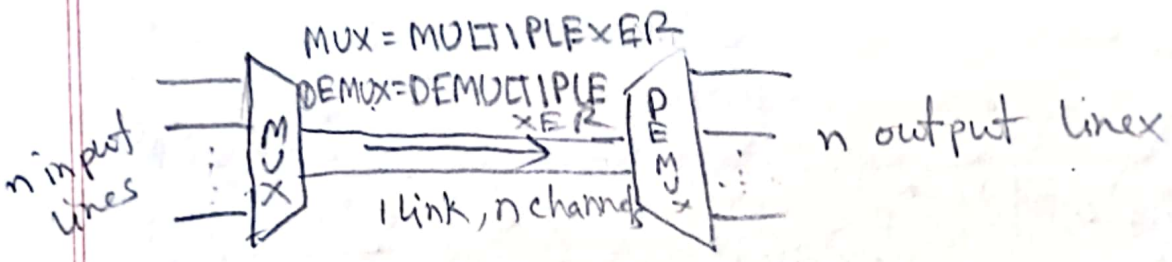
Chapter-6

Bandwith Utilization

#Multiplexing

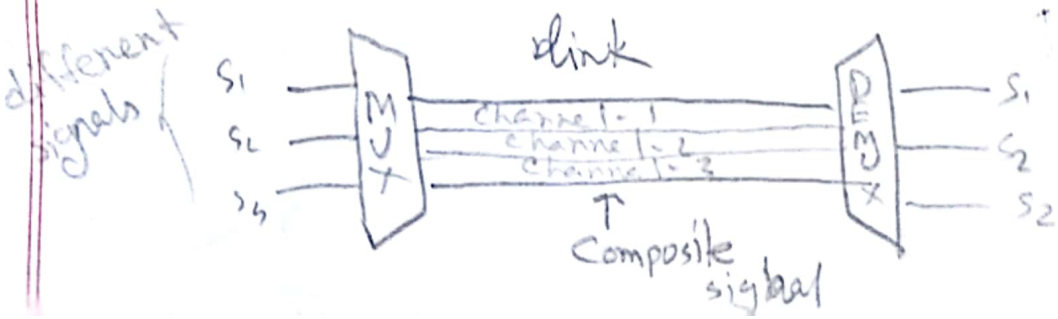
Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. As data and telecommunications use increases, so does traffic.



Multiplexing
- → Frequency-division Multiplexing (FDM) — Analog
- → Wavelength-division Multiplexing (WDM) — Analog
- → Time-division Multiplexing (TDM) — Digital

#FDM

→ Analog multiplexing technique that combines analog signals.



(i) An analog ~~tone~~ technique that can be applied when the bandwith of a link (in hertz) is greater than the combined bandwiths of the signals to be transmitted.

(ii) Signals generated by each sending device modulate different carrier frequencies

(iii) These modulated signals are then combined into a single composite signal

Modulating Signal → Original signal

Carrier frequency → Applying a certain frequency

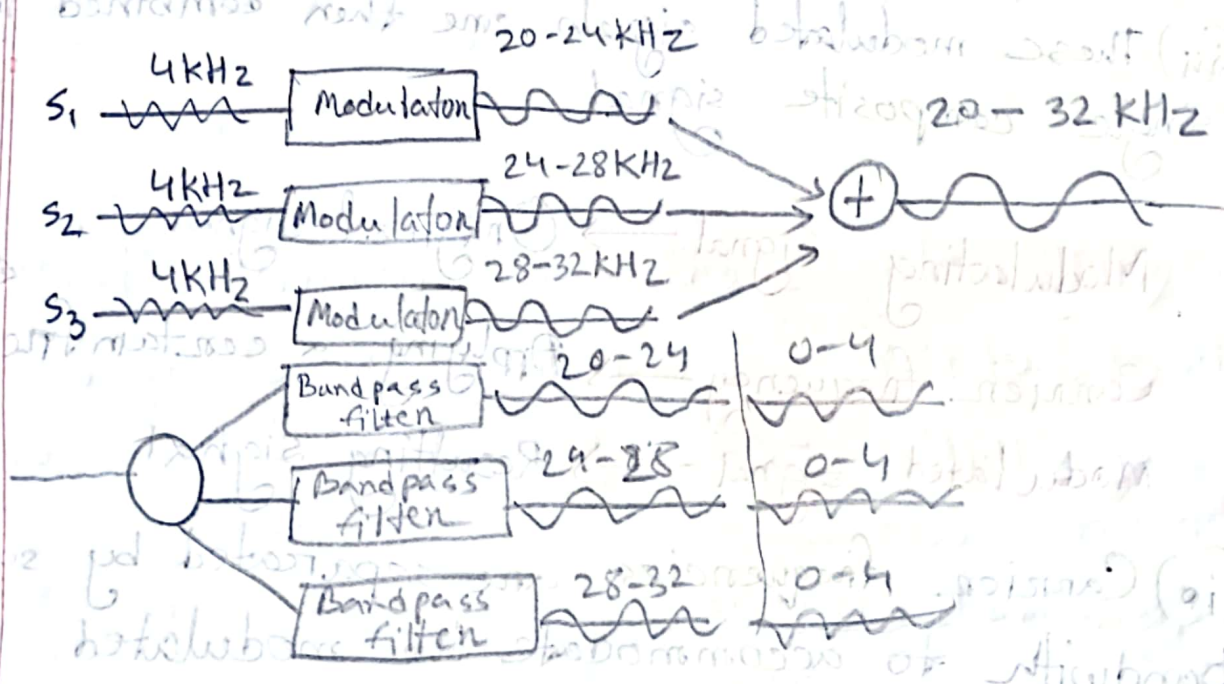
Modulated Signal → Resulting signal

(i) Carrier frequencies are separated by sufficient bandwith to accommodate the modulated.

(ii) These bandwith ranges are the channels through which the various signals travel

(iii) Channels can be separated by strips of unused bandwith - guard bands - to prevent signals from overlapping.

Assume that a voice channel occupies a bandwith of 4 KHz. We need to combine three voice channels into a link with a bandwith of 12 KHz, from 20-32 KHz. Show the configuration, using the frequency domain, Assume there are no guard bands.



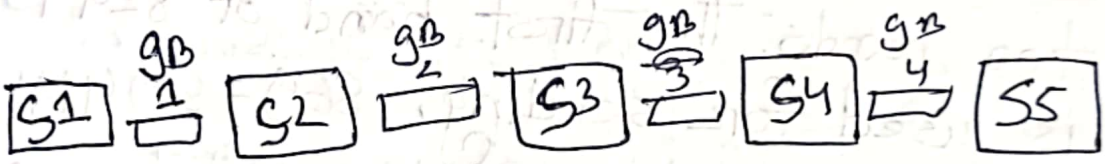
5 channels, each with a 100-kHz bandwith, are to be multiplexed together. What is the minimum bandwith of the link if there is a need for a guard band of 10 KHz between the channels to prevent interference.

Here, Channel number = 5 ; bandwith = 100 [each containing]

So the Composite Signal = 5×100 = 500 KHz

We know Guard-band is placed between 2 signal

So, total no. of guard band will be.

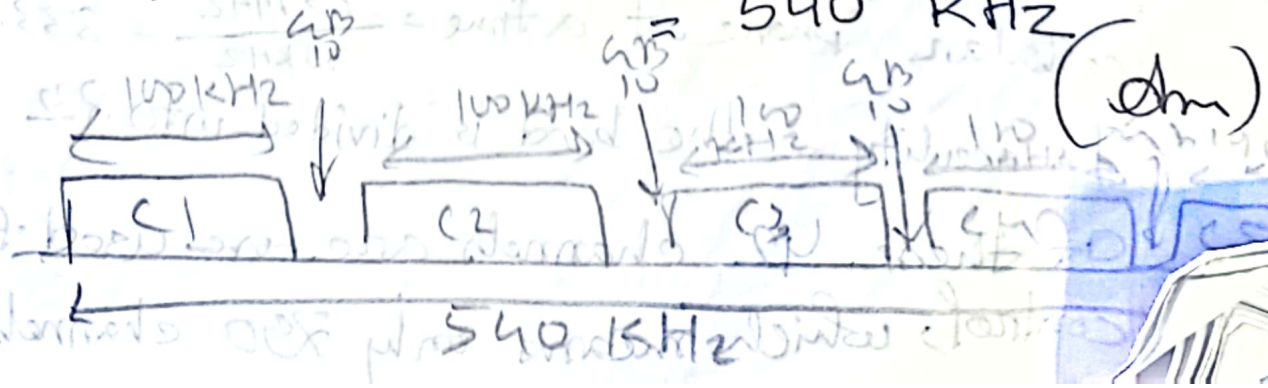


So, The bandwith of each guard band is 10KHz

So, the composite guard band = 10×4 KHz
= 40 KHz

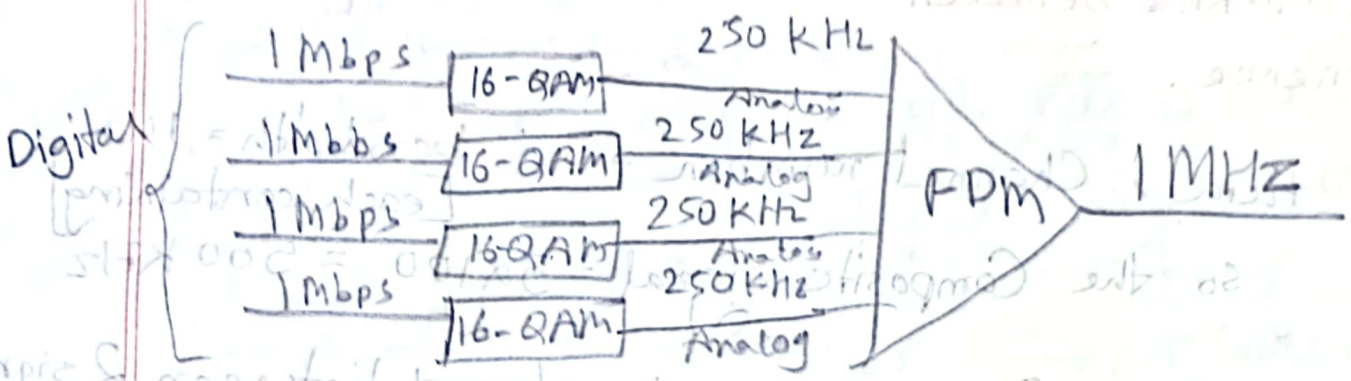
∴ Required Bandwith = (500 + 40) KHz
= 540 KHz

(Ans)



(Digital)

4 data channel, each transmitting at 1 Mbps, use a satelite channel of 1 MHz. Design an appropriate configuration, using FDM.



The Advanced Mobile Phone System (AMPS) uses two bands. The first band of 824 to 849 MHz is used for sending, 869-894 MHz is used for receiving. Each user has a bandwith of 30 KHz in each direction. How many people can use their cellular phones simmultaneously?

Each band is 25 MHz. Per user can use this cellular phone at a time $= \frac{25\ MHz}{30\ KHz} = 833.33$.

In reality the band is divided into 832 channels. Of these 42 channels are ~~use~~ used for control, which means only 790 channels are

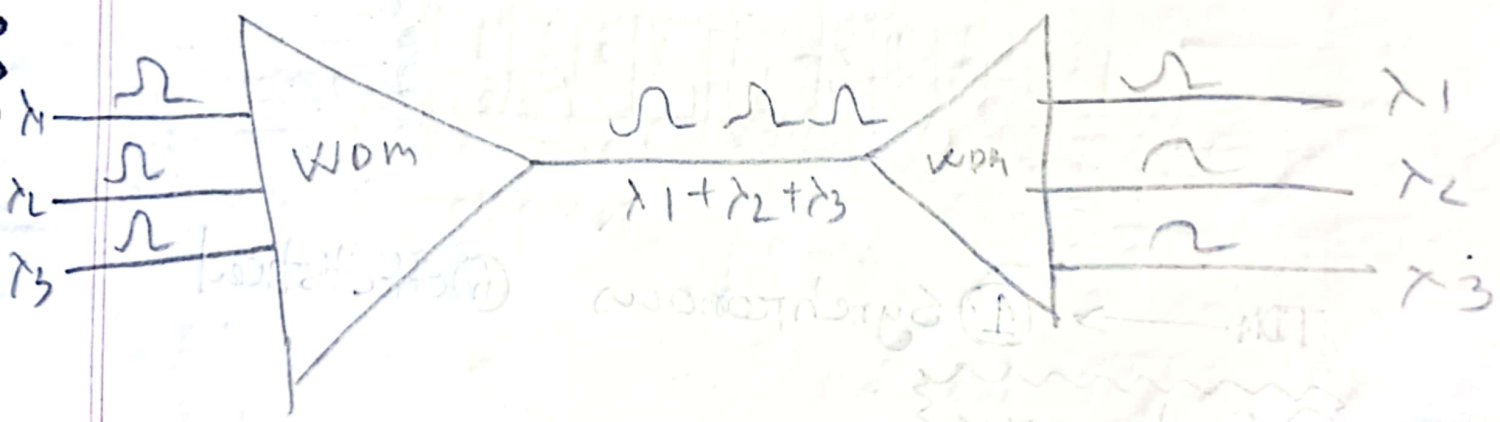
available for cellular phone users.

#WDM

(i) The multiplexing and demultiplexing involve optical signals transmitted through fiber-optic channels

(ii) We are combining different signals of different frequencies

(iii) The difference is that the frequencies are very high

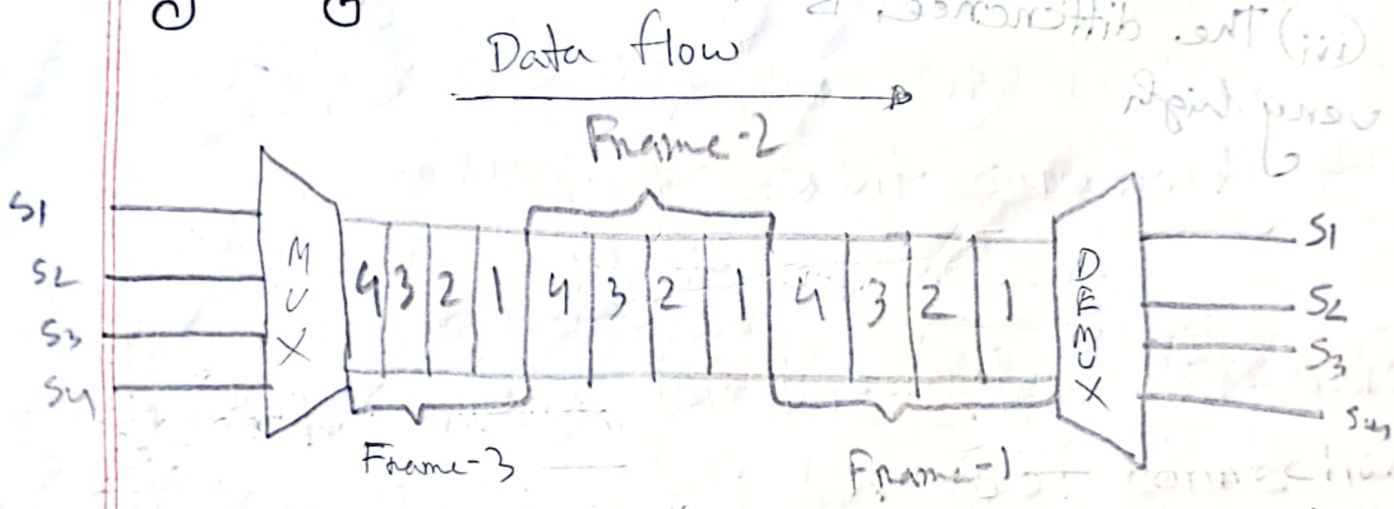


TDM

(i) TDM is a digital multiplexing technique for combining several low-rate channels into one high-rate one.

(ii) Instead of sharing bandwith, time is shared

(iii) Sources with analog signal can also be multiplexed by using TDM



TDM ⟶ (i) Synchronous (ii) Statistical

(i) Synchronous

(i) Each input connection has an allotment in the output even if it is not ~~sed~~ sending data.

(ii) The data flow in each input connection is divided into units, where each input occupies one input time slot.

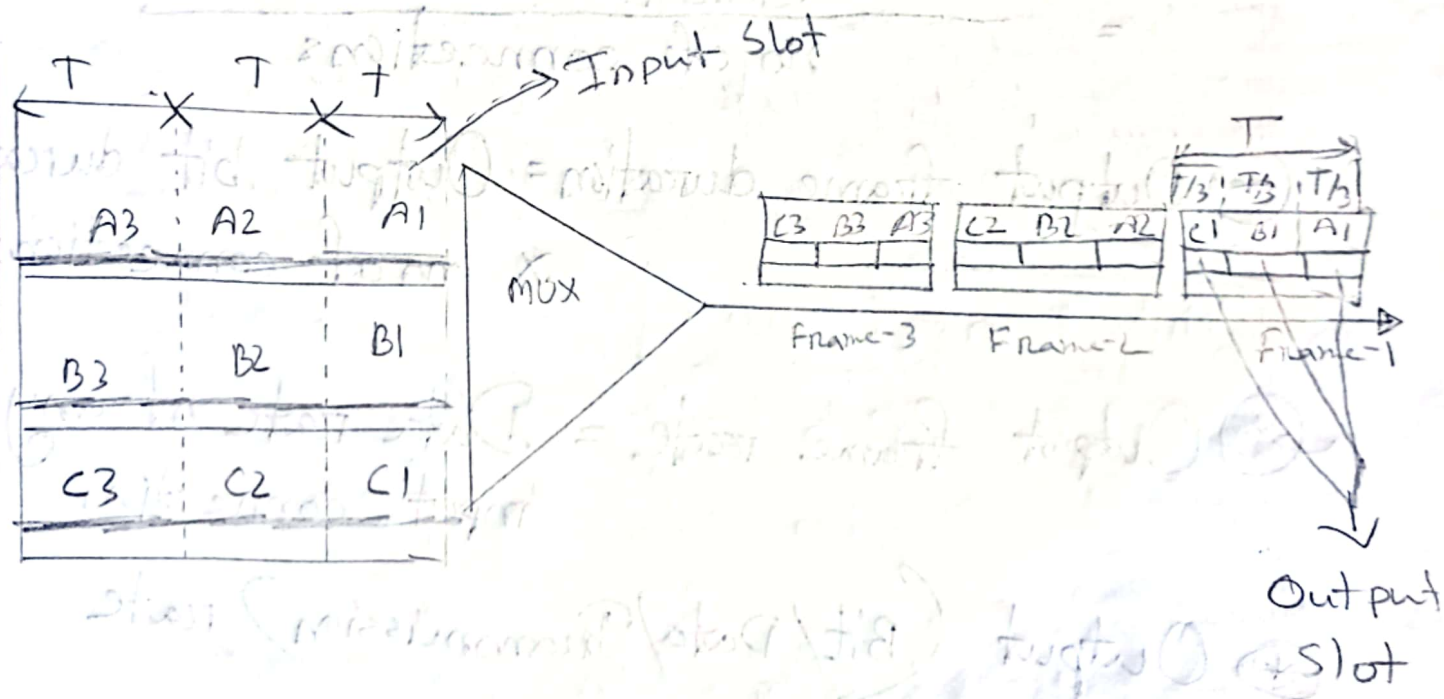
(iii) System with n input lines, each frame has at lasts n slots

(iv) In TDM, the data rate of the link is n times faster and unit duration is n times shorter.

- Time slots
- Frames.

T = Input Slot duration ; Input slot duration = Frame duration

$$\text{Output Slot} = \frac{T}{\text{No. of input channel}}$$



$= \frac{1}{200}$

{Formula}

$T = 10^{-6}$ ms

10^{-6} s —— 1 sec

1s ——

- T = input slot duration
- input slot duration = $\frac{\text{Frame duration}}{T}$
- Output Slot duration = $\frac{T}{\text{No. of input channels}}$
- Input (Bit/Slot) duration = $\frac{1}{\text{Input bit rate}}$
- Output (Bit/time slot) duration

$$= \frac{\text{input bit duration}}{\text{no of connections}}$$

- Output frame duration = Output bit duration × no of connections.
- Output frame rate = Data rate of any input connection
- Output (Bit/Data/Transmission) rate

= Bit rate of any input × number of connections.

~~# The data rate for each input connection is 3 kbps.~~

The data rate for each one of the 3 input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit). What is the duration of

(a) Each input slot? (b) Each output slot?

(c) Each frame?

(a) We know Input slot duration $= \dfrac{1}{\text{input bit rate}}$

$= \dfrac{1}{1000}\,s = 1\,ms$

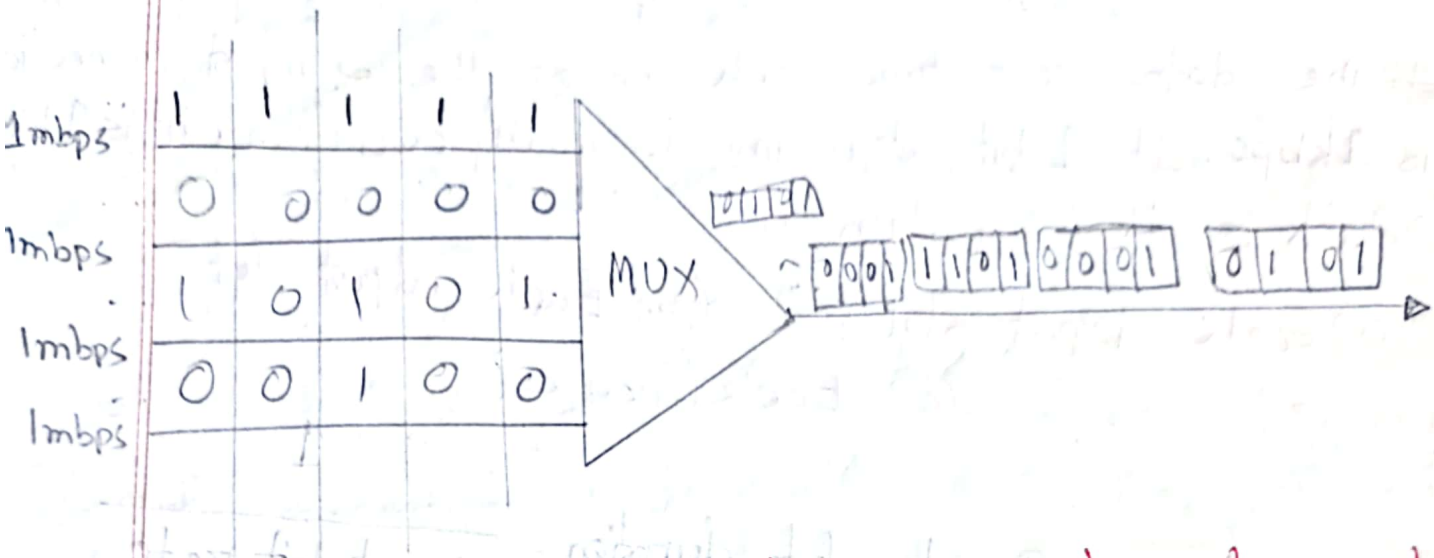
(b) Output Slot duration $= \dfrac{\text{input bit duration}}{\text{no. of connection}}$

$= \dfrac{1}{3}\,ms$

(c) Frame duration = Input slot duration

$= 1\,ms.$

#



Here 4, 1mbps data stream inputs and one data stream for the output. The unit of data is 1 bit.

(a) Input bit duration? (b) Output bit duration

(c) Output bit rate? (d) Output frame rate?

a

$\boxed{\text{Without using formula}}$

$[1\,mb]$ 10^6 b $\longrightarrow$ 1s

$\therefore$ 1b $\longrightarrow$ $\frac{1}{10^6}$ s = μs

Input ~~bit~~ slot duration = $\frac{1}{\text{input bit rate}}$

$= \frac{1}{10^6 \text{ bits}} = 1\mu s.$

b

Output ~~bit~~ slot duration = $\frac{\text{input bit duration}}{\text{no. of connection}}$

$= \frac{1}{4}\ \mu s$

d

Here frame ~~rate~~ duration $= 1\ \mu s$

10^{-6} s ($1\ \mu s$) সময়ে মোট 1 frame তৈরি হবে,

$\therefore 1$ s ——— $\frac{1}{1\times10^{-6}}$ ———

$= 10^{6}$ frame তৈরি হবে

$= 10^{6}$ fps

~~Output slot duration = $\frac{\text{input bit duration}}{\text{number of channel}}$~~

~~$= \frac{1}{4}\ \mu s$~~

c

Output ~~bit~~ slot rate = bit rate × no. of connection

$= \cancel{10^{6}\times4\ Mbps}\ 1\times4$ mbps

d

~~Output frame rate = 10^{6} fps~~

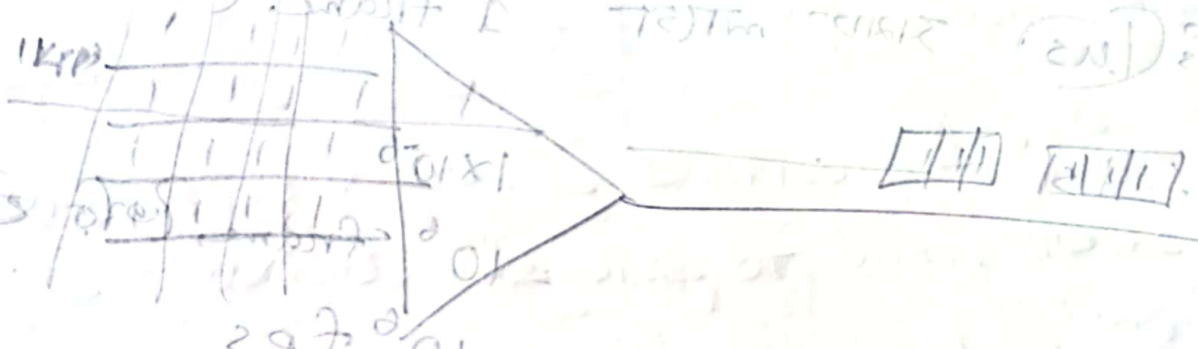
#4, 1-Kbps connections are multiplexed together. A unit is 1-bit.

(a) The duration of 1 bit before multiplexing?

(b) The transmission rate of the link?

(c) Duration of time slot?

(d) Duration of a frame?



(a) Input bit duration $= \frac{1}{1}$ Kbps $= 1$ ms

(b) Output bit/transmission rate $= 1 \times 4 = 4$ Kbps

(c) According to this.

Frame ~~rate~~ duration $= 1$ ms

Output slot duration $= \frac{1}{4}$ ms

1 Frame তৈরি হতে সময় লাগে 1 ms

1 ms ——— 1

1 s ——— $\frac{1}{1\times10^{-3}s} = 10^3 s$

$\therefore$ Output frame rate $= 4\times10^3 s$

$= 4$ kbps.

c

The duration of time slot is $\frac{1}{4}$ of the duration of each bit before multiplexing.

$= \frac{1}{4}$ ms

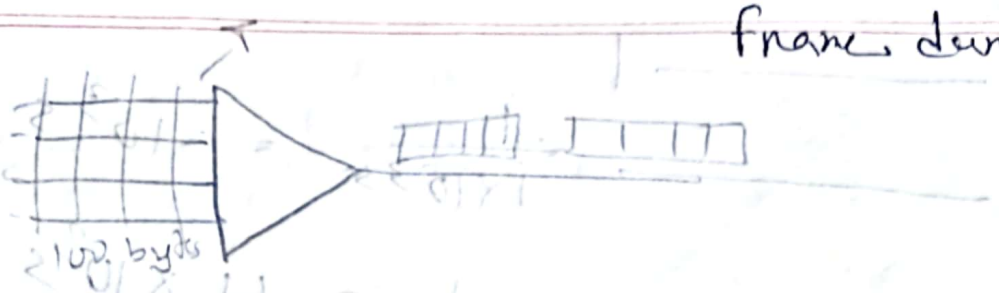
d

Input slot duration = frame duration

= 1 ms

#

frame duration = $\frac{1}{100}$ s



4 channels are multiplexed using TDM. If each channel sends 100 bytes/s and we multiplex 1 byte per channel (b) show the frame travelling on the link, (c) The size of the frame (d) The duration of a frame (e) The frame rate (f) The bit rate for the link.

(c)

Here, Each frame carries 1 byte from each channels; The size of each frame is 4 bytes, Because each channel is sending 100 bytes/s and a frame carries 1 byte from each channel, the frame rate must be 100 frames per second.

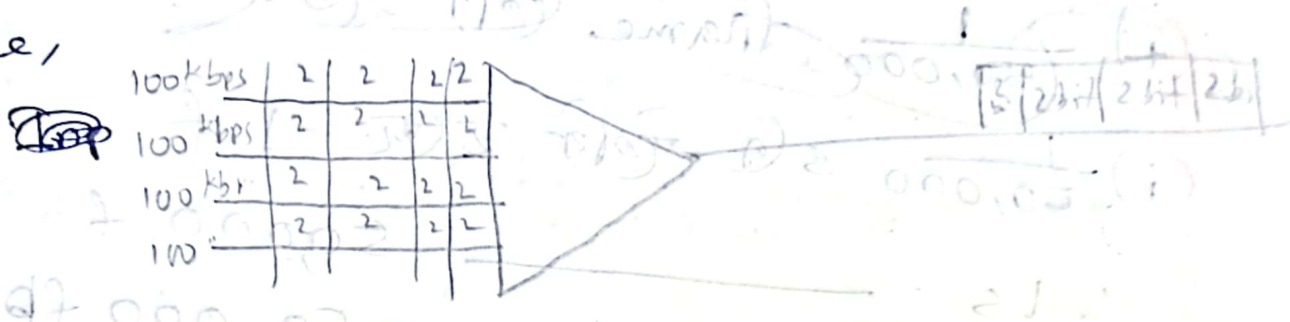
The bit rate is $100 \times 32 = 3200$ bps.

A multiplexer combines four 100-kbps channels using a time slot of 2 bits. Show the output with four arbitary inputs.

(a) What's the frame rate? (b) frame duration?

(c) bit rate? (d) bit duration.

Here,



So here Input Slot duration $= \frac{2}{100 \times 1000}$

(a) [∵ প্রতি slot এ 2টি করে bit থাকে]

$= \frac{1}{50000}$ bps

Frame duration $= \frac{1}{50000}$ bps.

Output slot duration $= \frac{T}{\text{no. of channel}}$

$= \frac{1}{50000 \times 4}$

$= \frac{1}{200000}$

Output bit duration $= \frac{\text{Input bit duration}}{4}$

গ,

(iv) Output bit duration $= \frac{\text{Output slot duration}}{2}$

$= \frac{1}{200000 \times 2}$

~~(i) $\frac{1}{50,000}$ frame তৈরি হতে লাগে.~~

(i) $\frac{1}{50,000}$ s এ তৈরি হচ্ছে 1 f

$\therefore$ 1 s ———— 50,000 f

(1) Frame rate $= 50,000$ fps

Here per frame এ data আছে 8 bit.

(ii)

$\therefore$ Output bit rate $= 50000 \times 8$ bps

$=$

Data rate Management

If there is data rate mismatch. Then there's 3 ways to solve this problem.

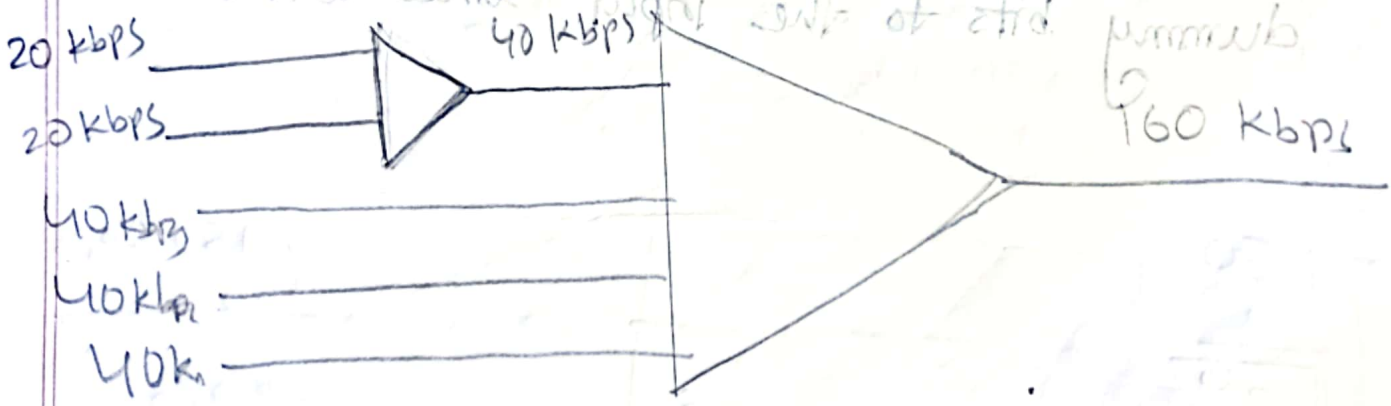
(i) Multilevel Multiplexing

(ii) Multiple-Slot Allocation

(iii) Pulse Stuffing

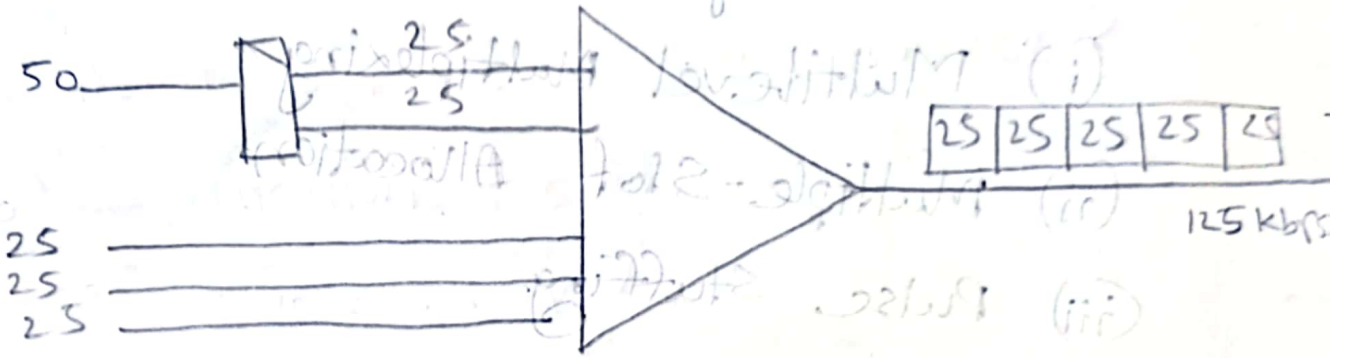
(i) Multilevel Multiplexing

It is used when the data rate of the input links are multiples of each other



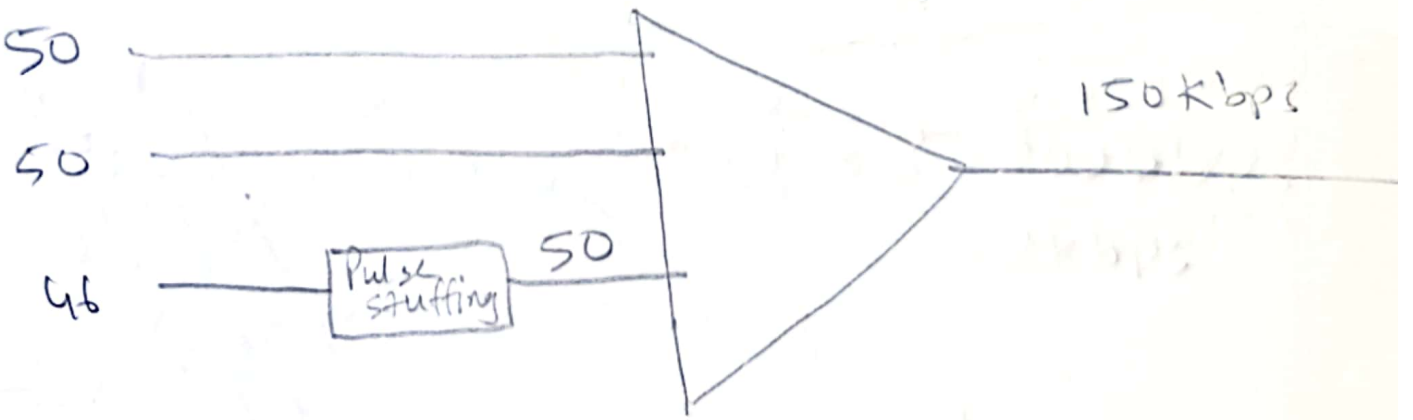
(ii) Multiple Slot Allocation

It is used to allot more than one slot in a frame to a single input line



(iii) Pulse Stuffing

It is used to make the highest input data rate the dominant data rate and then add dummy bits to the input lines with lower rates



Frame Synchronization

(i) Synchronization between the multiplexer and demultiplexer is a major issue in TDM

(ii) Bit belonging to one channel may be received by another.

(iii) Solution → Framing Bits, follows a pattern, frame to frame.

(iv) Framing bits are used to provide synchronization.

1	0	1

We have 4 sources, each creating 250 8-bit characters per second. If the interleaved unit is a character and 1 synchronizing bit is added to each frame, find.

(a) The data rate of each source?

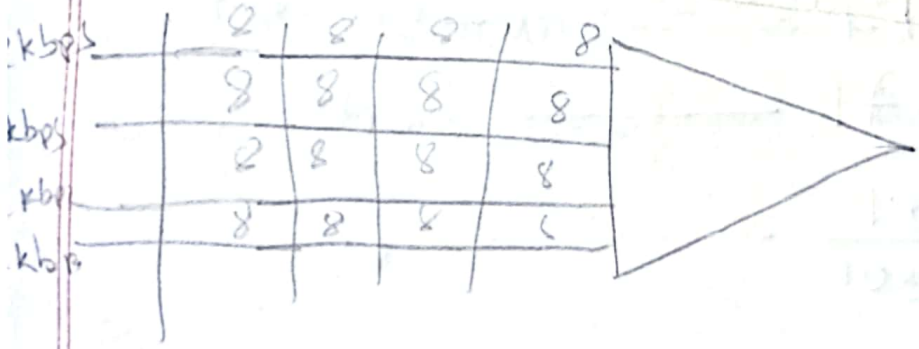
(b) The duration of each character in each source?

(c) The frame rate?

(d) Duration of each rate?

(e) Number of bits in each frame?

(f) Data rate of the link?



a

Data rate $= 250 \times 8 = 2000$ bps

$= 2$ kbps

b

Input bit rate $= \frac{8}{2000} = \frac{1}{250} = 0.004$ kbps

$= 4$ ms

d

frame duration $= \frac{1}{250}$ kbps or 4 ms.

(c) 4ms ——— 1 frame

~~∴ 1s ——— $\frac{1}{4\times10^{-3}}$ = 0.25~~

∴ 1s ——— $\frac{1}{4\times10^{-3}}$ = 250 fps

frame rate = 250 fps.

e

frame size = ~~320~~ (4×8) + 1 synchronizing bit.

= 33 bit.

f

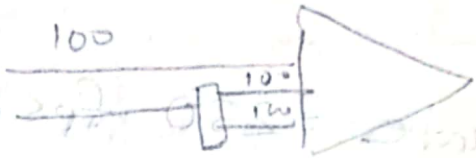
Output bit rate = 250×33 = 8250 fps

d

~~Duratio Frame du~~

Two Channels, one with a bit rate of 100 kbps and another with a bit rate of 200 kbps, are to be multiplexed. How this can be achieved? What is the frame rate? frame duration? bit rate of the link?

⇒



Bit rate = 100000 × 3 = 300 kbps

$$\text{frame duration} = \frac{3}{300\,000} = 10 \text{ ms}$$

Frame rate,

10 ms ——— 1f

∴ 1s ——— $\frac{1}{10 \times 10^{-3}}$

Statistical Time Division Multiplexing

(i) Slots are dynamically allocated to improve bandwith efficiency

(ii) Only when an input line has a slot's worth of data to send is it given a slot in the output frame.

(iii) The number of slots in each frame is less than the number of input lines.

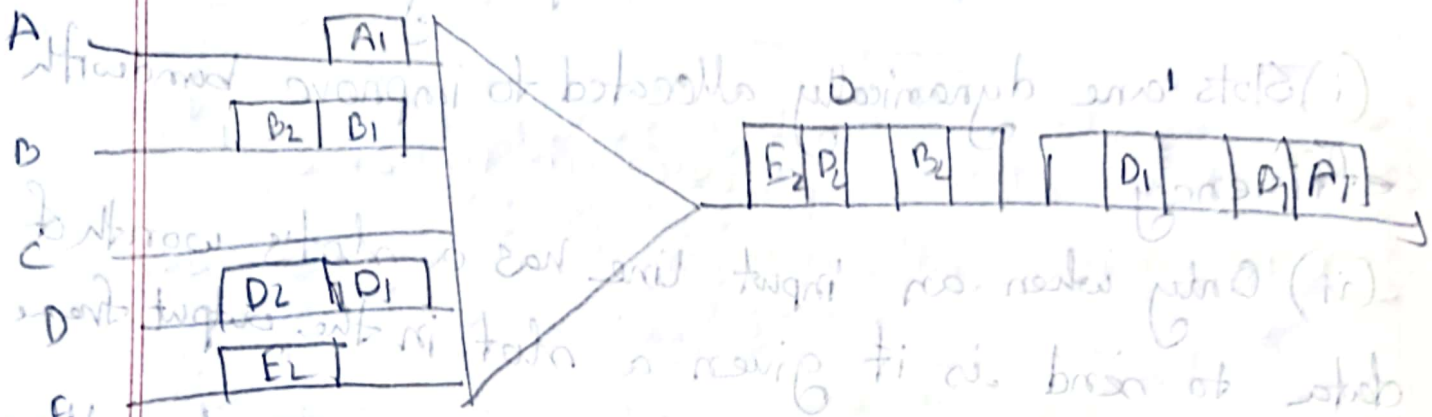
Statistical TDM — Differences

① Addressing | A slots needs to carry data as well as the address of the destination.

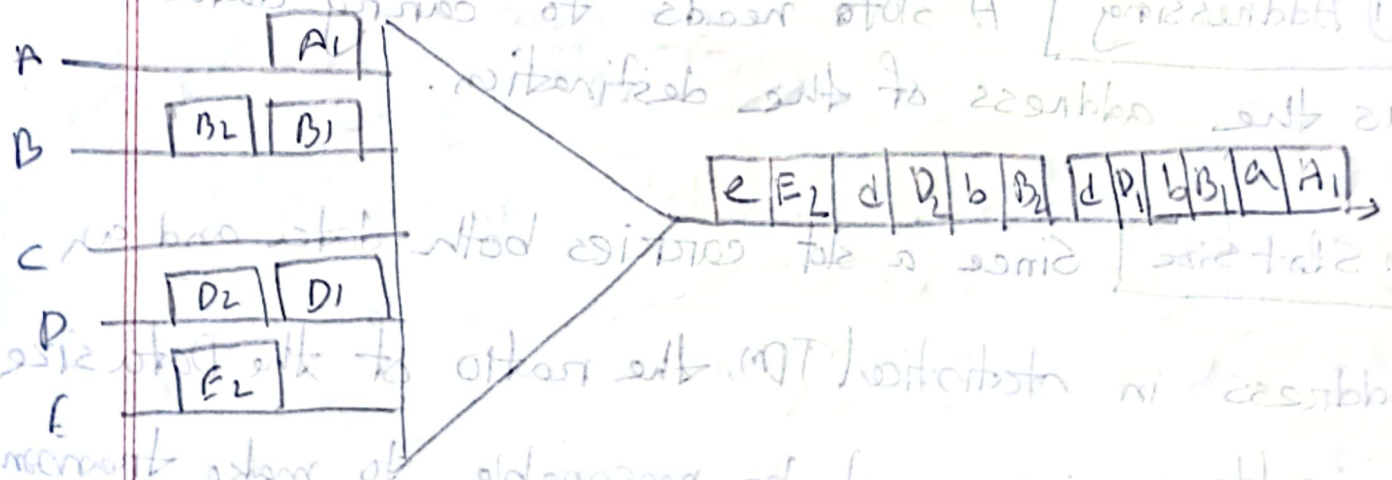
② Slot Size | Since a slot carries both data and an address in statistical TDM, the ratio of the Data size to address size must be reasonable to make transmission efficient

A block of data is usually many bytes while the address is just a few bytes.

CS CamScanner



Synchronous [Bandwith utilization ভালো হয় না]



Statistical

Spread Spectrum

(i) In spread spectrum, we combine signals from different sources to fit into a larger bandwith, but our goals are to prevent eavesdropping and jamming. Spread Spectrum techniques add redundancy

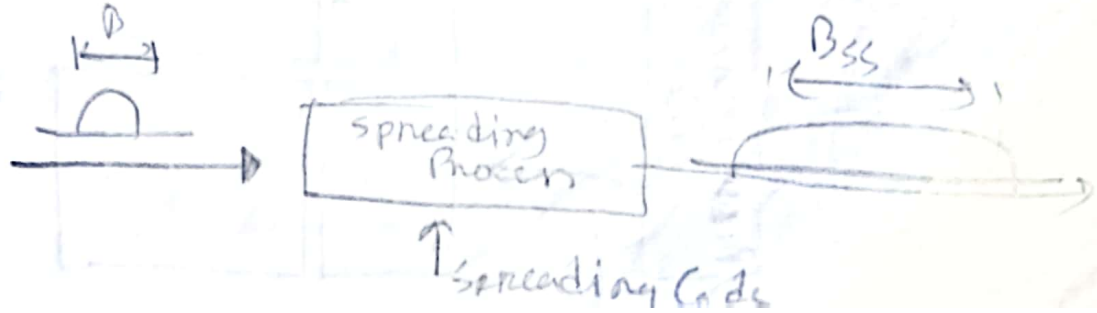
(ii) If the required bandwith for each station is B, spread spectrum expands it to B_{ss}.

$$B_{ss} \gg B.$$

Two principle

- Redundancy: The bandwith allocated to each station needs to be larger than what is needed.

- Independent Process: The spreading process occurs after the signal is created by the source



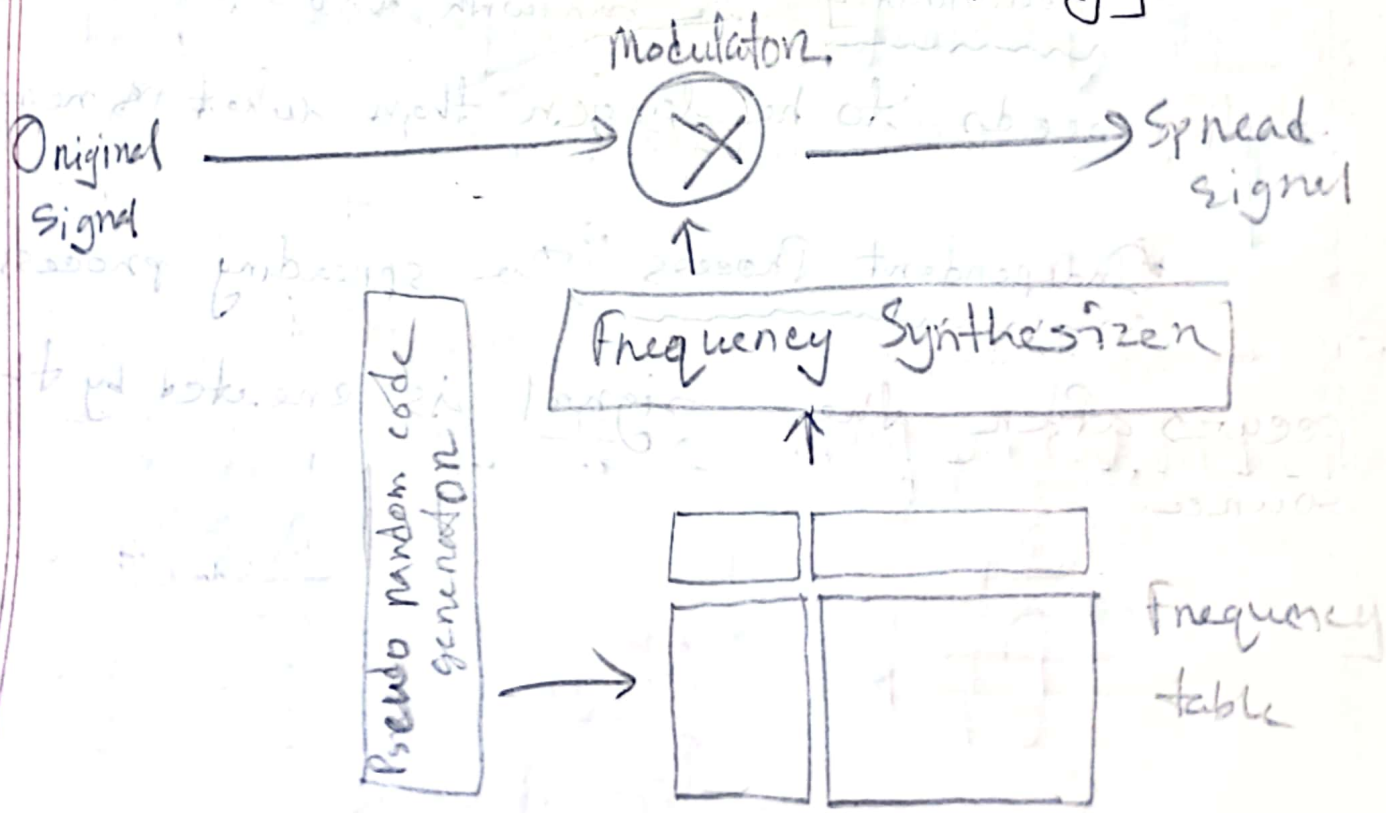
Frequency-Hopping Spread Spectrum (FHSS)

(i) Uses M different carrier frequencies that are modulated by the source signal

(ii) At one moment, the signal modulates one carrier frequency; at the next moment, the signal modulates another carrier frequency.

(iii) The bandwith occupied by a source after spreading is $B_{FHSS} \gg B$.

(iv) Used in ~~Blut~~ Bluetooth technology.

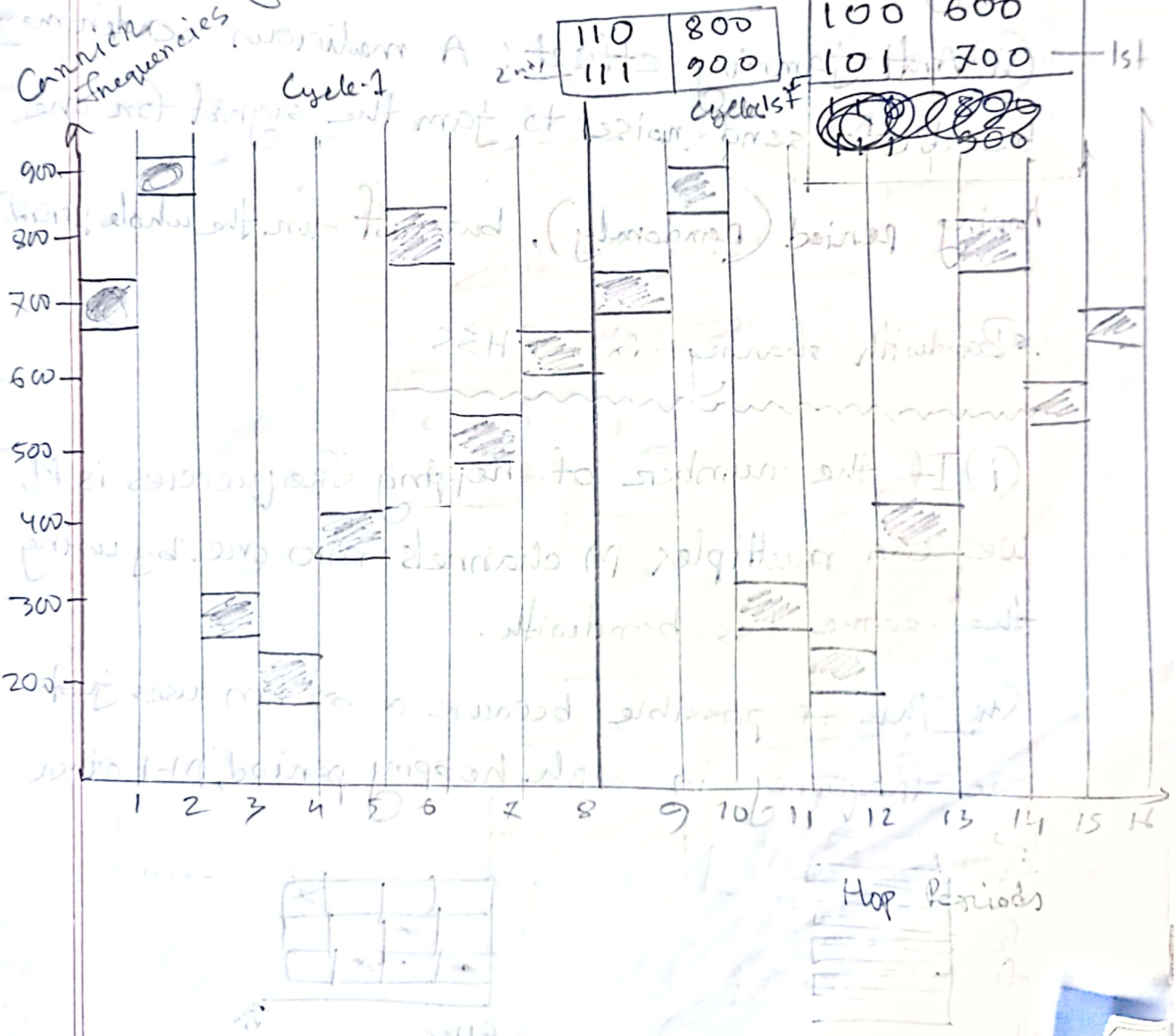


• Frequency selection in FHSS

For 3bit, K bit pattern

1st	2nd	3rd	4th	5th	6th	7th	8th
101	111	001	000	010	110	011	100

K-bit	Frequency (kHz)
000	200
001	300
010	400
011	500
100	600
101	700
110	800
111	900



Advantages

(i) If an intruder tries to intercept the transmitted signal, (s)he can only access a small piece of data because they dont know the spreading sequence to quickly adopt to the next hop.

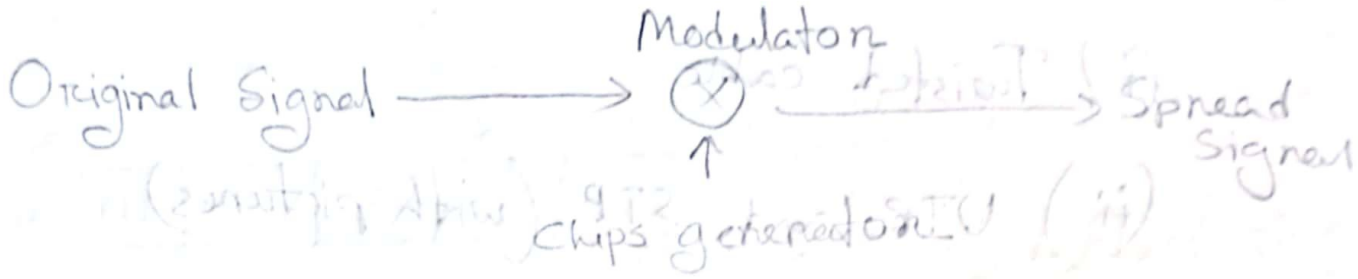
(ii) Anti-jamming effect: A malicious sender may be able to send noise to jam the signal for one hoping period (randomly), but not for the whole period.

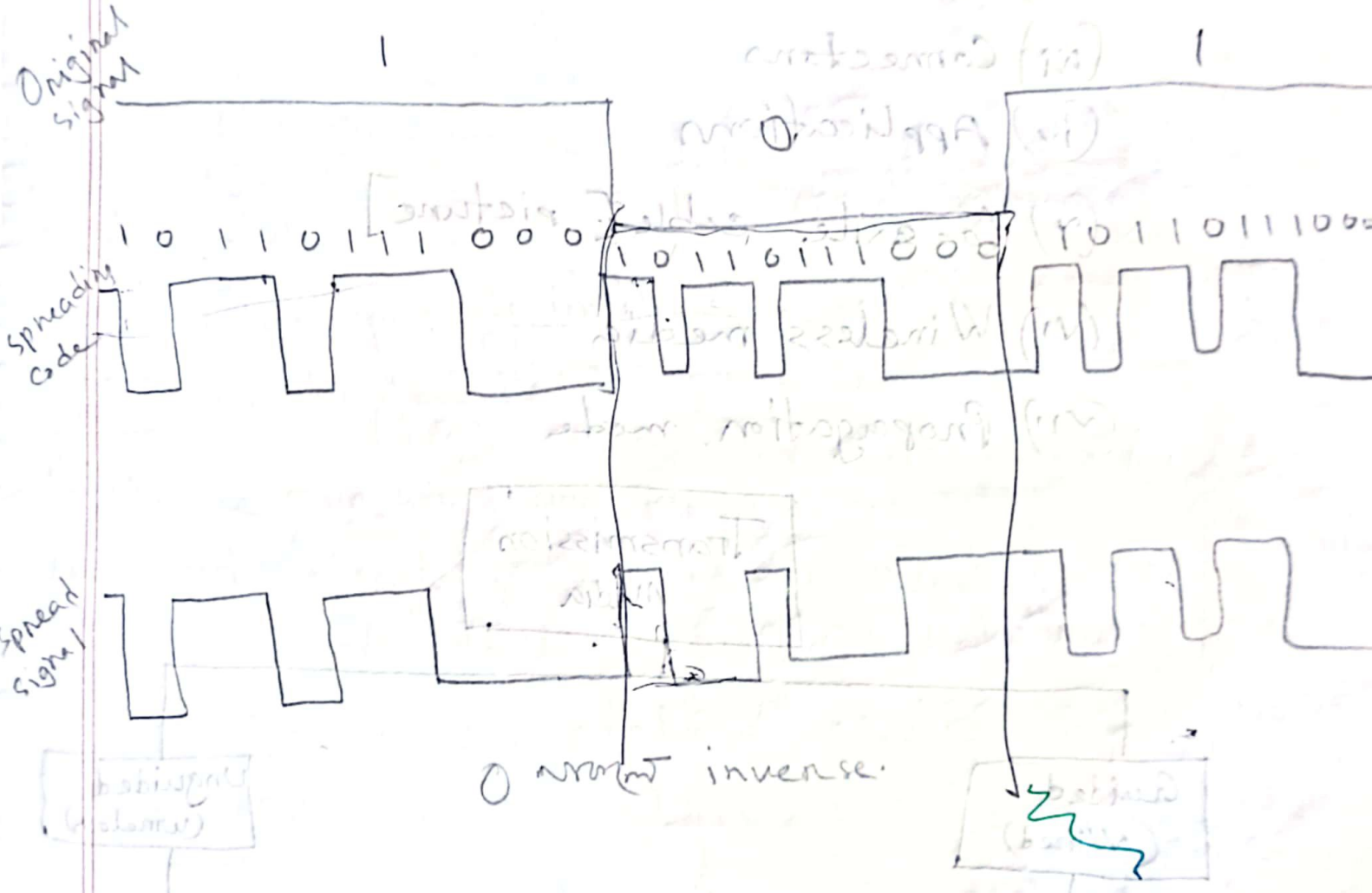
Bandwith sharing in FHSS

(i) If the number of hopping frequencies is M, we can multiplex M channels into one by using the same B_{ss} bandwith.

(ii) This is possible because a station uses just one frequency in each hopping period, M-1 other

Direct Sequence Spread Spectrum (DSSS)





Done a mistake here .
it'll go upwards when the signal is 1
and lower when the signal is 0