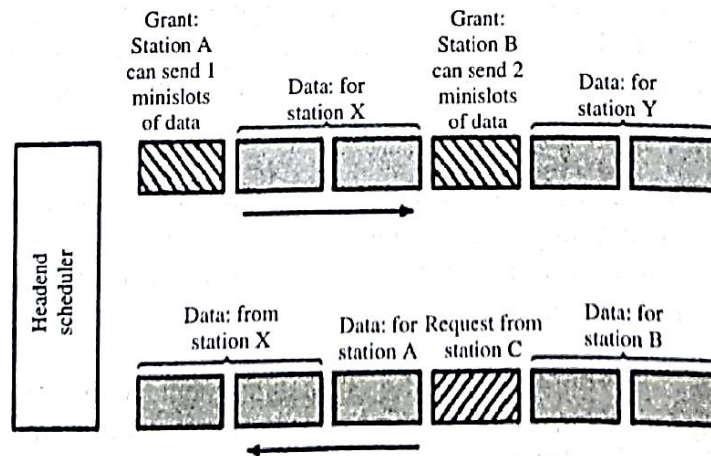
- In general, the frame can be divided into two main areas: transport overhead and the synchronous payload envelope (SPE).
 - Transport overhead is composed of section overhead and line overhead.
 - The main function of the section layer is to properly format the SONET frames, and to convert the electrical signals to optical signals.
 - Line overhead originates or terminates one or more sections of a line signal. The Line-Terminating Equipment (LTE) does the synchronization and multiplexing of information on SONET frames.
 - The synchronous payload envelope can also be divided into two parts: the STS path overhead (POH) and the payload.
 - Path-Terminating Equipment (PTE) interfaces non-SONET equipment to the SONET network. At this layer, the payload is mapped and demapped into the SONET frame.
 - STS-1 is a specific sequence of 810 bytes (6,480 bits), which includes various overhead bytes and an envelope capacity for transporting payloads. It can be depicted as a 90-column by 9-row structure.
 - The order of transmission of bytes is row-by-row from top to bottom and from left to right (most significant bit first).
 - With a frame length of 125 μ s (8,000 frames per second), STS-1 has a bit rate of 51.840 Mbps.
- $(9) \times (90 \text{ bytes/frame}) \times (8 \text{ bits/byte}) \times (8,000 \text{ frames/s}) = 51,840,000 \text{ bps} = 51.840 \text{ Mbps}$

4. Cable Modem


- A cable modem is a peripheral device used to connect to the Internet.
- It operates over coax cable TV lines and provides high-speed Internet access.
- Since cable modems offer an always-on connection and fast data transfer rates, they are considered broadband devices.



- To support data transfer to and from a cable modem, a cable TV provider dedicates two channels, one for transmission in each direction.
- Each channel is shared by a number of subscribers, and so some scheme is needed for allocating capacity on each channel for transmission.
- Typically, a form of statistical TDM is used, as illustrated in figure



- In the downstream direction a cable scheduler delivers data in the form of small packets. Because the channel is shared by a number of subscribers, if more than one subscriber is active, each subscriber gets only a fraction of the downstream capacity.
- An individual cable modem subscriber may experience access speeds from 500 kbps to 1.5 Mbps or more, depending on the network architecture and traffic load.
- When a subscriber has data to transmit, it must first request time slots on the shared upstream channel.
- Each subscriber is given dedicated time slots for this request purpose.
- The headend scheduler responds to a request packet by sending back an assignment of future time slots to be used by this subscriber.
- Thus a number of subscribers can share the same upstream channel without conflict.

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1. What is CDMA? Explain.
 2. Explain Space Division Multiplexing.
 3. Differentiate between Synchronous TDM and Statistical TDM. Why is a statistical time division multiplexer more efficient than a synchronous time division multiplexer?
 4. Explain frequency division multiplexing. How is interference avoided by using FDM?
 5. Discuss Synchronous Optical Network (SONET).
 6. What are the advantages of using multiplexing in data communication? How does a synchronised time division multiplexer stay synchronized with de-multiplexer on receiving end?
 7. What type of multiplexing is preferred in optical fibre communication? Justify your answer
 8. Explain the modulation technique used in Asymmetric Digital Subscriber Line (ADSL) and cable modems
 9. With suitable example explain the working principle of Code division multiplexing for CDMA technology.
 10. Explain the frame format of Synchronous Optical Network (SONET) for the version SDH.
 11. How Time division Multiplexing (TDM) handle disparity in the input data rate, if data rate of all input lines are not same?
 12. Which of the multiplexing technique is suitable for fiber-optics links? Explain with reasoning.
 13. How upstream and downstream data transfer is done in cable modem.
 14. Explain the process of statistical time division multiplexing.
 15. Explain the necessity of pulse stuffing in synchronous time division multiplexing.
 16. Explain how Statistical TDM utilizes channel bandwidth better than Synchronous TDM.
 17. How interference is avoided in frequency division multiplexing? Explain with suitable figures.
 18. Explain SONET/SDH frame format.
 19. Explain Frequency Division Multiplexing process.
 20. Discuss Digital Carrier Systems.
 21. Discuss wave length division multiplexing