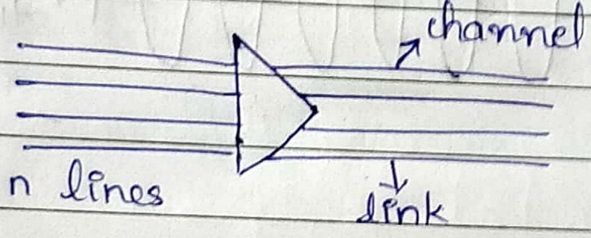
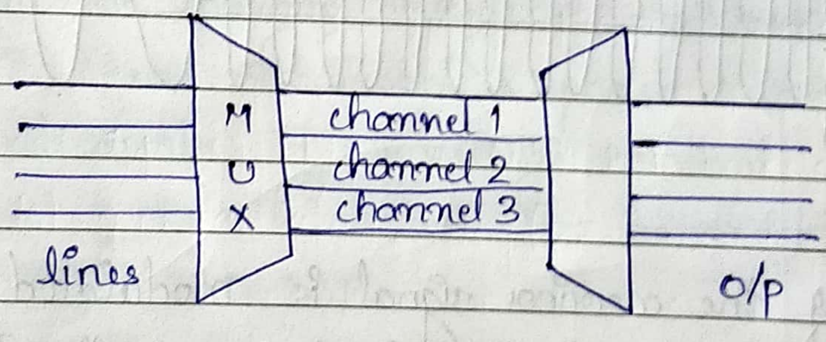
MODULE - 1

Multiplexing

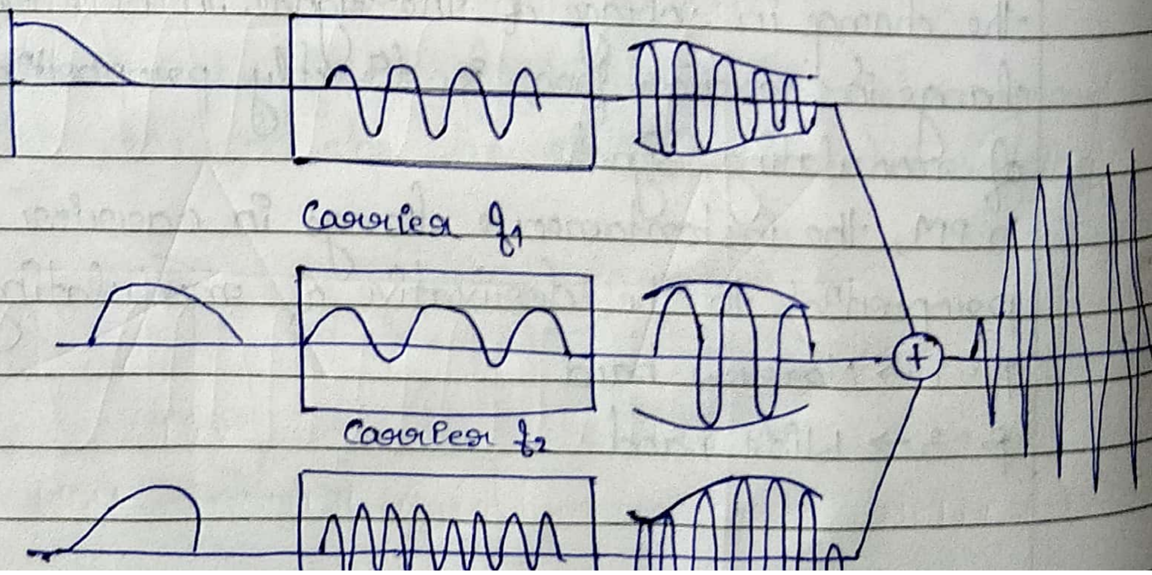
- FDM (Freq.)
- TDM (Time-period)
- WDM (Wavelength)



(i) Freq. Division Multiplexing (FDM)



Note:- Bandwidth of the channel must be greater than that of i/p signals.



$f_1 \neq f_2 \neq f_3 \rightarrow$ to avoid noise & interference with channels/links in the band.

Freq. of guard bands $\neq f_1 \neq f_2 \neq f_3$ (10 kHz)

FDM is an analog technique where the bandwidth of a link is greater than the combined bandwidth of the signals to be transmitted. In FDM, the signals generated by each sending device modulate different carrier frequencies which is then combined into a single composite signal. The carrier frequencies are separated by bandwidth to accomodate the modulated signals. The channels are separated by strips of unused bandwidths called as guard bands which prevent signals from overlapping. The guard bands must not interfere with original data frequencies. The demultiplexing process uses series of filters to decompose multiplexing signals into its components.

Q) 5 channels each with a bandwidth of 100kHz are to be multiplexed together. What is the min. bandwidth if there is a guard band of 10 kHz btw channels to prevent interference?

ans. Min bandwidth, $B_{min} = 100 \times 10^3 \times 5 + \underbrace{(4)}_{(5-1) \text{ guard bands}} \times 10 \times 10^3 = \underline{\underline{540 kHz}}$

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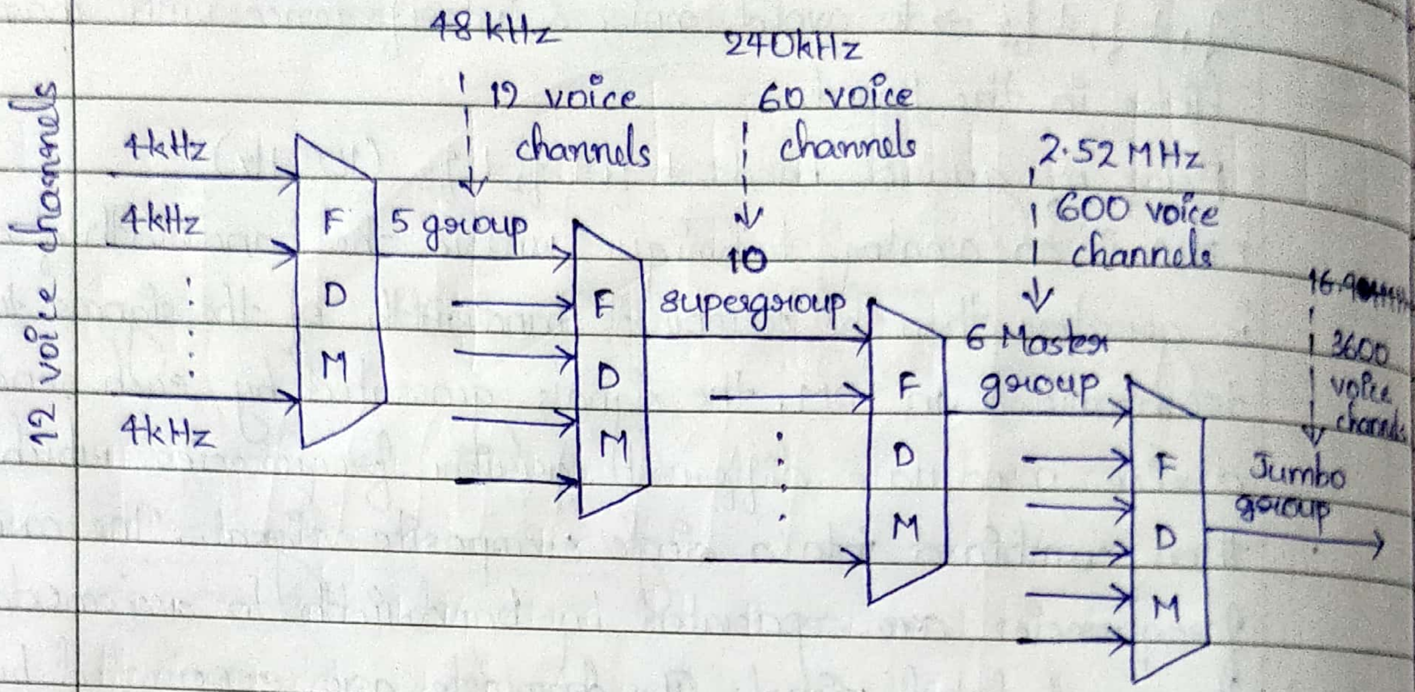
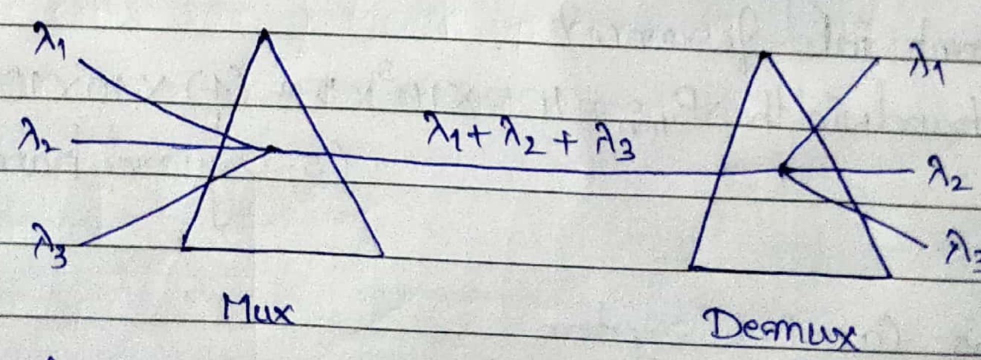
Analog Carrier System



Analog carrier system is implemented in traditional telephone companies to mux signals from lower b/w lines to higher b/w lines.

Other apps of FDM are AM & FM broadcasting. Another app is 1st gen. cellular telephones

(ii) Wavelength Division Multiplexing (WDM)



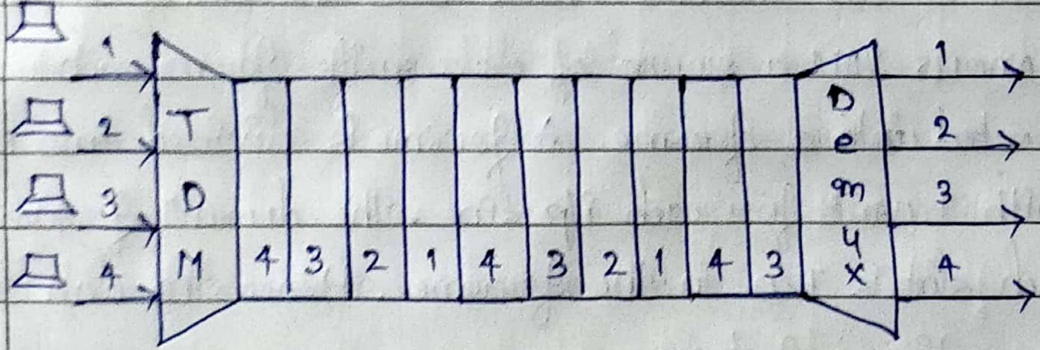
App of WDM → SONET (Synchronous Optical NETwork)

It is an analog mux technique. It uses high data rate based on the capacity of optical fibre cable. It combines the optical signals of different frequencies & the freq range is very high. The basic idea of WDM is to combine multiple light sources into 1 single light at the mux & do the reverse at demux. The combining & splitting of light sources are handled by a prism based on the angle of incidence & freq.

Apps → SONET

A new method called Dense WDM (DWDM) can multiplex a very large no. of channels by spacing the channels very close to each other.

(iii) Time Division Multiplexing (TDM)



TDM is a digital process that allows several connect's to share the high bandwidth of a link. It combines several low rate channels into high rate one. There are 2 types:

(a) Synchronous TDM
(b) Statistical TDM

Synchronous TDM

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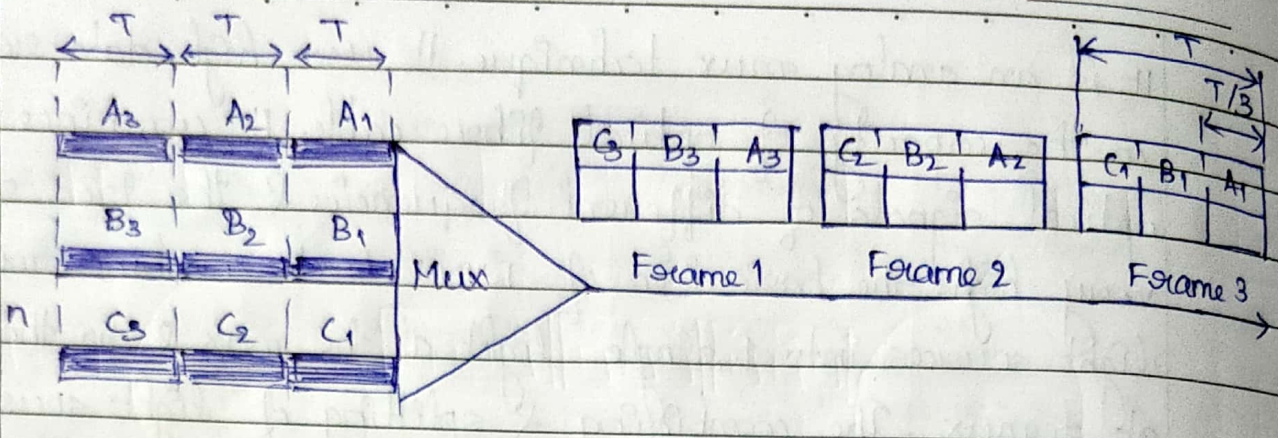


Synchronous TDM has an allotment in the o/p even if it is not sending data. The data flow of each i/p connectⁿ is divided into 1 i/p time slot. It can be 1 bit, 1 character or 1 block of data. Each i/p unit occupies 1 o/p time slot. But the duratⁿ of an o/p time slot is n times shorter than the duratⁿ of i/p time slot i.e. if i/p time slot is T seconds then the o/p time slot is T/n seconds where n is the no. of connectⁿs. In synchronous TDM a round of data units from each i/p connectⁿ is collected into a frame. A frame is divided into n time slots with 1 unit for each i/p line. The duratⁿ of each frame is T & each slot is T/n in the frame. Hence the data rate of the link is n times faster.

① The data rate for each i/p connectⁿ is 1kbps : if 1 bit at a time is multiplexed, what is the duratⁿ of

ⓐ Each i/p slot

ⓑ Each o/p slot

ⓒ Each frame

ans. Data rate = 1kbps = 1000 bps

Bit duratⁿ = 1/Data rate

For each i/p slot = $\frac{1}{1000}$ = $\underline{1ms}$

For each o/p slot = $\frac{1}{3000}$ = $\underline{0.33ms}$

For each frame = $\frac{1}{1000}$ = $\underline{1 ms}$

② 4 1 kbps connectn's are multiplexed together. A unit is 1 bit
Find:

ⓐ Duratn of 1 bit before multiplexing
ⓑ The txm rate of the link
ⓒ The duratn of a time slot
ⓓ The duratn of a frame.

ans $n = 4$

Data rate = 1 kbps = 1000bps

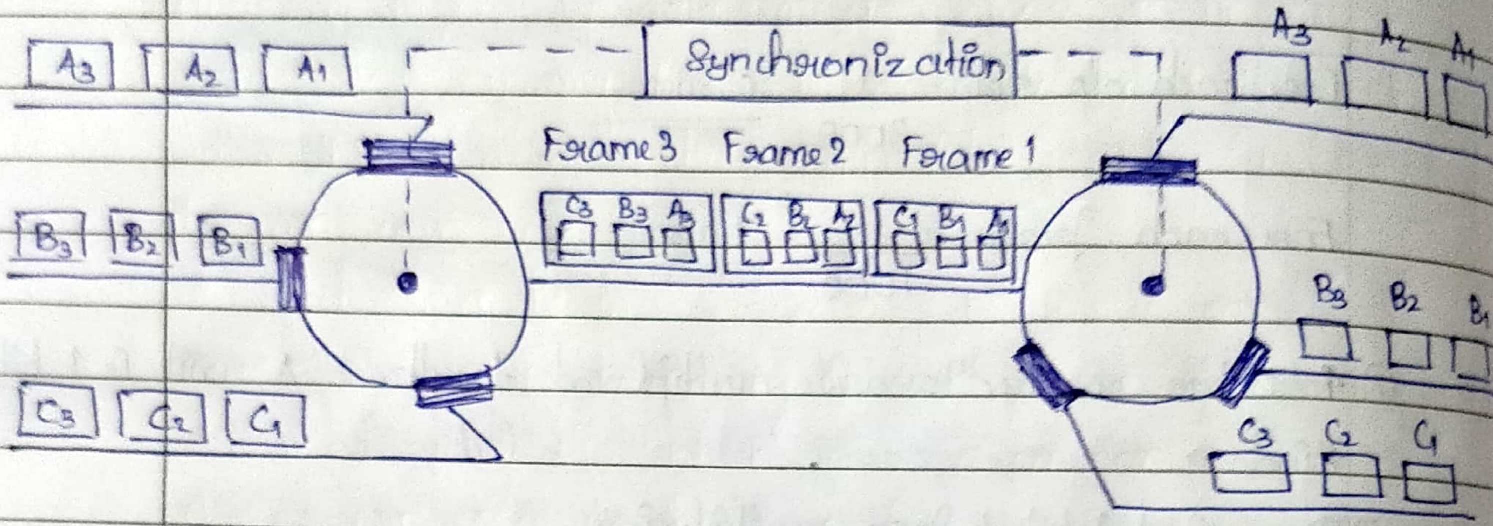
(a) Duratn of 1 bit before multiplexing = $\frac{1}{1000}$ = $\underline{1 ms}$

(b) txm rate of link = 4 X 1kbps = $\underline{4 kbps}$

(c) Duratn of time slot = $\frac{1}{4000}$ = ~~1ms~~ $\underline{0.25 ms}$

(d) Duratn of frame = $\frac{1}{1000}$ = $\underline{1 ms}$

Interleaving

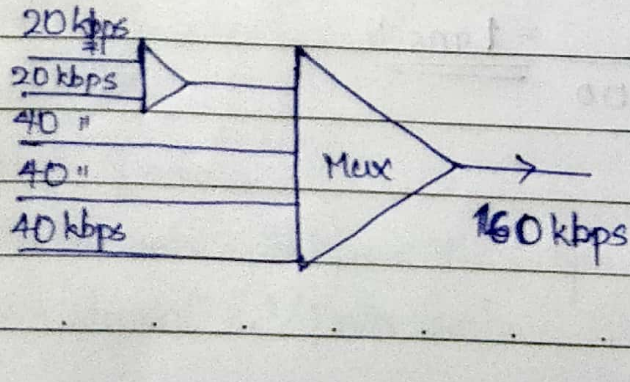


TDM has 2 fast-rotating switches on the multiplexing & demultiplexing side, which are synchronized & rotated at same speed, but in opp. directⁿ. On the multiplexing side, the switch opens to a connectⁿ that sends a unit onto the path. This process is called interleaving. On the demultiplexing side, the connectⁿ receives a unit from the path.

Disadvantage → The synchronous data is not that efficient because if the source does not have data in the i/p slot, the corresponding slot in the o/p frame is empty.

Data Rate Management

(i) Multilevel Mux



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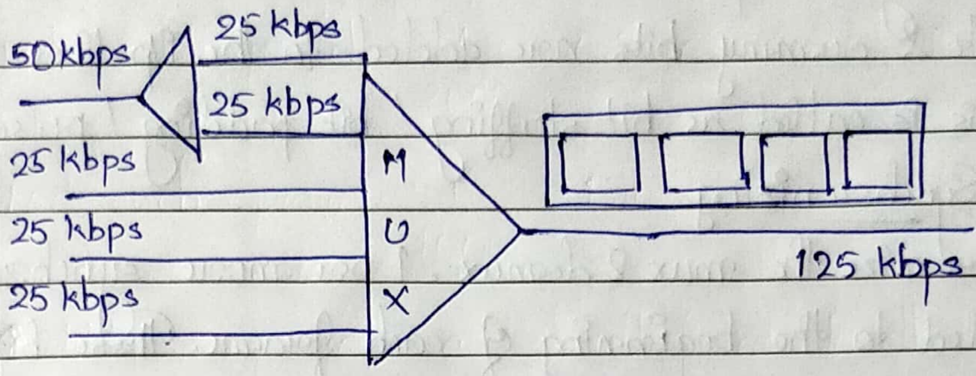
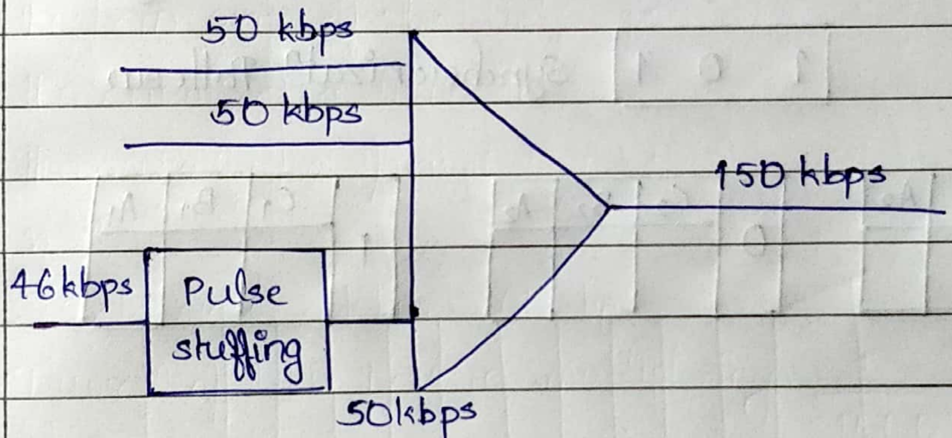
(ii) Multiple Slot Mux



(iii) Pulse Stuffing



~~Data r~~. To handle disparity in the i/p data rate, 3 strategies are used:

(i) Multilevel Multiplexing

It is used when the data rate of an i/p line is a multiple of others. Any 2 i/p lines can be multiplexed together to ~~pro~~ provide a data rate equal to others.

(ii) Multiple Slot Allocatⁿ

Here, more than 1 slot is assigned in a frame for a single i/p line. A demux is used in the line to make 2 i/ps out of 1.

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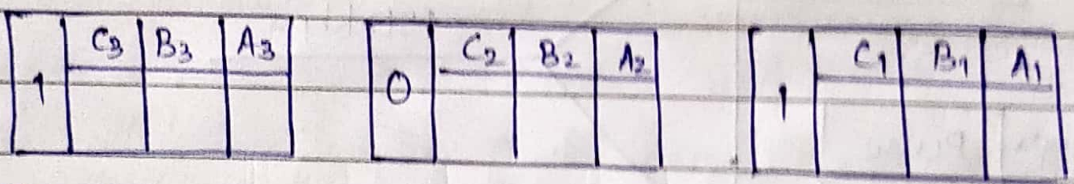
(iii) Pulse Stuffing

Here, the highest i/p data rate is selected as the dominant data rate & dummy bits are added to the i/p lines with lower rates. This is called as bit stuffing / bit padding / pulse stuffing.

Frame Synchronizing

To synchronize the mux & demux, 1 or more synchronizatn bits are added to the beginning of each frame. These bits are called framing bits, which follow a pattern so that the demux can separate the time slots accurately.

| 1 | 0 | 1 | Synchronizatn Pattern



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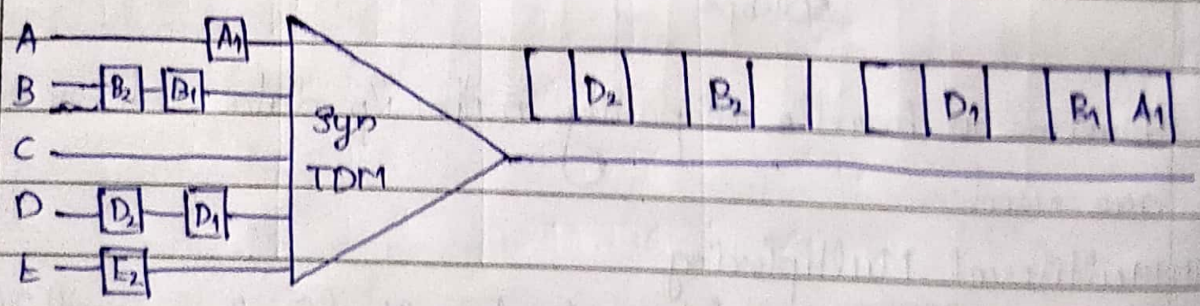
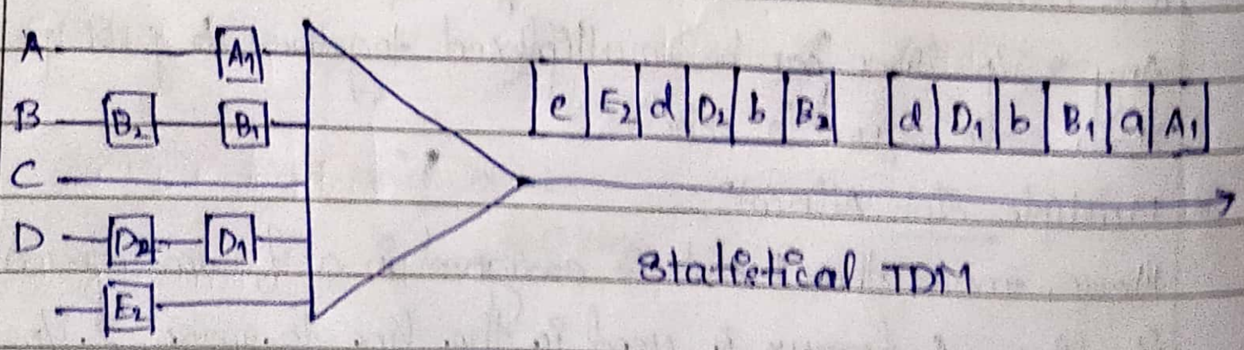
Statistical TDM





$n = \log_2 N$

$N \rightarrow$ No. of lines

The disadvantage of synchronous TDM is that many time slots are wasted. In statistical TDM, the time slots are allocated dynamically on demand. Each I/O line has a buffer associated with it. The i/p buffers are scanned when data is collected until frames are filled & sent. Statistical TDM supports more devices & doesn't send empty slots. The no. of slots in each frame is less than the no. of i/p lines.

Addressing

The slots need to carry data as well as the address of the destination. The address can be given by n bits to define N different o/p lines with $n = \log_2 N$.

Slot Size

In statistical TDM a block of data is usually many bytes while the addr. is just a few bytes. The ratio of the data size to the addr size must be reasonable to make txm efficient. There is no synchronizatn bit. Bandwidth, the capacity of the link is less than ~~same~~ sum of the capacities of each channel

Statistical TDM Frame Format

Flag	Addr	Control	Statistical TDM subframe	FCS	Flag

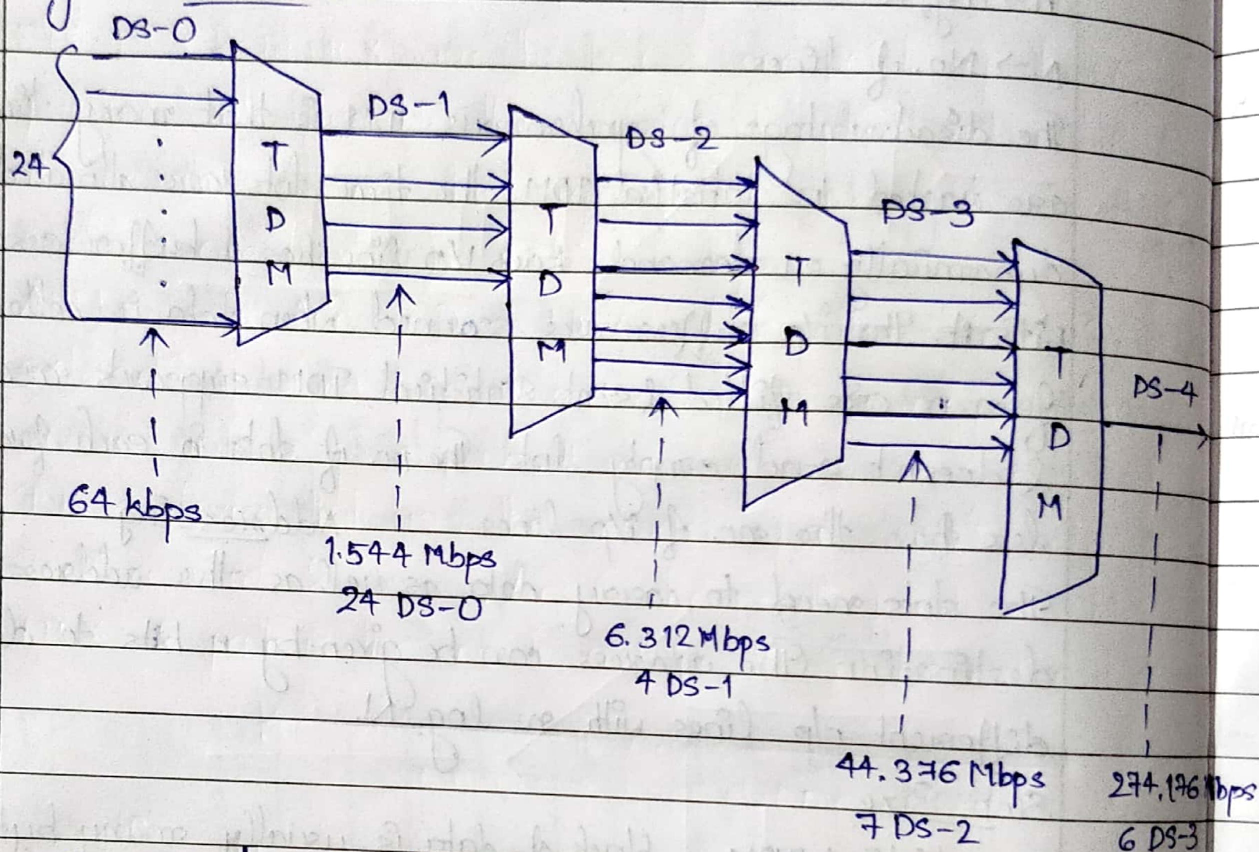
Subframe

Addr.	Data

Subframe with Multiple ~~[illegible]~~ Frames

Addr	Length	Data	...	Addr	Length	Data

Synchronous TDM



Service	Line	Rate	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.37	96
DS-3	T-3	44.376	672
DS-4	T-4	274.176	4032

5/11/19 E-lines → European version of T-Lines

SONET / Synchronous Digital Hierarchy (SDH) Sync. Optical Network

SONET Devices

T → Terminal R → Regenerator

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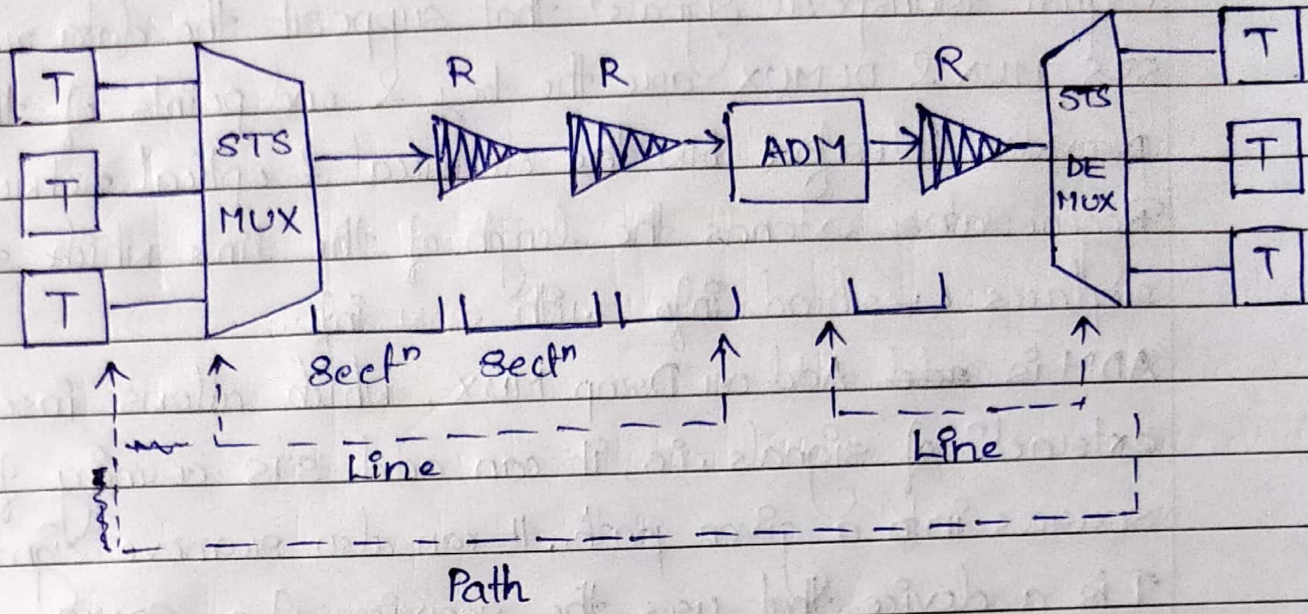
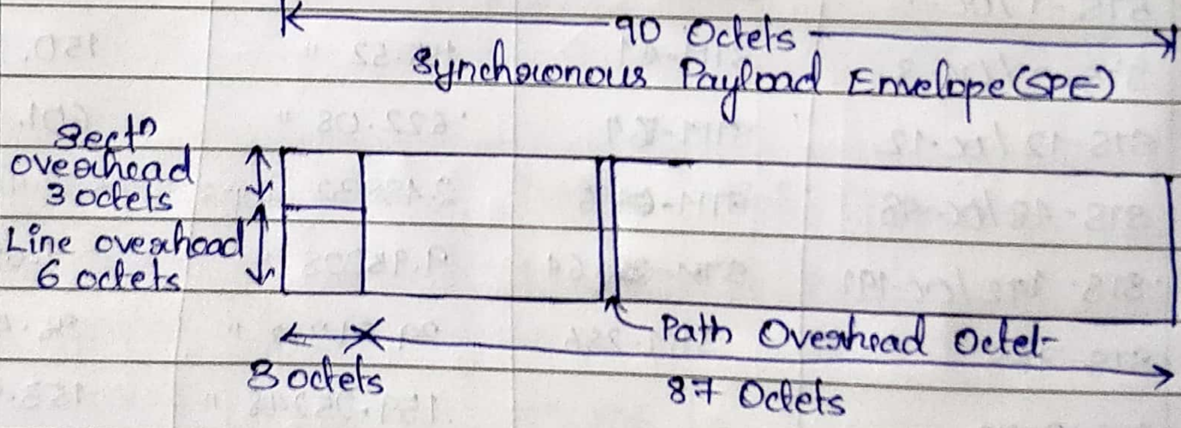


SONET Designat^n	ITU-T Designat^n	Data Rate	Payload Rate (Mbps)
STS-1/OC-1	~~STM~~	51.84 Mbps	50.112
STS-3/OC-3	STM-1	155.52 "	150.336
STS-12/OC-12	STM-4	622.08 "	601.344
STS-48/OC-48	STM-16	2.48832 Gbps	2.405
STS-192/OC-192	STM-64	9.95328 "	9.621
STS-768	STM-256	39.81312 "	38.48
STS-3072		159.25248 "	153.944 Gbps

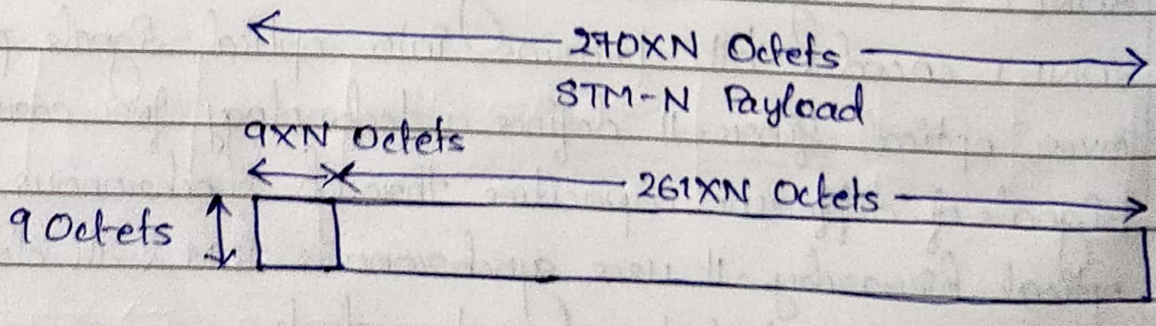
SONET is a digital carrier system & is the ANSI standard. SONET encodes bit streams into optical signals propagated over optical fibre. It defines a technology for carrying any signals of different capacities through synchronous, flexible optical hierarchy. It uses synchronous TDM & all clocks in the system are locked to a master clock.

SONET defines hierarchy of electrical signalling levels i.e. STS.

(Synch. Transport Signals) that support the data rate.
STS MUX & DEMUX are the beg & end points of the link which provides interface btw the electrical & optical network.
Regenerator extends the length of the link which repeats & replaces overhead info with new info.
ADM is ~~add~~ Add or Drop MUX, which allows insertⁿ & extractⁿ of signals, i.e., it can add STS coming from different sources into a given path. It can also remove signals.
T is a device that uses the services of a SONET network.
Sectⁿ connects 2 devices. Line is the portⁿ of network btw 2 MUX's & path is the end-to-end portⁿ of the network.



STS-1 Frame Format



STM-N Frame Format

Section				Path
Sect^n Overhead	Framing A1	Framing A2	tore/growth J0/Z0	Path Trace J1
	BIP-8 B1	Orderwire E1	User F1	BIP-8 B3
	DataCom D1	DataCom D2	DataCom D3	Signal Label-C2
Line Overhead	Pointer H1	Pointer H2	Pointer Act^n H_3	Path Status G1
	BIP-8 B2	APS K1	APS K2	User F2
	DataCom D4	DataCom D5	DataCom D6	Multiframe H4
	DataCom D7	DataCom D8	DataCom D9	Growth Z3
	DataCom D10	DataCom D11	DataCom D12	Growth Z4
	Status S1/Z1	Error M10/M1	Orderwire E2	Growth Z5

BIP-8 → Bit-Interlinking Parity-8

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- A1 → Framing/alignment bit which gives the bit pattern for synchronizat^n
- B1 → Bit interleaved parity which provides even parity for error checking.
- J0/Z0 → Verify the connect^{n}s by transmitting a 16-byte message.

- E1 → Order wire bytes which uses PCM for communicatⁿ b/w regenerators & terminals
- F1 → User bytes
- D1 - D3 → Data communicatⁿ channel for alarms control & administratⁿ
- Line overhead → H1 - H3
→ Pointer bytes for frame & freq. alignment
- B2 → Interleaving for error monitoring
- K1, K2 → Automatic protectⁿ for switching equipment
- D4 - D12 → 576 kbps data communicatⁿ for alarms & administratⁿ.
- S1/Z1 → Transporting synchronizatⁿ messages
- M0/M1 → Remote error indicatⁿ
- E2 → PCM orderwire at line 11
- Path overhead → J1 used to verify integrity of a path
- B3 → Bit interleaved parity
- C2 → STS path signals
- G1 → Status bytes for path terminating equipment
- F2 → Path user
- H4 → Multiframe indicator
- Z3 - Z5 → Future use

① Find the data rate of ~~an~~ STS-1 signals

ans STS signals send 8000 frames per second

$\underbrace{9 \times 1 \times 90}$ octets bytes

Data rate = $8000 \times [9 \times 1 \times 90] \times 8 = 5.184$ Mbps

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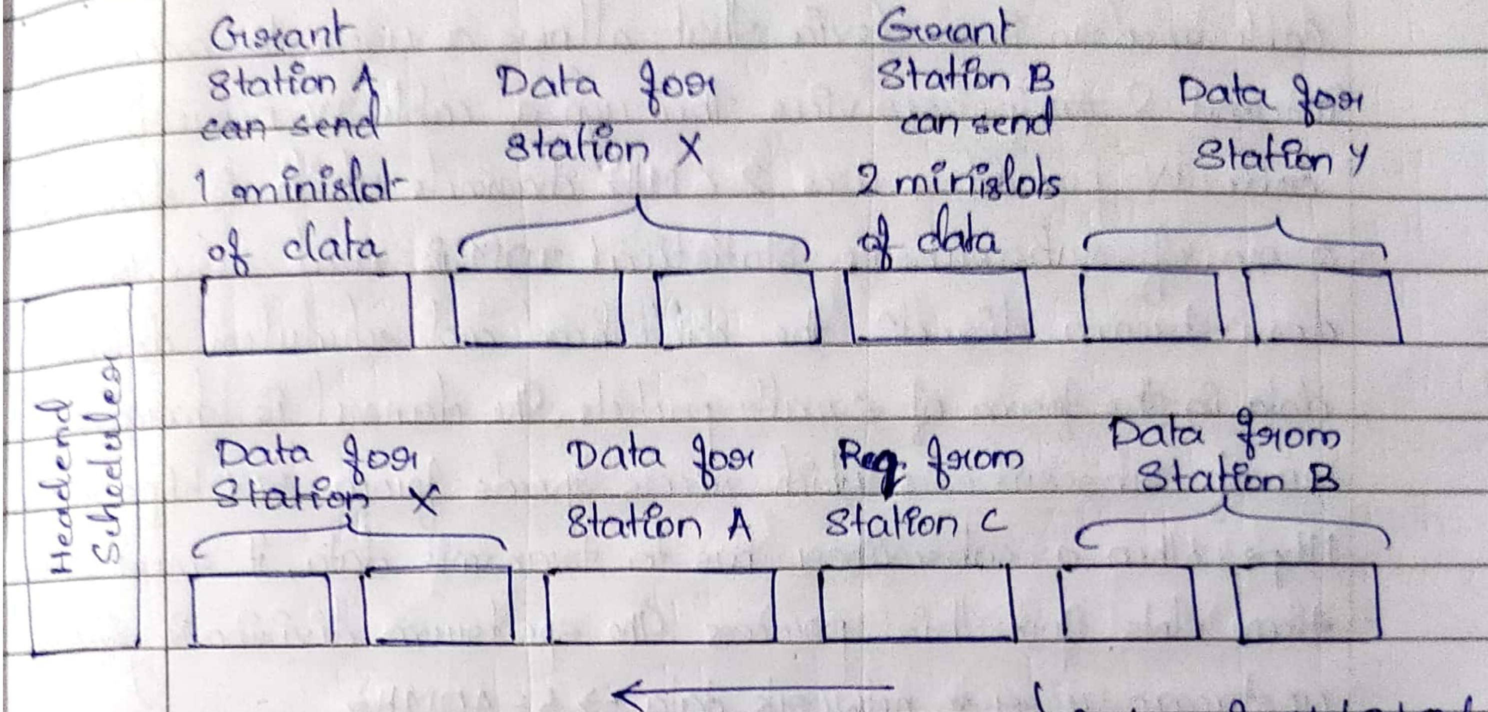
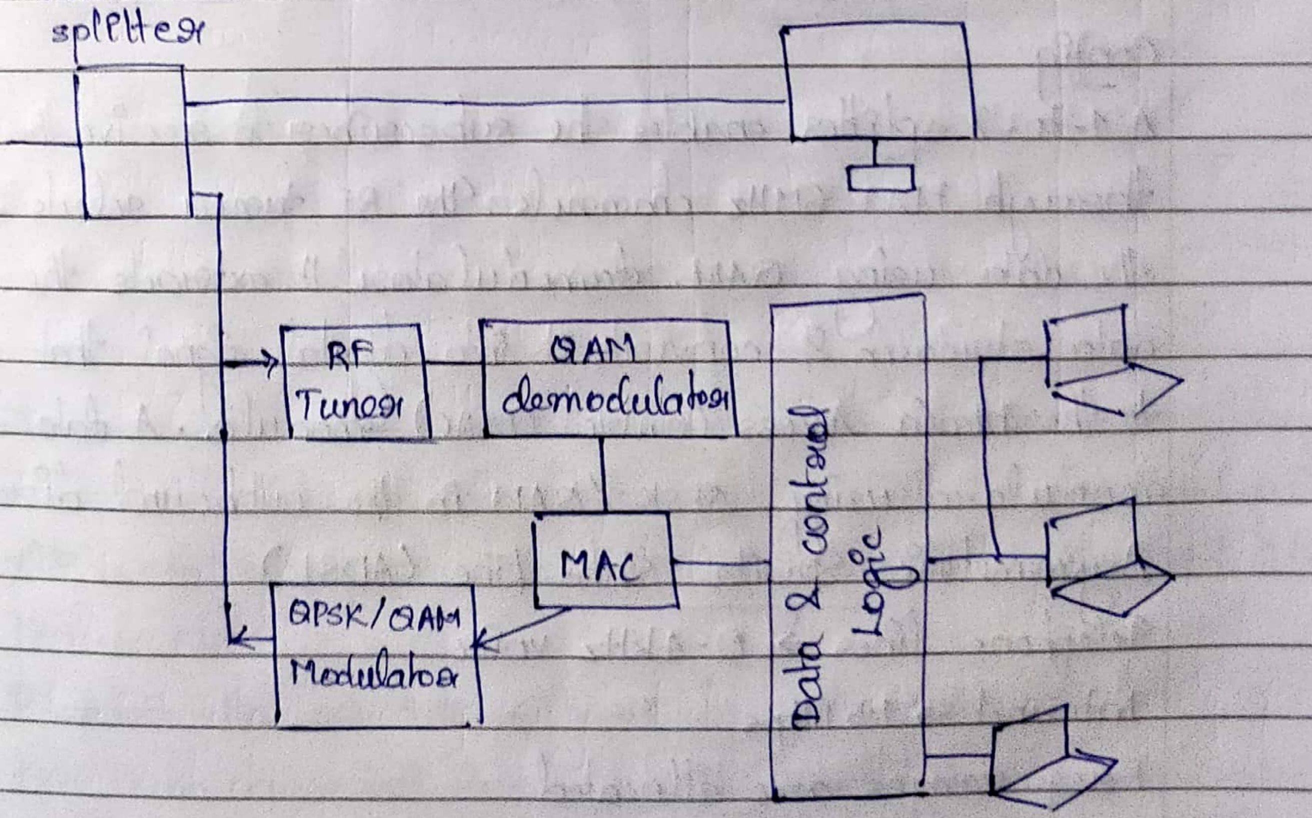
Cable Modem



Speed upto 1.5 Mbps

↳ App of statistical TDM

Configuratn



Cable modem is a device that allows a user to access the internet & online services through a cable TV network. A cable TV provider uses 2 6 MHz channels which is shared by a no. of subscribers. Statistical TDM is used here. In downstream direct^n, the cable head end scheduler delivers data in the form of small packets. The channel is shared by no. of subscribers which access speeds from 500 kbps to 1.5 Mbps. When a subscriber has to transmit data, it must request time slots for this process. The spectrum division is given as

upstream user to network data → 5–40 MHz

downstream TV " " " → 50–550 MHz

Network to user data (downstream) → 550–750 MHz

Config

A 1-to-2 splitter enables the subscriber to receive the TV service through FDM 6MHz channels. The RF tuner selects & demodulates the data using QAM. demodulator. It extracts the encoded data stream & converts it into digital signal that passes it to the Media Access Control (MAC) module. A data stream is modulated using QPSK / QAM in the outbound direct^n.

Asymmetric Digital Subs. Line (ADSL)

Telephone lines → 0–4 kHz voice

Internet → 1.5 Mbps

Freq. ranges are allocated

POTS → Plane Old Telephone Service

Range → 5.5 km

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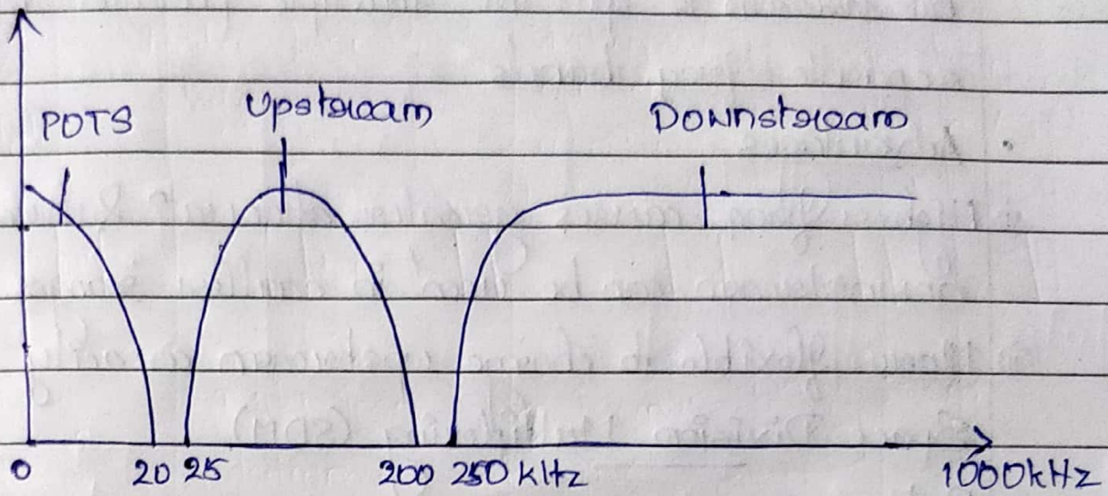
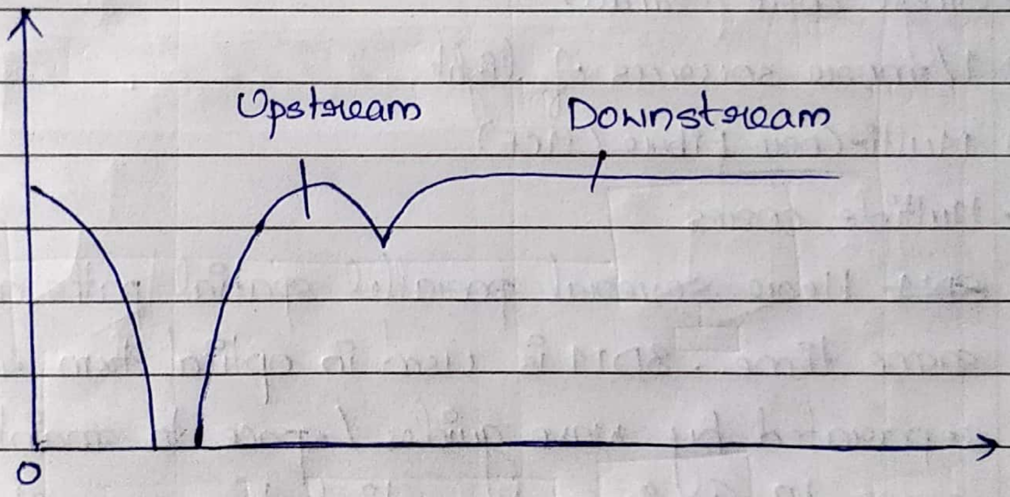


Echo Cancellatⁿ



ADSL provides high-speed digital data txm over ordinary telephone lines. It exploits the installed ~~space~~ base of twisted-pair links to telephone network with capacity > 1MHz bandwidth. It uses FDM.

(i) Reserve lowest 20kHz for voice called POTS

(ii) Use echo cancellatⁿ to allocate larger upstream & downstream bands

(iii) Uses FDM within upstream & downstream bands i.e a single bit stream is split into multiple parallel bit streams with separate freq. bands

- Advantages

(i) Higher freq. causes greater attenuatⁿ & hence more of downstream can be used in earlier ranges.

(ii) More flexible to change upstream capacity

Space Division Multiplexing (SDM)

2 types:

(i) Few Mode Fibres (FMF)

- Single core (small)
- 1/more sources of light

(ii) Multi-Core Fibre (MCF)

- Multiple cores

~~SDM~~ Here several parallel spatial paths are used at the same time. SDM is used in optical txm media that are separated by wave guides / space to maintain the channel separatⁿ. To increase optical txm capacity over a fixed bandwidth,

(i) Modulatⁿ using different amplitude levels

(ii) Polarizatⁿ

(iii) Freq

There are 2 strategies:

(i) Few Mode Fibre (FMF)

(ii) Multi Core Fibre (MCF)

FMF

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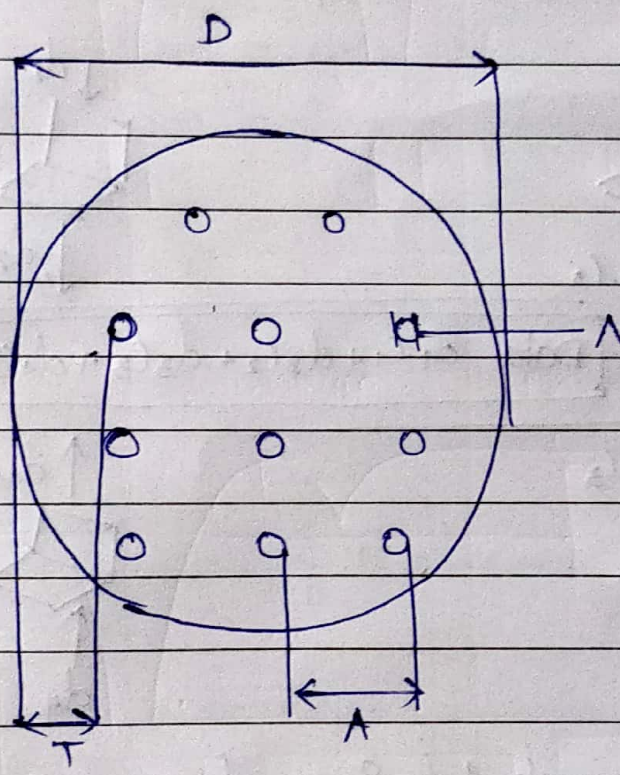
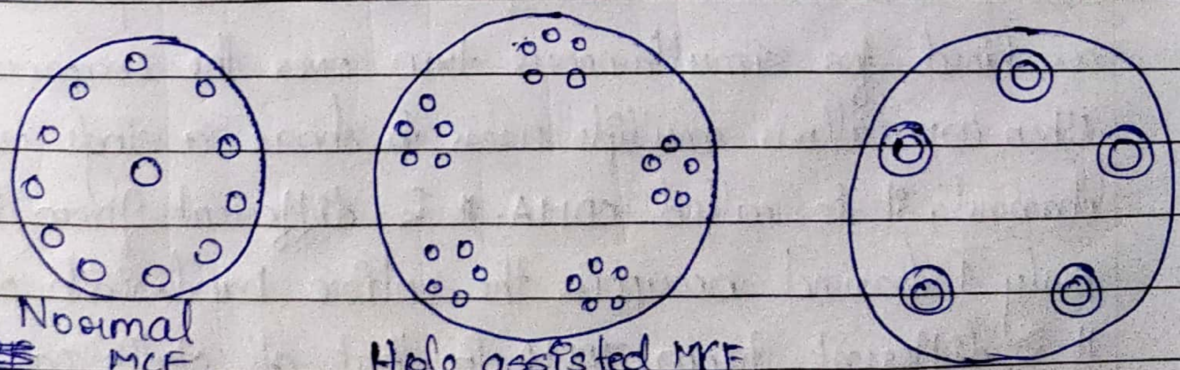
The size & refractive index of a single fibre is made such that several propagatⁿ modes are supported. through
(a) core is larger
(b) Through large numerical aperture
(c) The mode acts as individual communicatⁿ channel.



Λ → Core to core distance
D → Cladding diameter
A → Refractive index diff b/w core
T → Outer cladding thickness

MCF



Normal MCF

Hole assisted MCF

Trench filled MCF

The Multi core arrangement creates cross talk suppression & core density improvement.

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Advantages
It gives better utilizatⁿ of optical fibres
Disadvantage
(i) There is inter-core crosstalk & compatibility problem
(ii) Costly equipment

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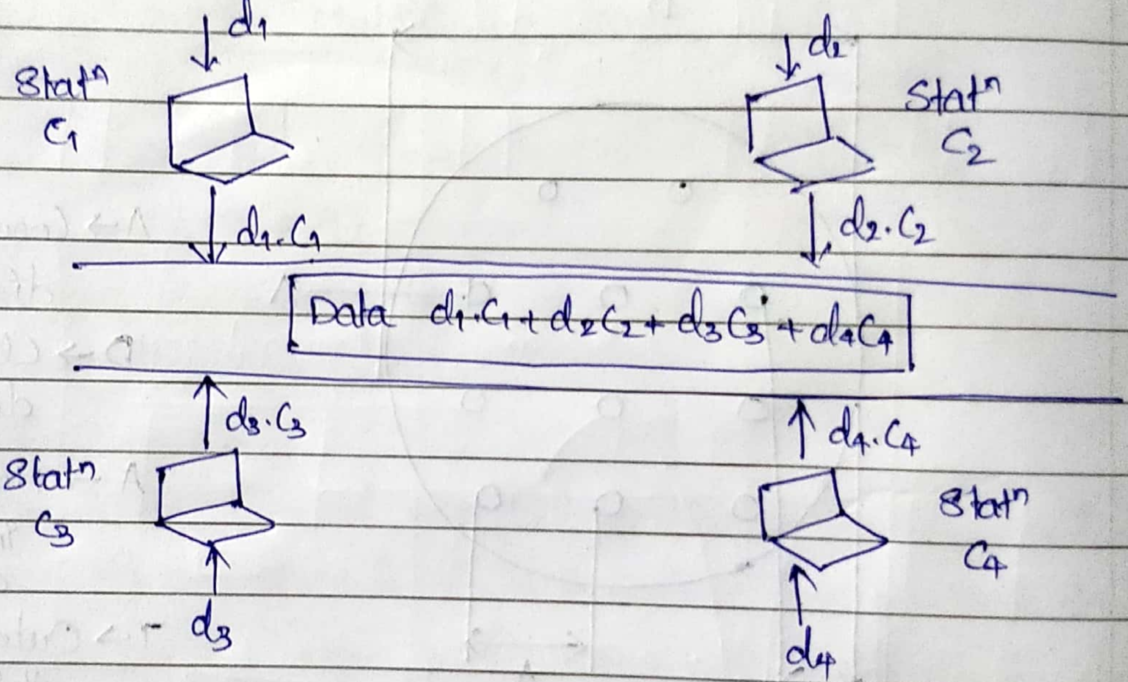
CDMA (Code Division Multiple Access)



CDMA is a network technique where multiple data signals are combined for simultaneous txm over the common freq band. When CDM allows multiple users to share a single communicatⁿ channel, it is called CDMA. It is different from FDM in that only 1 channel occupies the entire bandwidth of the link. It is different from TDMA in that all statⁿs can send data simultaneously. In CDMA, each user is given a unique code sequence, assuming we have 4 statⁿs; 1, 2, 3 & 4 with data d_1, d_2, d_3 & d_4. There are 2 properties.

(i) If we multiply each code by another, we get 0.
(ii) If we multiply each code by itself, we get 4 i.e. the no. of stat^{n}s

The data that go on the channel are sum of all the terms. Any stat^n that wants to receive data from one of the other, multiplies the data on the channel by the code of the sender
Each stat^n is assigned a code which is a sequence of no.s called as chips, which is an orthogonal sequence

eg: C_1 [+1 +1 +1 +1]
C_2 [+1 −1 +1 −1]
C_3 [+1 +1 −1 −1]
C_4 [+1 −1 −1 +1]

Properties
(i) Each sequence is made of N elements where N is the no. of stat^{n}s
(ii) If we multiply a sequence by a no., we get scalar multiplicat^n
(iii) If we multiply 2 equal sequences, & add the results, we get N where N is the no. of elements called as inner product of equal sequences.
(iv) If we multiply 2 different sequences & add the results, we get 0.
(v) Adding 2 sequences results in another sequence

Data
Bit 0 → −1   Bit 1 → +1   Silent → 0

To create a chip sequence, we use Walsh table

$W_1 = [+1]$

$$W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & \bar{W}_N \end{bmatrix}$$

$$W_2 = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix}$$

$$W_4 = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 \\ +1 & -1 & -1 & +1 \end{bmatrix}$$