Grading :

Minor I : 20
Minor II : 20
Major : 35
Assignments : 25
Attendance (Bonus) : 5

Bridge

Top down Approach ↓

Applicat^n
Transport.

Physical Layer ↑

Textbook: Peterson & Davie : Computer Networks
→ A system's approach (5th)

Ref: Kurose & Ross : Computer Networking
→ A top-down approach (6th)

Applications → Networking ← Technology
Hi-fi

Pokemon Go, Whatsapp → Research

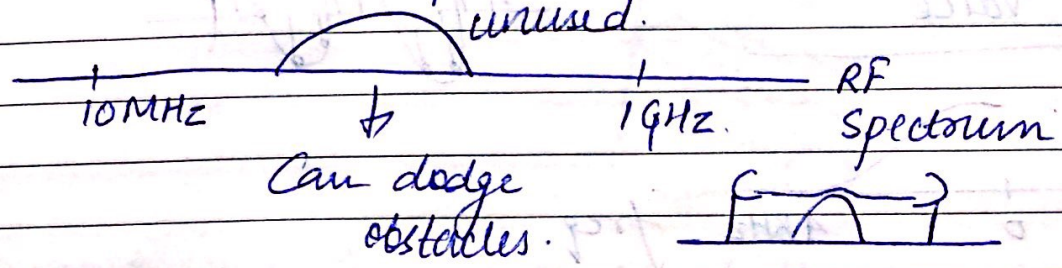
IOT = Machine to Machine Communication.
Objects communicating with each other.

Eg: Sensors in buildings.
↳ Temp. sensor ⇒ When to turn on/off AC.
↳ Room empty ⇒ Electricity save.

*// SKYPE (VOIP) } → Cheaper from business pt. of view.
Voice over IP

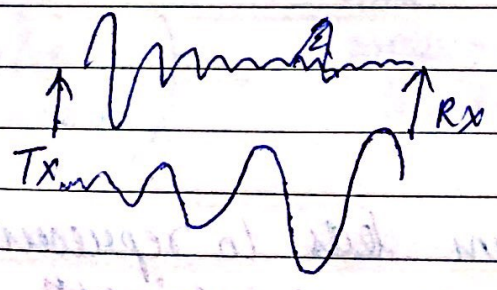
*// Cloud.
Data Centre.

*// Rural Internet :
TV White Space (TVWS).



*// Technology :
LiFi
LTE → Long Term Evolution.
4G ..... 5G.

*// Simplex : Tx in One Direction
Duplex : Tx in Both direct^n.
Half Duplex : ——————— but not simultaneously



Sunday 03

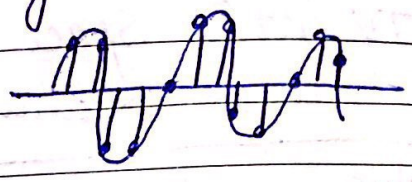
① SDN : Software Defined Networking
② NFV : Network Function Virtualization.

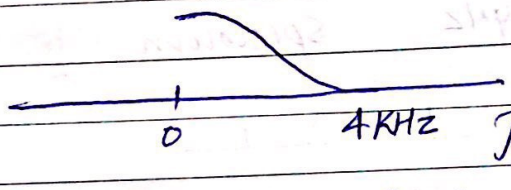
Voice over IP →

A — B

SPOKEN → Digital Bits 00110011. —— ADC ≡ Digital

Analog.

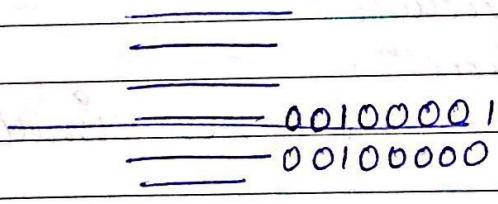




Sample → 8KHz (Nyquist rate)
8000 per second.

27/07/2016

Quantization Noise



* Information Theory → Shannon.

Entropy Source. → Minimum bits to represent a source of information

Channel Capacity

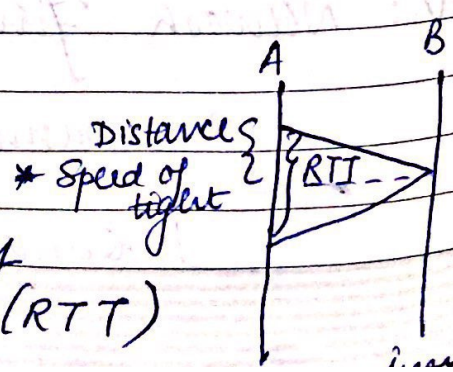
Image, Video.

Performance :

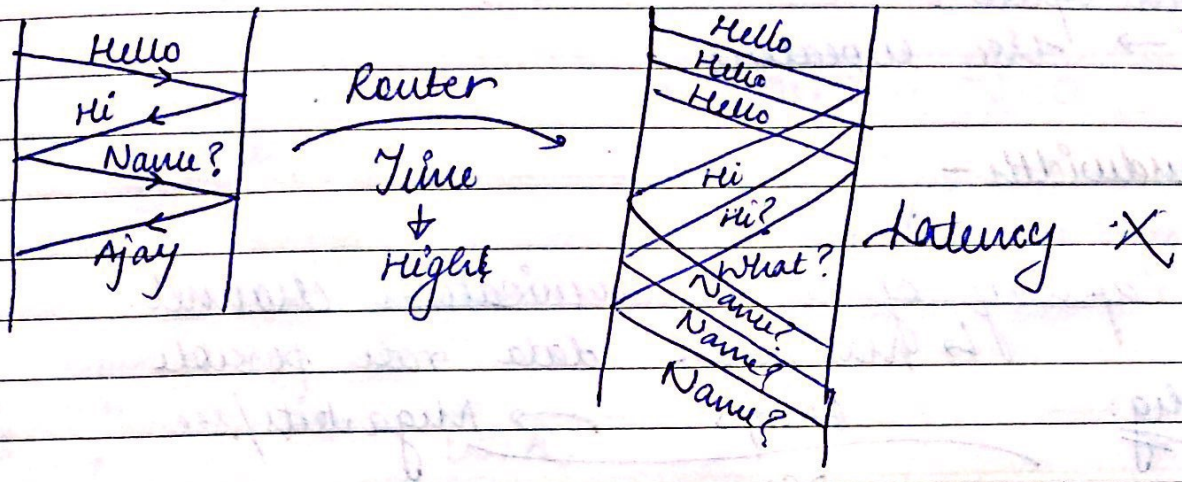
① Latency : Delay

ⓐ One Way Latency

ⓑ Round Trip Time (RTT)



RTT for voice :



② Throughput : Avg. rate of successful message delivery ~~time~~ over a communication channel.

③ Goodput : Useful information bits per ~~informat~~ time delivered to an application.

Applicat^n Info. (Voice Signal) A ——— B Throughput (includes retransmission)

Add protocol header

Voice application.

$$\boxed{\text{Goodput} < \text{Throughput}}$$

Youtube Video Streaming :

Depends on resolution HD - 8 1-2 Mbps.
1Mbps.

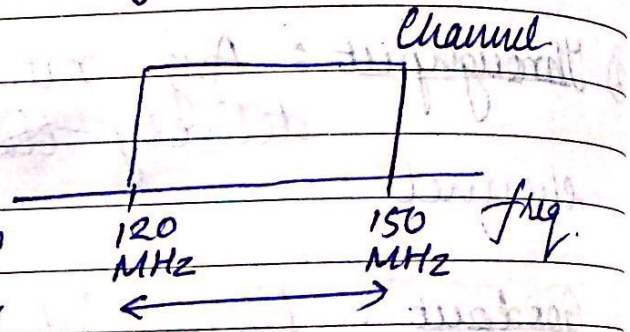
* How to communicate? What if 2 points are far apart?
→ Use repeaters.

• Bandwidth –

(a) Capacity of a communication channel.
↳ Maximum data rate possible

eg: 6Mbps → Mega bits/sec.
DSL

(b) Wireless

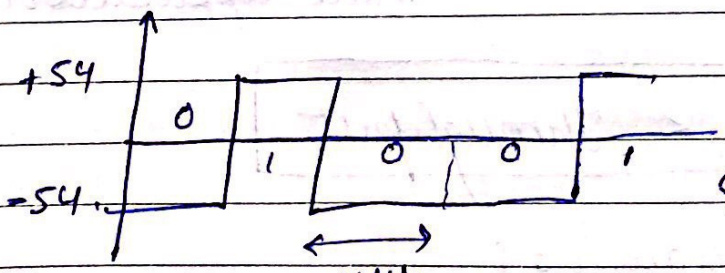


In case of wired connect^n, data needs to be sent as analog signal.

So, if 010011....0110 → Wired Channel.

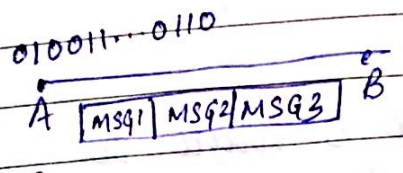
A — B
LHC — Bhasin.

Signal



Threshold.
↳ 1 if above it
0 if below it

Modulation - Conversion of bits to analog signal to transmit over channel.

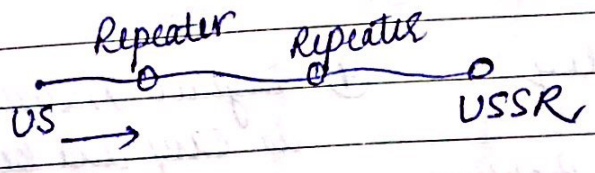


LHC.

01 0011 0110

Enter information to separate one msg from another.

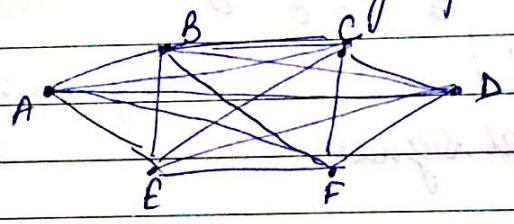
eg:



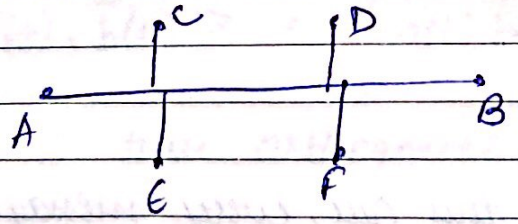
Distant Connections → These connections cannot help because of noise and attenuation.

Q How can we connect multiple users?

(a) Connect each & every pair.



(b) Common Connection



But simultaneous communicat^n is a problem

Orthogonality:

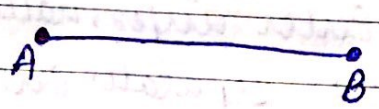
BITS → Signal (Modulat^n) → Physical layer (Layer 1)

Framing → Data link layer (layer 2.)

Voice Application

29/07/2016

(A) Two users :

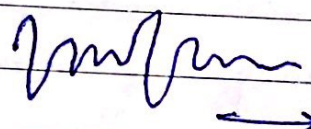


A and B want to communicate by sending voice signals.

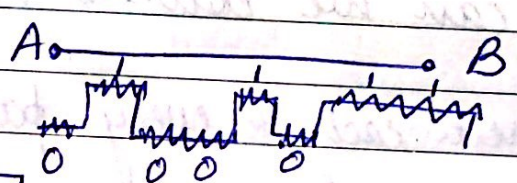
① Analog → Bits → Analog.
Tough ⇒ Problem

(+) Digital Transmission is easy and better.

② Directly transmit analog.
⇒ Noises and attenuation



→ 0100 ..... →



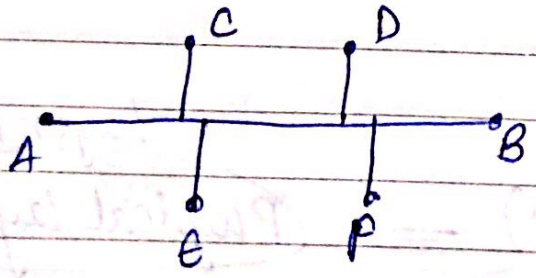
$\boxed{\text{Modulation}}$

Bits to digital signal.

easily transmitted

In this case, Goodput : 64 kbps
Latency (RTT) : ~ 300 ms

(5) Multi-users -



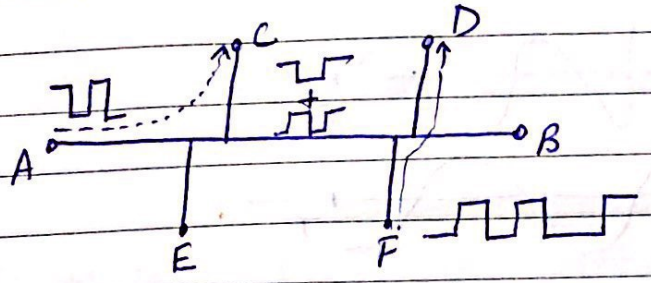
(a) In this case, every message is received to all.

(b) Also, if people want to communicate at same time, mixing occurs.

ⓐ To counter the problem of every message being received by every other person, we need →

ADDRESS IDENTIFICATION OF ENTITIES COMMUNICATION.

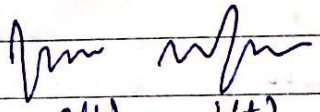
ⓑ If 2 conversat^n at same time, mixed signals.



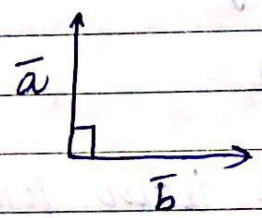
This problem is : MEDIUM ACCESS : WHO ACCESSES THE CHANNEL?

Solution -

① Orthogonality :



a(t) , b(t)



$\vec{a} \cdot \vec{b} = 0$

$\vec{a} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$

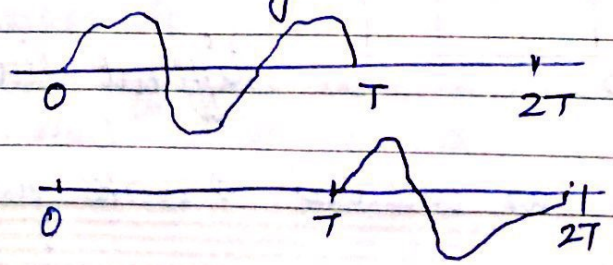
$\vec{b} = b_x\hat{i} + b_y\hat{j} + b_z\hat{k}$

$\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z$

$\langle \bar{a}(t), \bar{b}(t) \rangle = \int_{-\infty}^{\infty} a(t)\, b(t)\, dt$

If 0 then orthogonal.

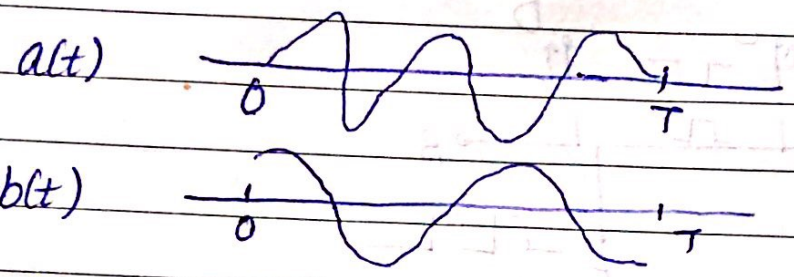
eg:



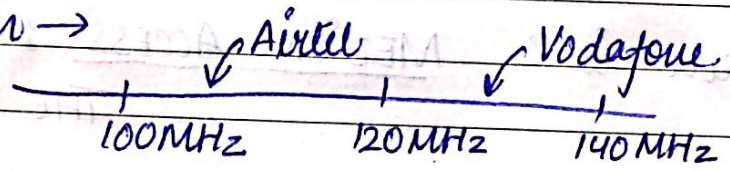
Orthogonal w.r.t time.

* Orthogonality comes as the signal transmission occurs at different intervals ⇒ no common region.
But this cannot be ensured always.

So, for simultaneous transmission which is orthogonal, frequency modulat" needs to be done.



Modulation →



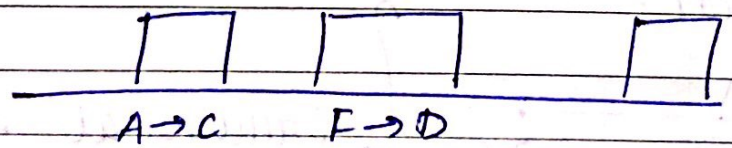
But we need orthogonality in time.

Concept of grant / Release (Token)

Every user can send token for whom to deliver the msg. And these tokens can be passed in round-robin method.

But again simultaneous communicat" cannot be done.

⇒ Bytes stick to different time slots



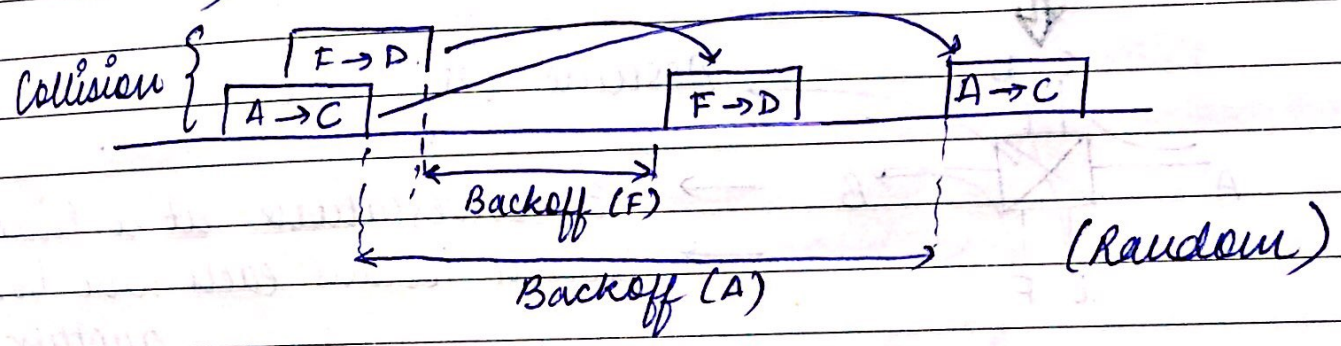
Different time slots.

Latency upto 300 ms is allowed ⇒ Works fine

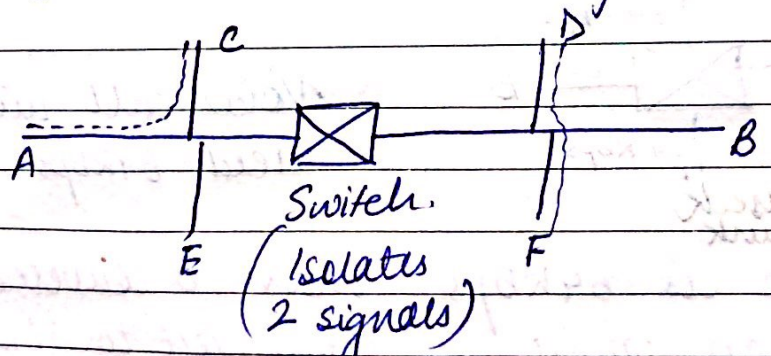
CSMA: Ethernet uses CSMA which stands for "Carrier Sense Multiple Access"

1. Sense channel
2. If silent, I transmit. If busy, I wait till it becomes silent.
3. Stop transmitting, if collision.
4. Random back off and retransmit (avoid collision)

(Wi-fi is poor at collision detection, it being wireless)



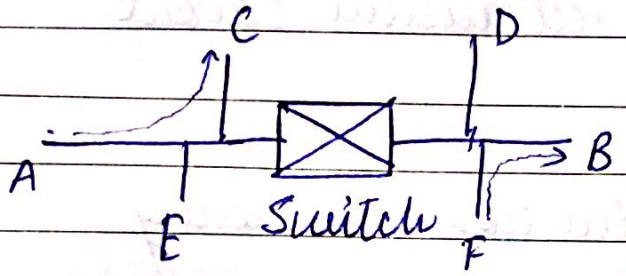
*// We can use switches to forward information



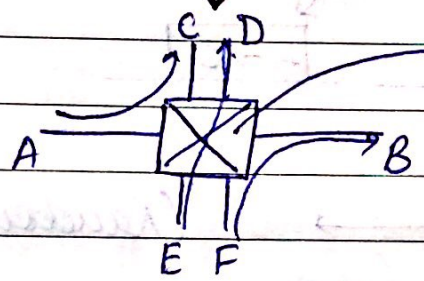
Use switches to selectively forward informat^n
- → More efficient use of resources.
- → Scalability of network.

If we have million users, normal wires will have lots of collisions.
If switches are used, sect^n in network can be isolated so that each isolated sect^n operates individually. ⇒ Scalability.

02/08/2016

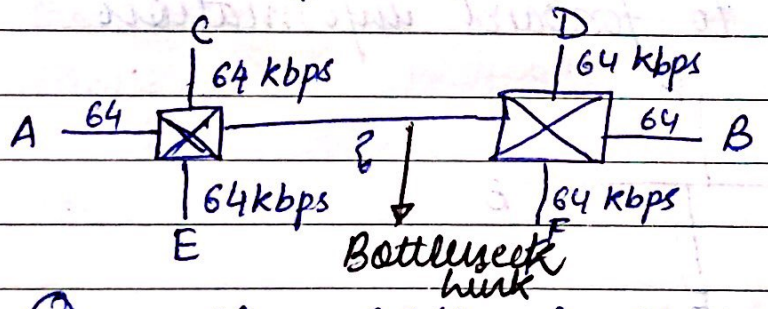


⇓



→ Assume very fast.
→ 3 conversations at a time
→ Switch isolates each wire from another

⇓ → If D, B, F are far away



Voice call will need 64kbps.

① If middle is 64kbps, max. 3 conversations. 1 on left, 1 on right, 1 from left to right. ↳ (poor)

② If middle is made 64 x 3 kbps, 3 conversations possible (across)

NETWORK PROVISIONING

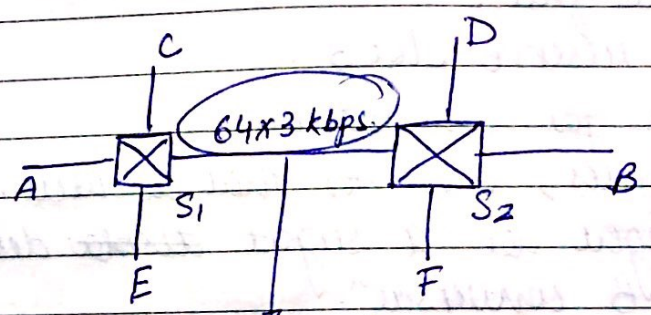
- Deciding link speeds / capacities.

- Say if we have large no. of people on ~~on~~ each end, we will need to use the capacity (64×n kbps). But this is not possible beyond a limit, also cannot estimate exactly.

OVER PROVISION

- Put in ~~more~~ much more capacity than required

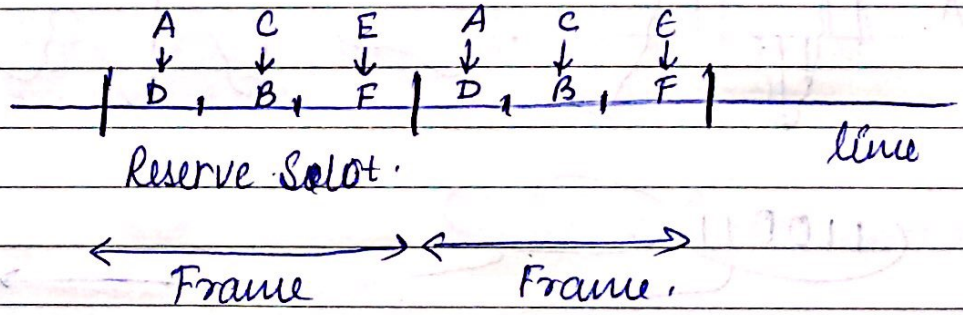
#



Voice
Max. 64kbps.

Provision for the worst case.

A → D
C → B
E → F



→ Switches need to know which slot's msg ~~to~~ is to be sent to which slot.

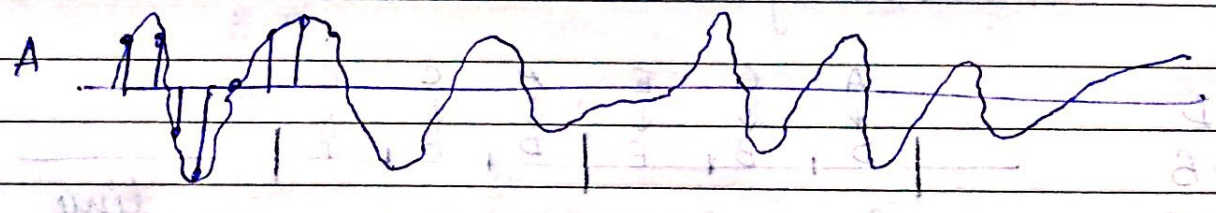
→ Here as time passes, msg is transferred to the corresponding slot., say if 1st slot, whatever it be, it goes to D, then next to B, ...

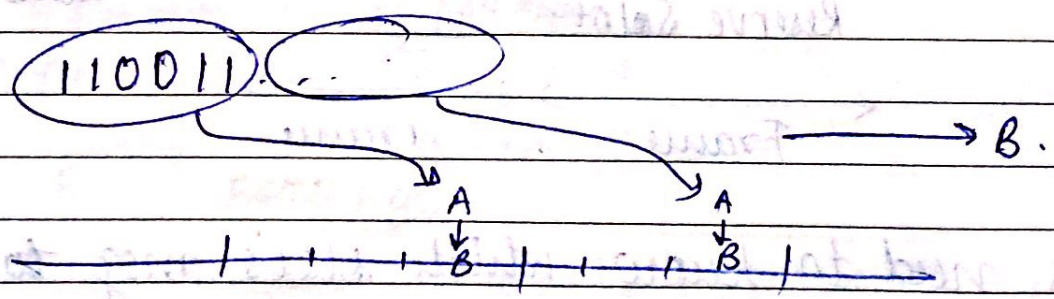
Also, if there might be delays. If msg is in 2 parts, 2nd would slipt to the 3rd from current (like 1st & 4th). ⇒ Msg in 4th would reach only after 2nd & 3rd are done.

Step wise →

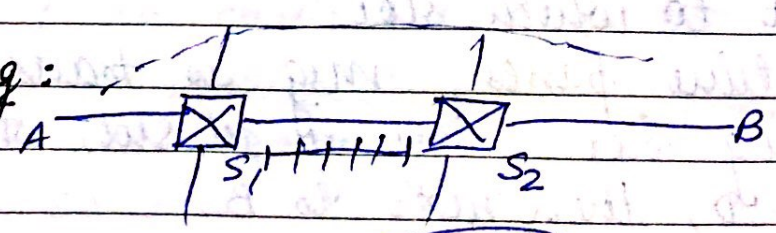
- A wants to talk to B.
- A tells S_1 (want to talk to B)
- S_1 tells S_2, want to reserve a slot for A→B conversation.
- S_2 checks if B is free.
- S_1 & S_2 agree to reserve slot 3.
- S_1 tells A, ready for conversation
- Now if E→D comes, slot for that as well.

§- Possible, there might be a slight ~~displa~~ delay in start of A→B conversat^n.





Circuit switching :

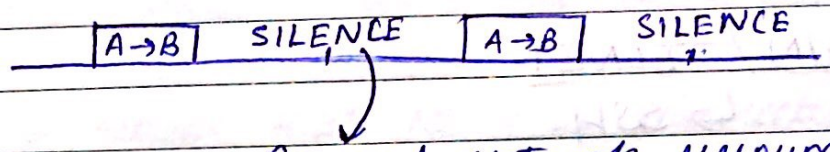


64 kbps → guaranteed

(for eg).
→ Each slot supports 64kbps
If we send ≤ 64kbps, guarantee of transfer.

POSITIVE : 1) Guaranteed Bandwidth.
2) Tight bound on latency.
3) All bits in any slot can be used for data (less overhead, no need to identify sender/receiver).

NEGATIVE : 1) A → B only.

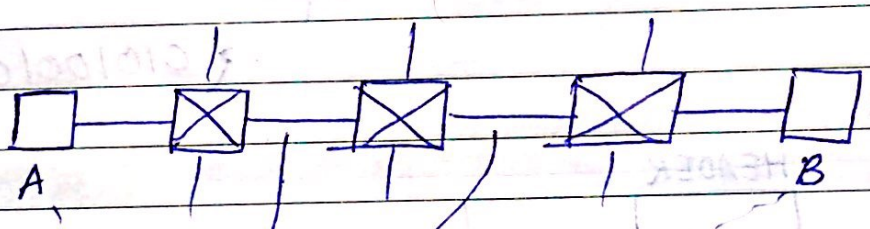


Reserved network resources not used.

⇒ Under-utilisation of resources.

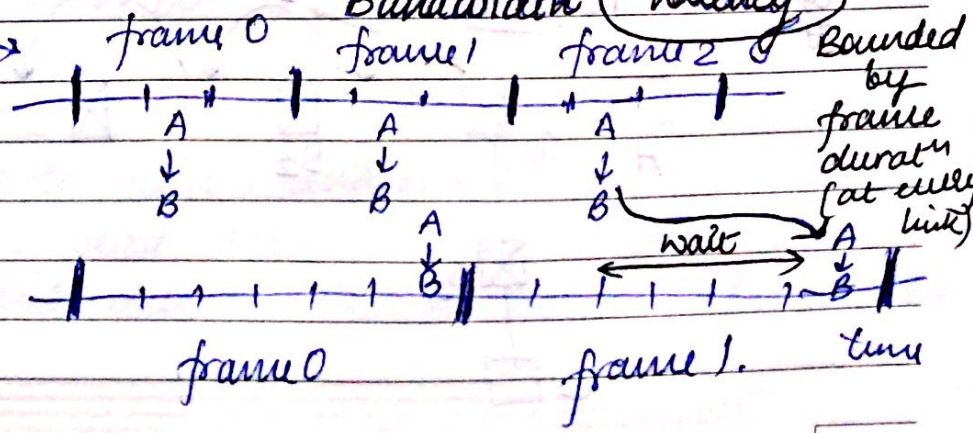
03/08/16

Circuit Switching :



Circuit Direct Connection.

Bandwidth latency



Bounded by frame duration (at every link)

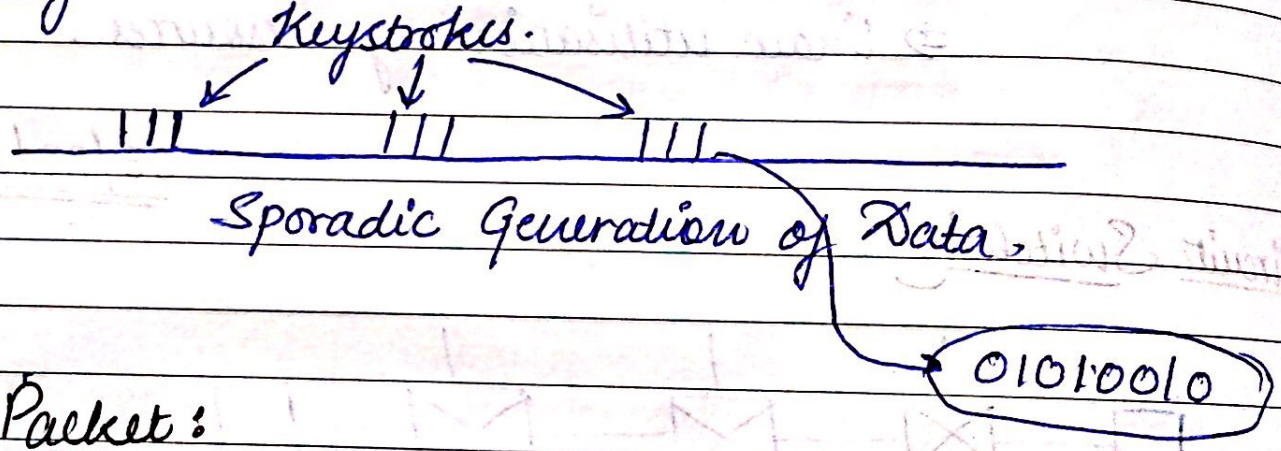
QoS : Quality of Service

↳ Throughput & Latency which an applicat^n gets.

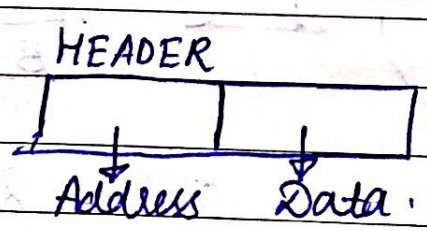
Voice QoS : 64 kbps throughput
≤ 500 ms latency (RTT)

RLOGIN / TELNET
↳ SSH.

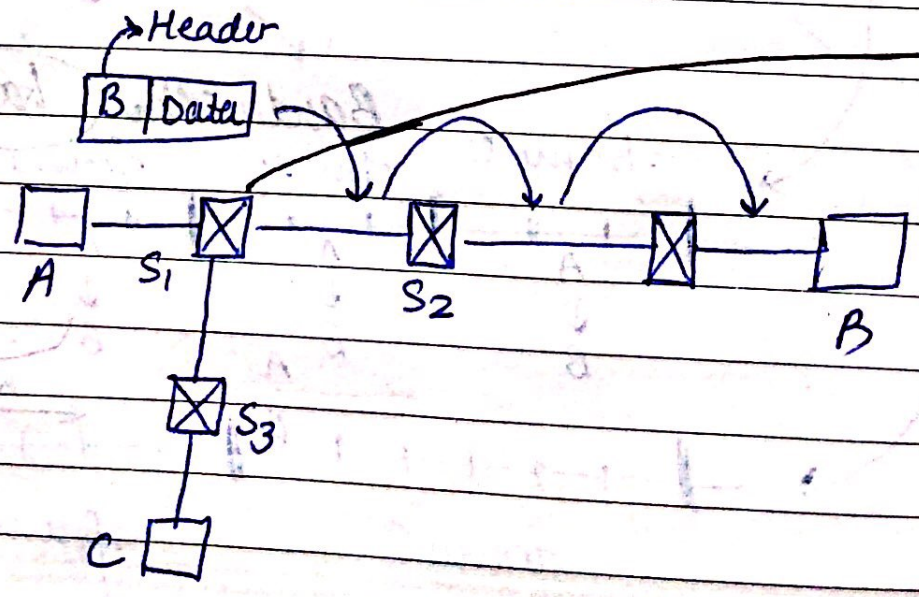
Typing :



Packet :

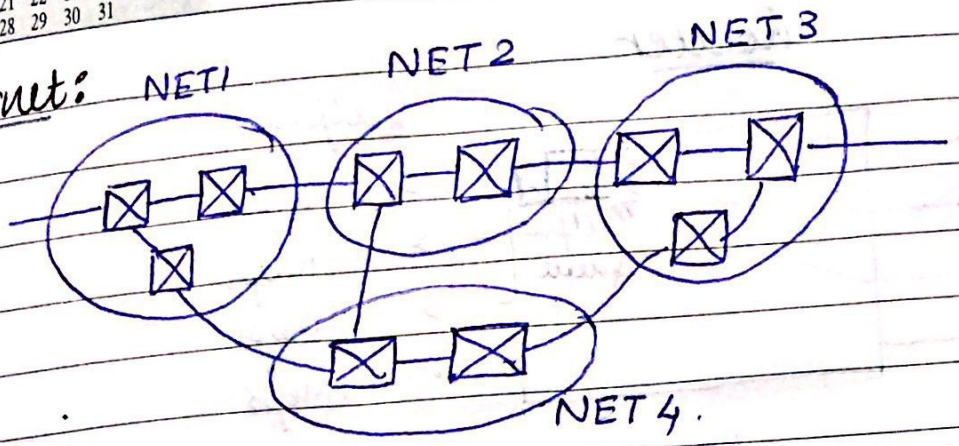


Eg:



Dest.	Next hop
⋮	
B	S_2
C	S_3
⋮	

Internet:



Sometime each group doesn't reveal to another about to who-else is it connected, to avoid overloading. like, If NET2 knows that NET4 is connected to NET3, instead of sending directly, NET2 might dump data to NET4, which would have to then do the work. So, to avoid this, there must be a agreement

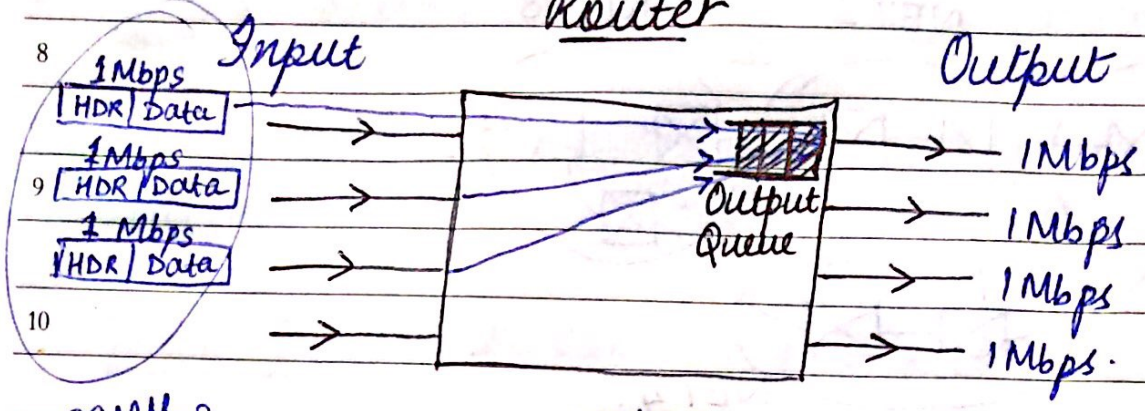
Routing Protocols
- → No loops
- → Quick Path if exists.

- Protocol: Rules for transmission and formating of data.

- IP Address: 32 bits.
  101 . 52 . 73 . 60
  Decimal of 8 bits

From the left ~~to~~ to right, informat^n gets more specific, for where to send data.
like, 101 might denote US, 52 might show the city, etc.

Router



at same time, with same capacity say 1 Mbps.

> If only first had come, it would have transmitted easily.

> But if 2 (for eg). more come for same output, we need to look →

Make a Queue

First in, First Out.

1) If Queue is empty, directly pass (no wait).
2) But if not, wait till your turn.

⇓

Packet Delay.

⋙ So,

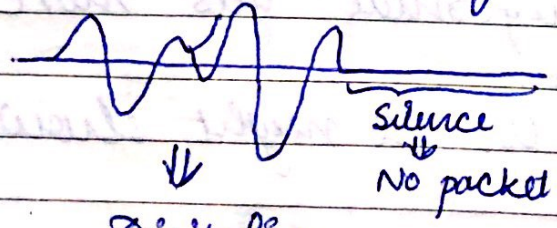
Latency might be because of packet delay.

3) If the queue is full, router might just discard the packet; that comes in. ⇒ PACKET DROP

SKYPE (VoIP) v/s TRADITIONAL VOICE CALL

↓ IP: Packet Switching

↓ Circuit Switching



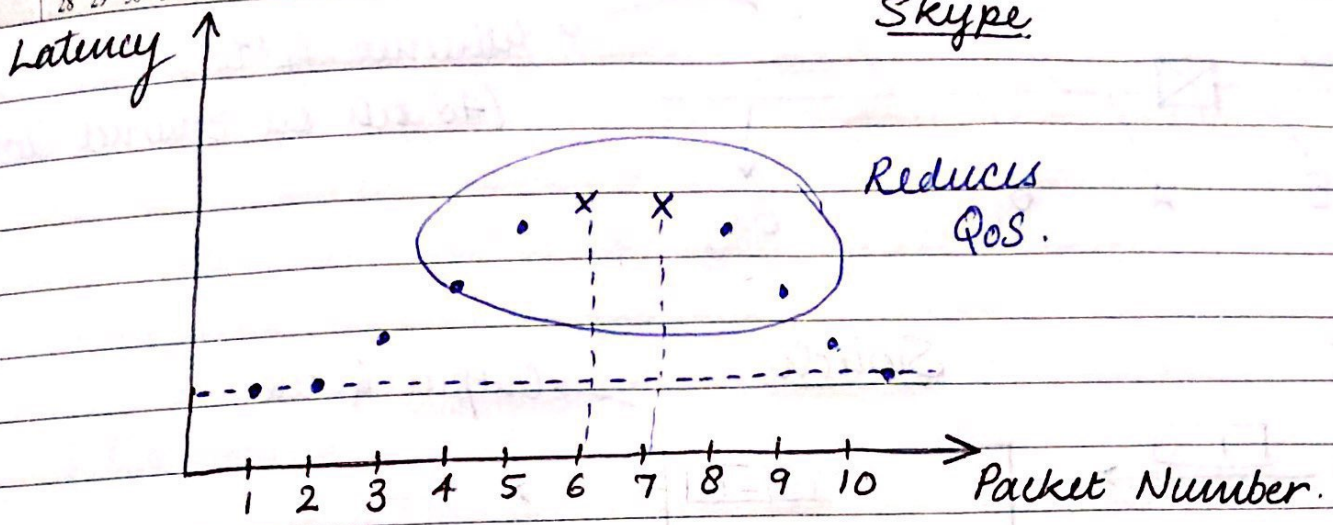
⇓

Digitalise

↳ [Data] .... [ ]

VoIP

Skype



If packets are being dropped, people need to slow down.

Packet Switching

05/08/2016

Header	Data

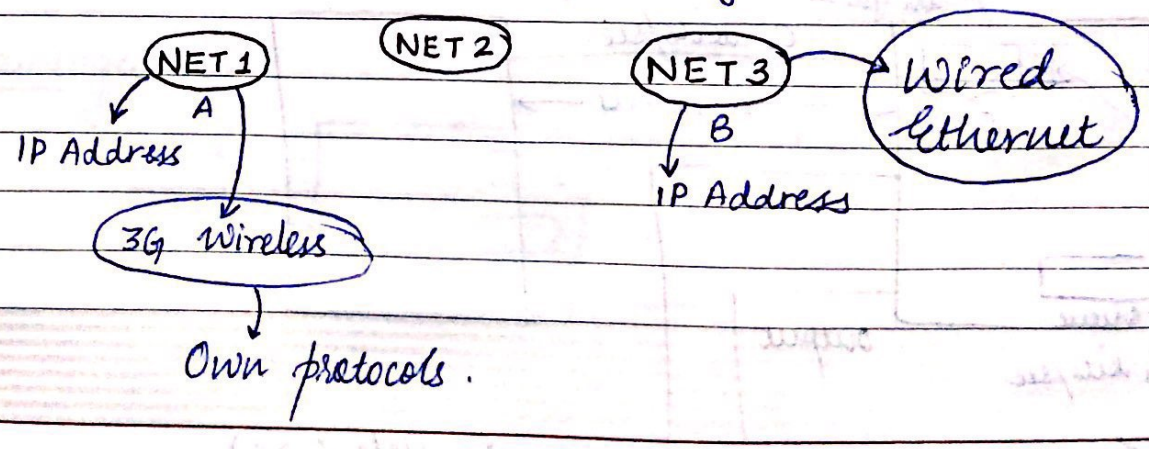
Header → Destination Address

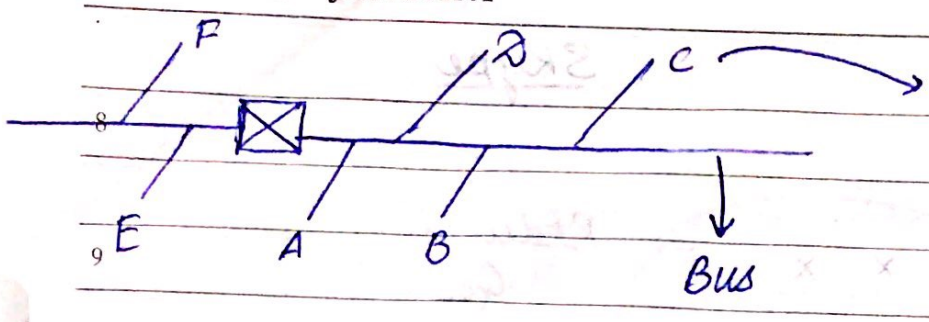
SWITCH / ROUTER

Switch: Used in context of ethernet or ATM, etc.

Router: Used when referring to IP Address

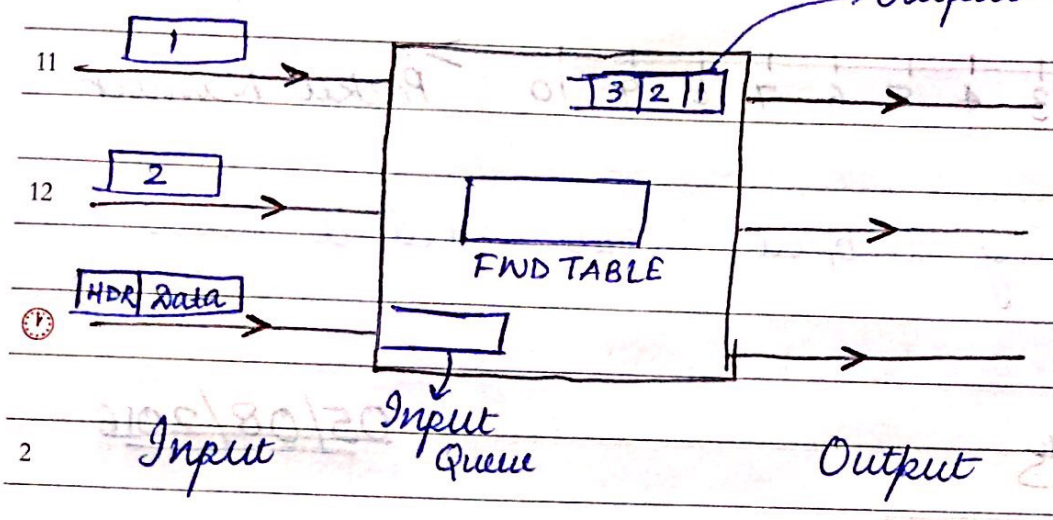
IP Address : Global Addressing System





Ethernet Address
(48 bits on Ethernet Card)

Switch

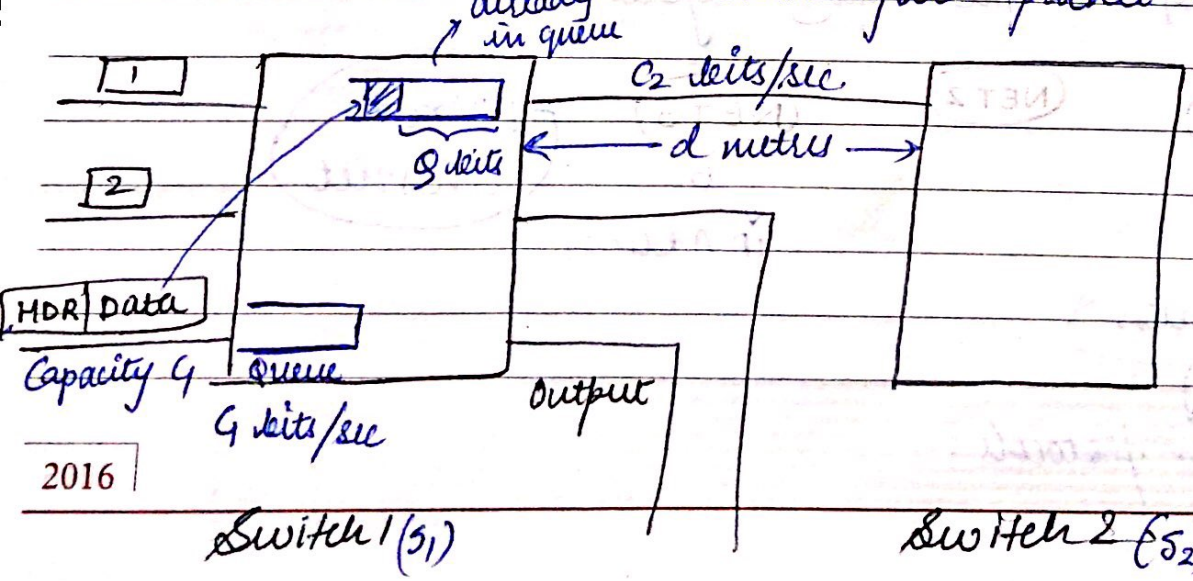


When we start receiving packets, it waits for the whole packet to come in & then forward. This is because, if forwarding continuously, if there is an error in packet, we might have already sent some part which should have actually been disposed. This is called <u>STORE & FORWARD</u>.

HDR Data error

↓

Wait till entire packet comes in and fwd packet if no error.



Speed of Light → c

Store — P/C_1
Queuing — Q/C_2
Propagation Delay — d/c
} delays.

$$\boxed{\text{Latency} = \frac{P}{C_1} + \frac{Q}{C_2} + \frac{d}{c}}$$

Time b/w^n first bit (1st) of packet entering S_1 to time first bit (1st) enters S_2.

Example - $C_1 = 100$ Mbps (→ bits) $d = 30$ km
$C_2 = 1$ Gbps $c = 3\times10^8$ m/s.
$P = 1200$ bytes
$Q = 5\times1200$ bytes. latency?

→ $\text{latency} = \frac{1200\times8}{100\times10^6} + \frac{5\times1200\times8}{10^9} + \frac{30\times10^3}{3\times10^8}$

$= 96\times10^{-6} + 48\times10^{-6} + 100\times10^{-6}$

$= 244\times10^{-6}$ s

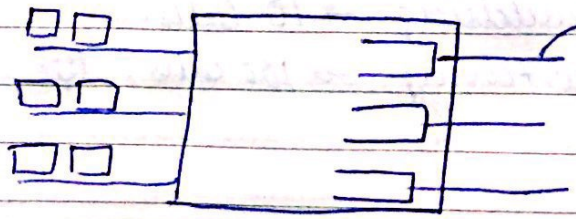
$= 2.4\times10^{-4}$ s $= 244\mu s = 0.244$ ms

Assumption -
* Time for looking up in fwd table is instantaneous. So, is the forwarding from input to output.

Sunday 24

Advantages :

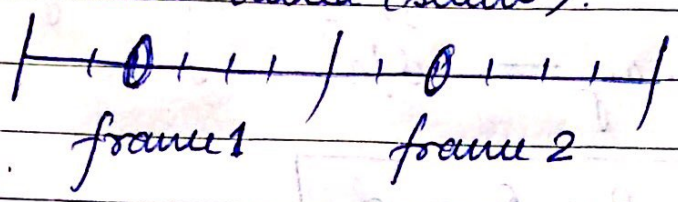
VoIP



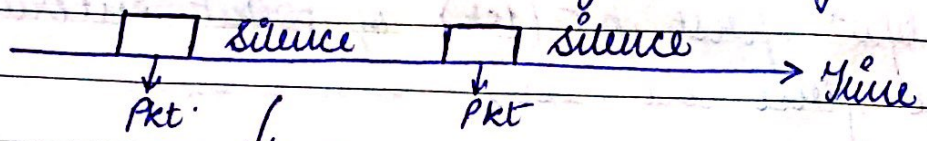
→ Suppose Capacity = 640 kbps. (10 Voice calls)

(1) > "Circuit Switching" allows maximum 10 calls on 640 kbps link.

In this, slots were reserved, which went unused when noone talked (silent).

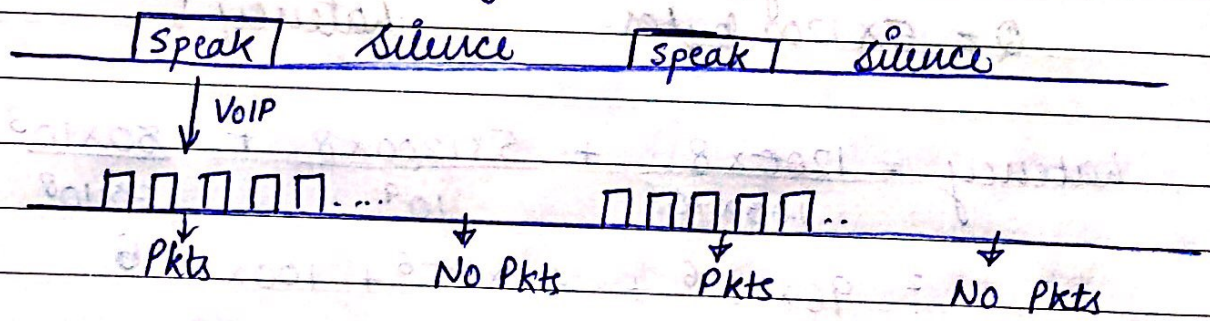


Suppose person speaks only 10% of time.



Avg. data rate $= \frac{64}{10} = 6.4$ kbps

Now, Packet Switching →



⇒ We can support [100 Voice Calls] on 640kbps link.

100 calls Generate 640kbps on average.

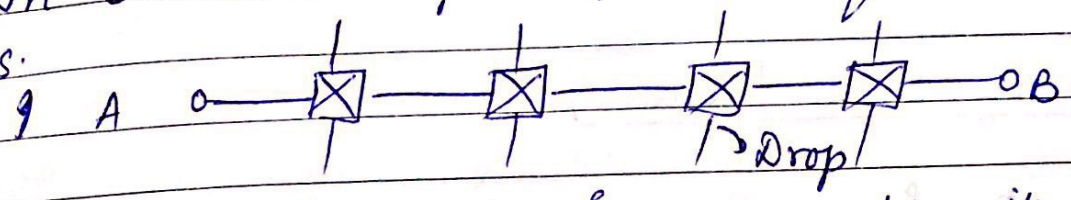
Queuing Analysis

So, Circuit Switching → 10 calls.
Packet Switching → 100 calls. ☺

Statistical Multiplexing Gain: Ability to support many more calls by multiplexing packets from these calls than possible by reserving bandwidth for each call.

Packet Drop?

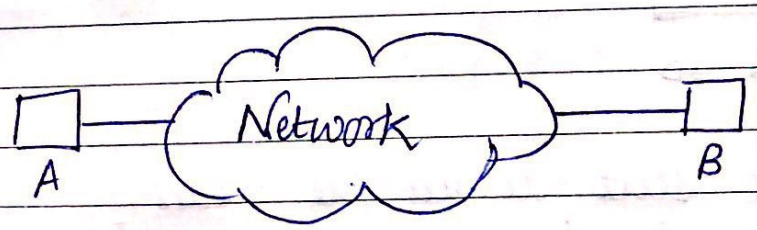
In case the output Queue is full, the packet drops.



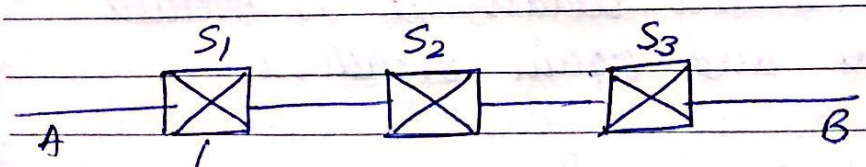
In case, B doesn't receive any pkt, it senses pkt. drop ⇒ informs A. But this might cause a lot of delay since complete round time to realise & inform A.

09/08/2016

Packet Switched Networks



Destination address



forwarding table. SWITCH/ROUTER

Data	Next hop

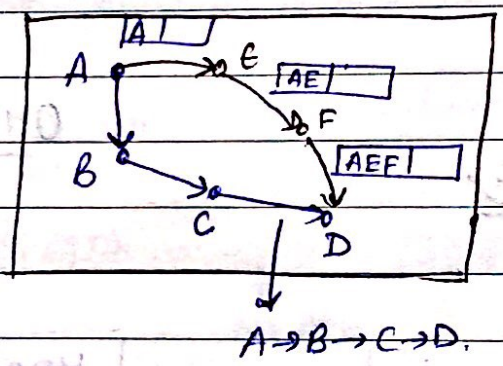
Idea: > Broadcast:
↳ Send to all nodes in network.

② > Unicast : Sending pkt. to single node.
③ > Multicast : Pkt. destined for group of nodes.
④ > Anycast : Pkt. destined for any one node of a group

S_1, S_2, S_3, B	Data

Source Routing: Put entire routing path.

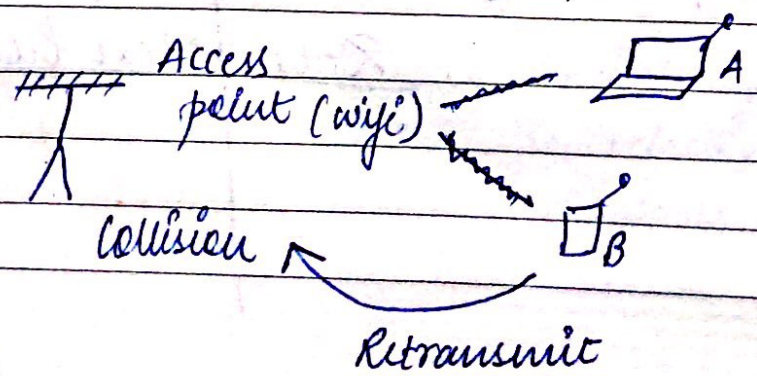
Mobile Adhoc Network:



Battle field.

While broadcast, pkt. is sent to all the nodes. According to the address in header, it is received by the destined node and again broadcast.

How to deal with packet loss?

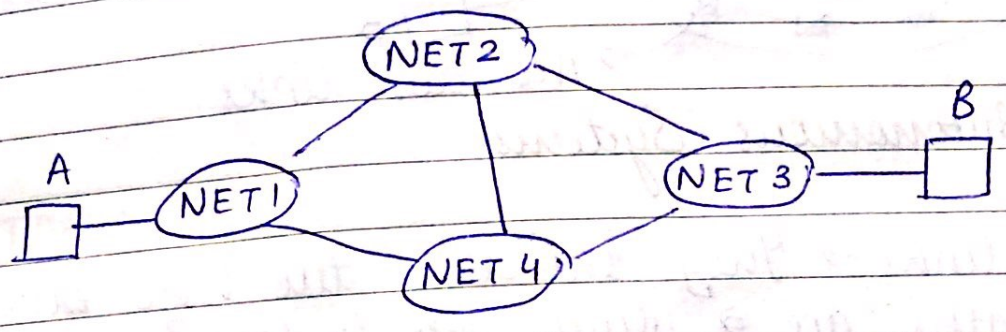


Both A & B sent at the same time, packet drop!

Retransmit packets → Who transmits?
→ When?

DARPA Project.

Timer Value?



* The packet will be retransmitted in b/w^n A & B. ~~instead o.~~
The (timer value > RTT) for A., in case the timer value crosses, the packet is retransmitted.

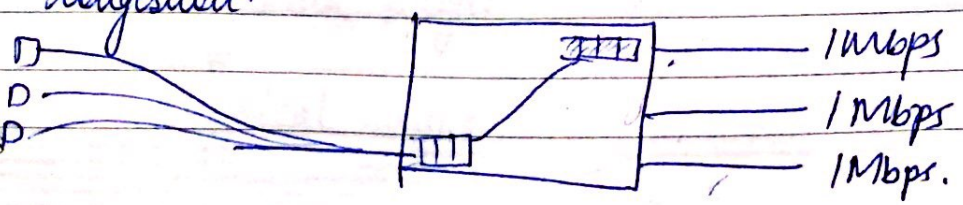
* In Internet: Source node retransmits (TCP)

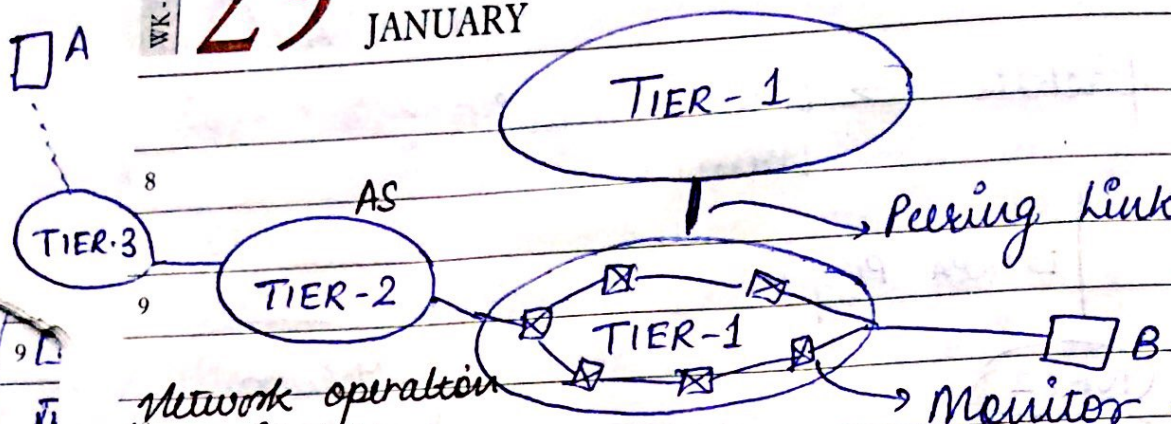
* Congestion: Input rate of packets higher than output rate leading to Queues filling and drops.

* TCP: Congestion Control.

Decrease Input Rate: How to do this?

① In case, I have 3 pkts coming from a node, the switch can send all of them from one port to decrease the input rate to 1/3 Mbps, while output rate remains 1 Mbps ⇒ Avoiding / Reducing congestion.





Network operation Centres.

A.S → Autonomous Systems.

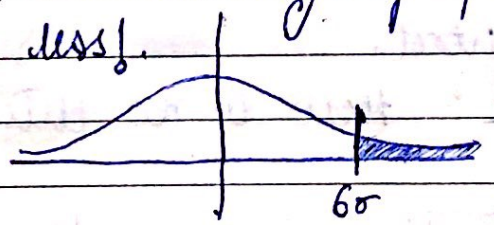
Monitor links → They basically tell how busy the paths are ⇒ which one to take?

Upgrade links – 1 Gbps → 10 Gbps.
Increase Capacity.

Over Provisioned – More capacity than input traffic

10/08/2016

* 6-σ system: Probability of pkt. getting lost is very less!



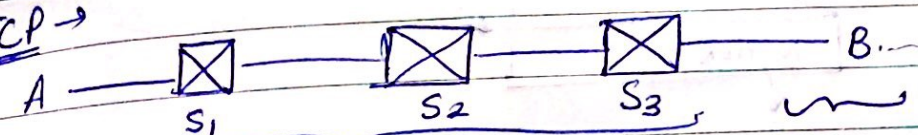
* Modulation, Framing, Routing, Congestion control, Reliability (Dealing with pkt loss), Medium Access.

• **Layering:**

Protocols

Application Layer	→ User Interface, Voice/Info to Bits, etc.
Transport Layer	→ Congestion Control, Reliability, Flow Control
Network Layer	→ Routing
Data Link Layer	→ Framing, Medium Access
Physical Layer	→ Modulation

TCP →



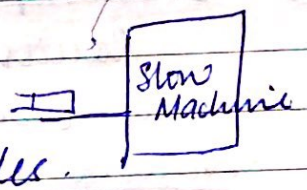
Congestion Control Flow Control

These are to control congestion.
Intermediate nodes by CC, end node by FC.

{ B can explicitly tell A to slow down while S1, S2, S3 can't }

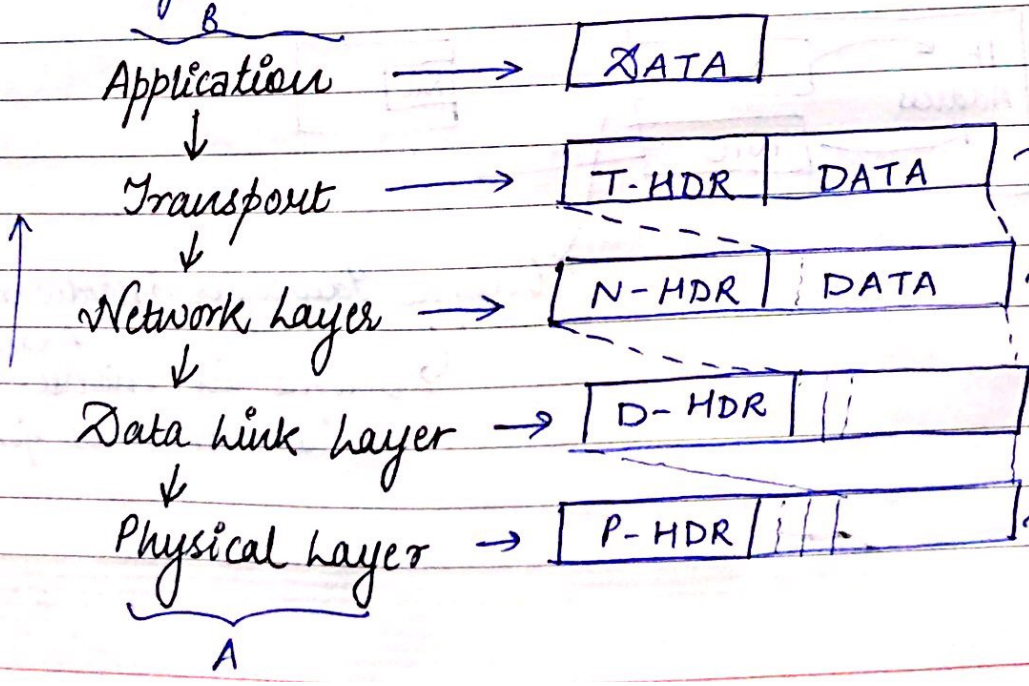
Flow Control:

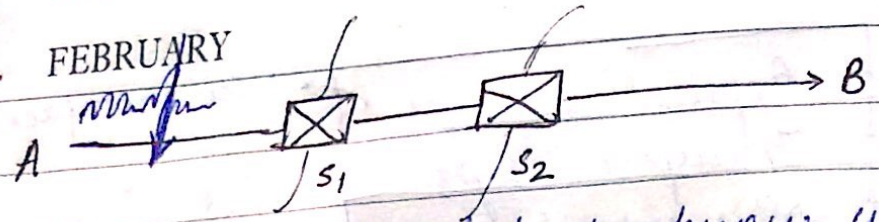
→ Handles Congestion in end nodes.



* Let's say, we have an application-

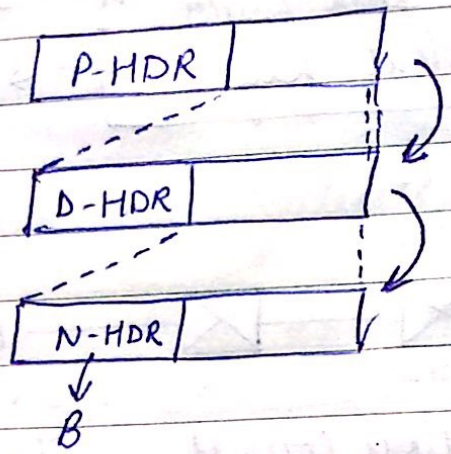
Examples

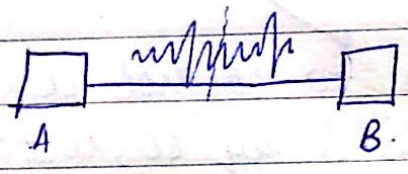




The switches now decoded to know where to send it.

Eg: S_1 :



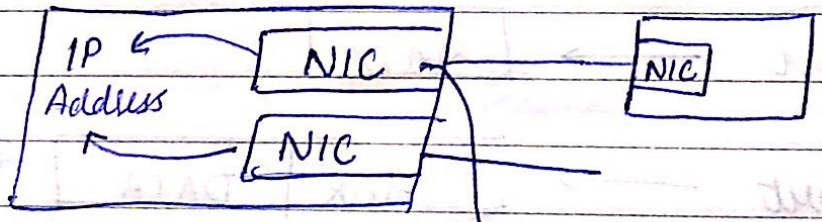
Note: ① 

Add preamble to sync both A & B.

② SWITCH / ROUTER :

Routes sends the data on the basis of IP Address, while Switch sends the data on the base of Network Address.

Network Interface Card



Unique Identifier {Hardware Address}
↳ Unique in universe :)
Cannot be same for any 2

Why IP Addressing?

1. Common Addressing System for Heterogenous Networks.
2. Scalability of Routing.

→ Flat Addressing (for network address)

Dest.	Next hop
S_2	
S_3	
S_4	
S_5	

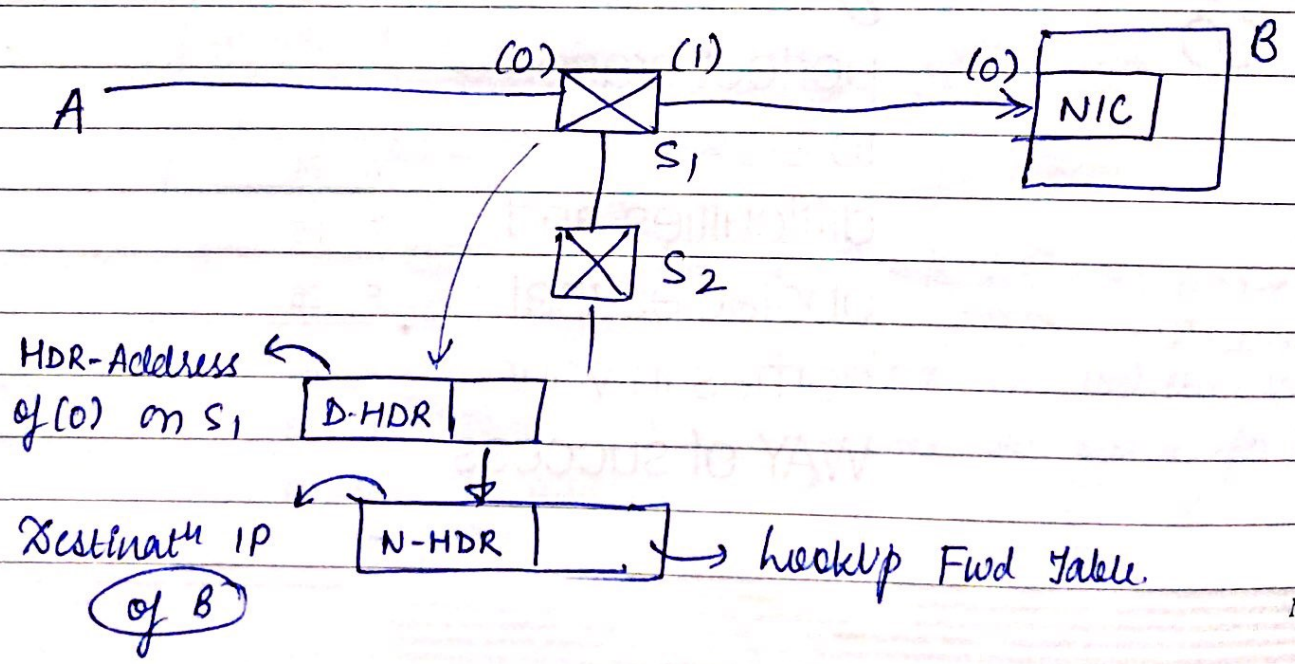
Each node must have hardware address entered in the table
⇒ Not scalable.

While IP Address can be scalable.
↓
~~Hierarchical~~ Hierarchical Address System.

→ **IP Address** -

Hierarchical Address System

↳ Say we have a cluster, say IIT. So, any network outside IIT mustnot store all IP addresses of IIT. It can instead have the main header or a part for complete IIT.



12/08/16

Protocol Layering

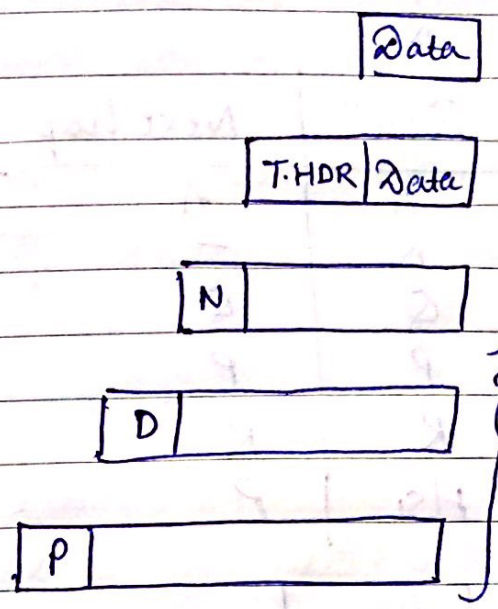
Application

Transport

L3 ← Networking

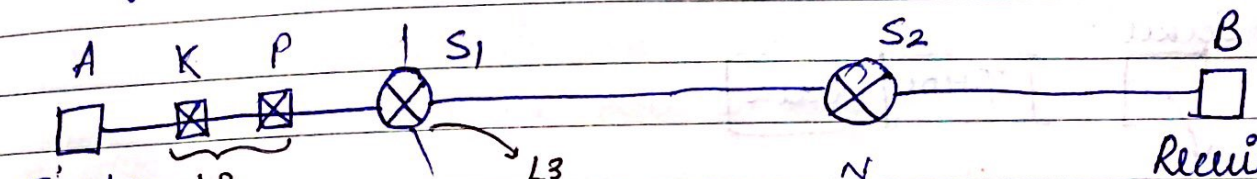
L2 ← DLL

L1 ← Physical.



Stays almost same.

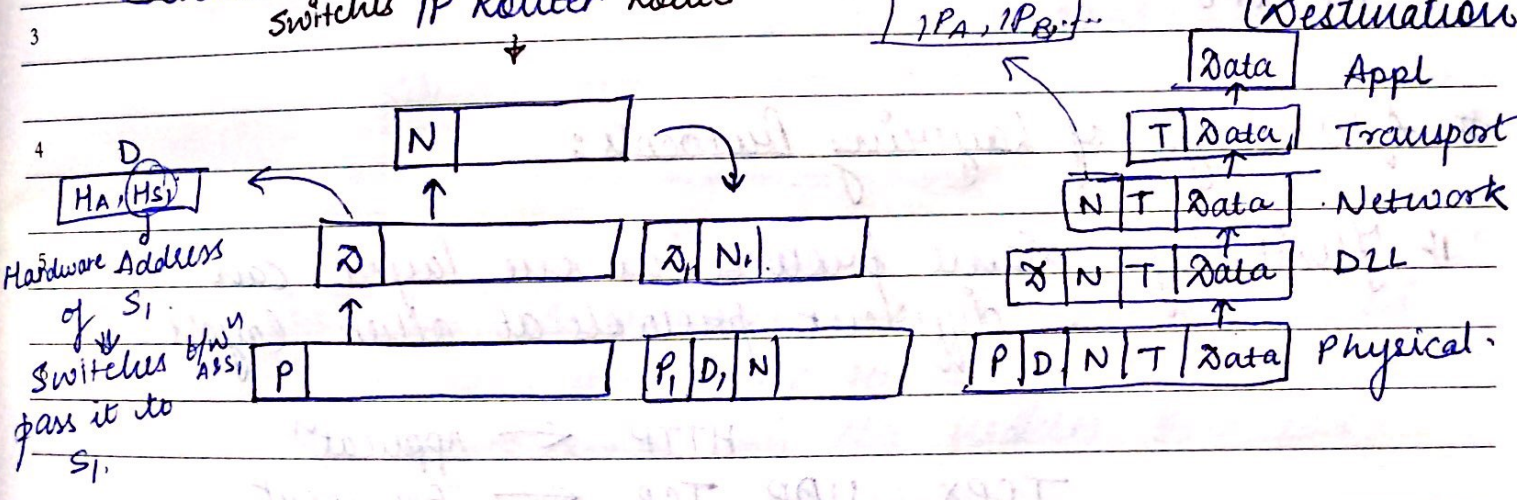
Change more often.



Sender

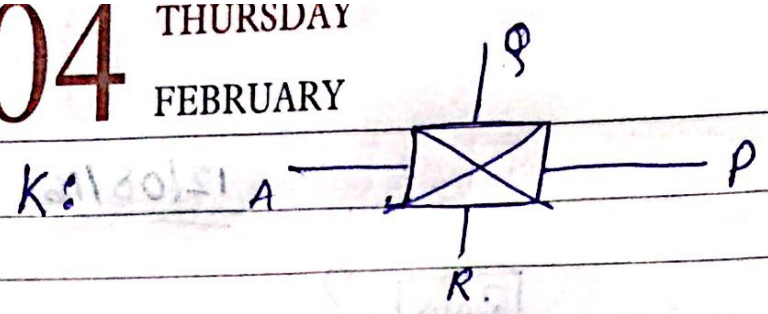
Switches IP Router Router

Receiver (Destination)



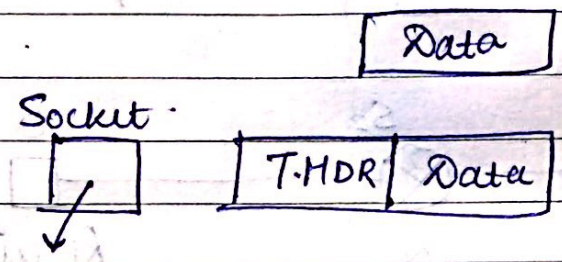
L_3 : $A - S_1 - S_2 \rightarrow B$

L_2 : $A \rightarrow K - P - S_1 - S_2 - B$



Forwarding Table :

Destn	Next hop
A	A
K	—
Q	Q
P	P
R	R
HS1	P



Advantages of Layering Protocols:

1) Flexibility: Same protocol at one layer can use different protocols at other layers.

HTTP ← Applicatn

TCPX, UDP, TCP ← Transport

IP

L2, L1 — (Ethernet, Wifi, ATM)

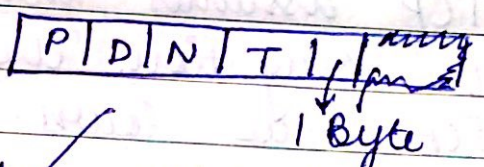
2) Ease of Implementation: Solve few problems at each layer.

3) Ease of Modification : Can change / improve any protocol at a particular layer without tampering with other layers.

Disadvantages of Layering Protocols :

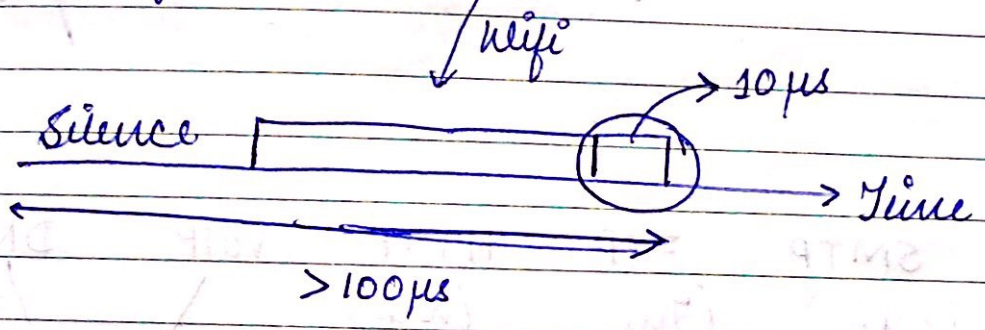
1) Overheads :

ⓐ Processing Delays.
ⓑ Header Overhead.



↓

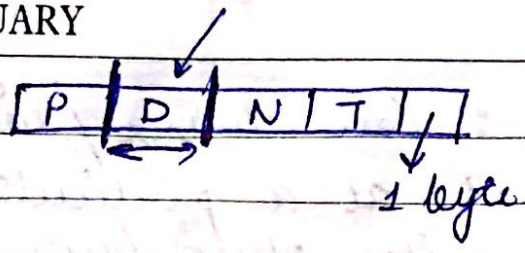
Even if data is just 1 byte, we end up sending a lot of data due to headers.

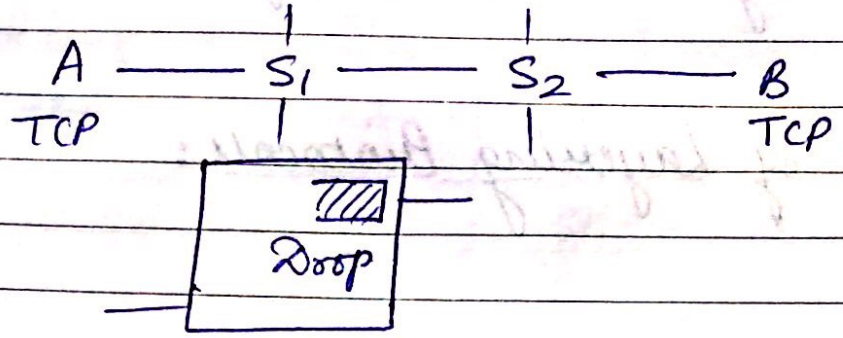


In wifi, sometimes even if the ~~seep~~ speed is 1 Gbps, we endup receiving only 50 Mbps, rest being used by the header overhead.

2) Assumption of Independence of Layers is not true :

Application
Transport —TCP→ Reliability
Network
Data Link
Physical



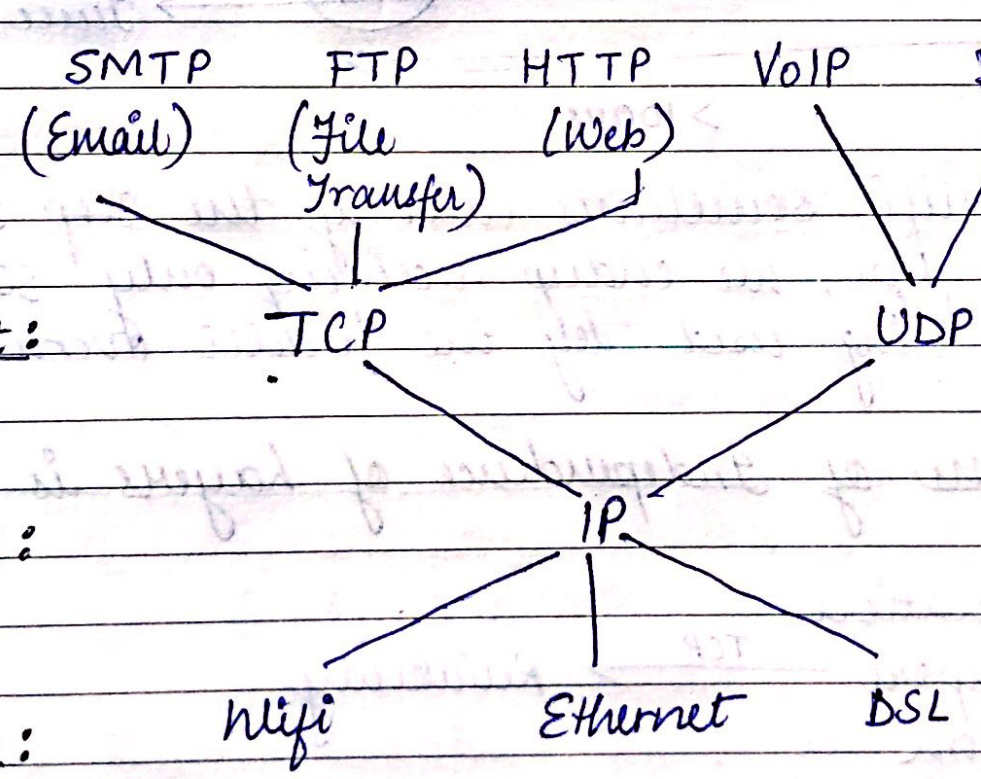


> TCP assumes that the drop is because of the congestion (even if it is not). Hence, TCP slows down.

⇓

Cross layer Solutions (To address such problems).

Note:



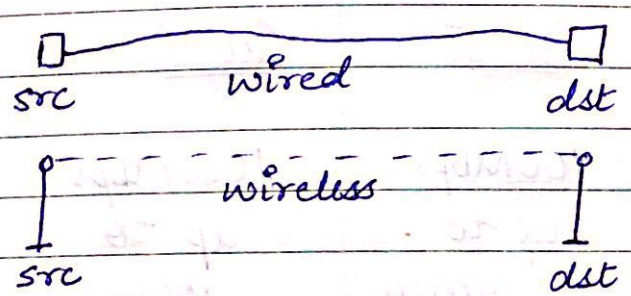
16/08/16

Protocol Layering

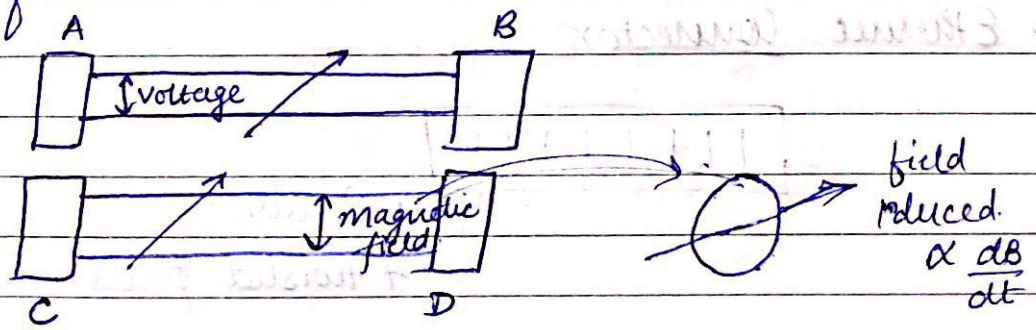
OSI

- Application
- Transport
- Networking
- Data Link
- Physical

① If we have a src. and a dstⁿ, the communicatⁿ can be wired or wireless.

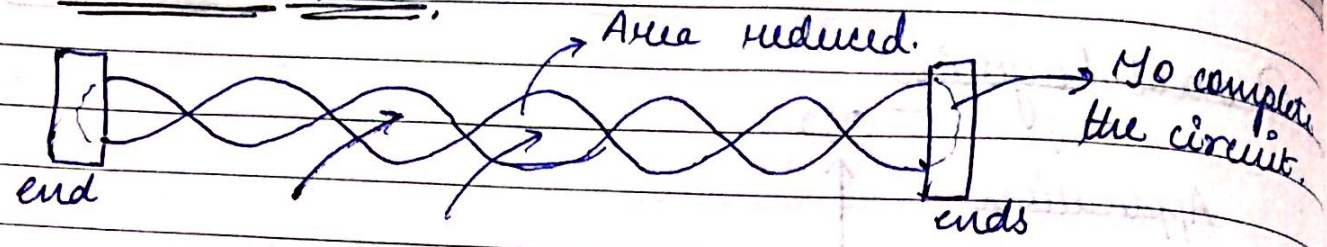


② The communicatⁿ can be through voltage or magnetic field.



We have 2 wires as one is for reference. Since Potential diff. is what matters ⇒ diff. b/wⁿ V's of 2 wires.

(A) Twisted Pair.

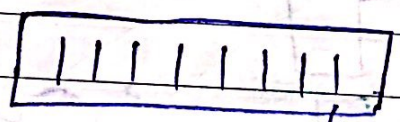


- Used in telephone network, ethernet, etc.
- Voltage induced in different twists may cancel each other.
- These can be of different types depending on quality of twists. Qualities →

eg:

Category 3	Cat 5	Cat 6
10 Mbps Data rate upto 100 meters	100Mbps up to 100 meters	1000Mbps up to 100m

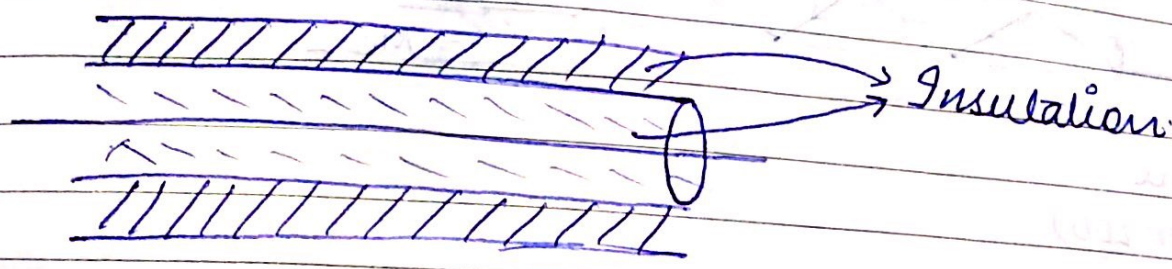
- Ethernet Connector



→ 8 wires
4 twisted pairs.

Cross talk: Signals on different twisted pairs interfere!

(B) Co-axial Cable



- Robust to induction from magnetic fields.
- Qualities →

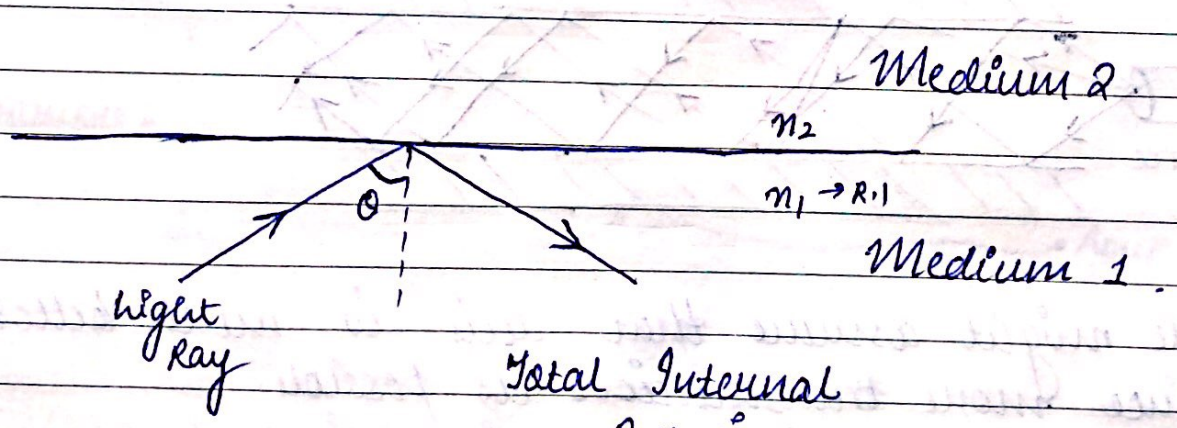
(a) Thick Net Coax : 0.4 inch diameter ⇒ 100 Mbps upto 500 m

(b) Thin Net Coax : 0.2 inch diameter ⇒ 100 Mbps upto 200 m.

↓

The diameter includes the insulatn as well, but mostly, the quality of conductor improves.

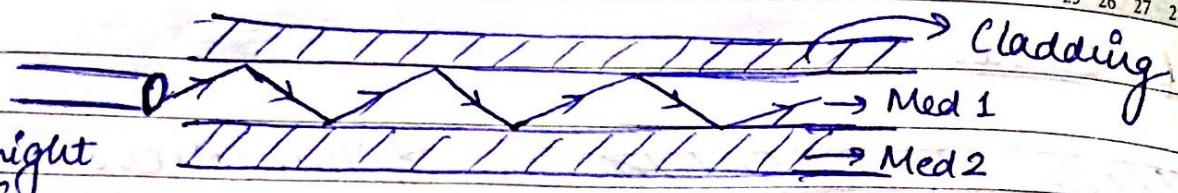
(C) Optic Fibre



$\theta > \theta_c$

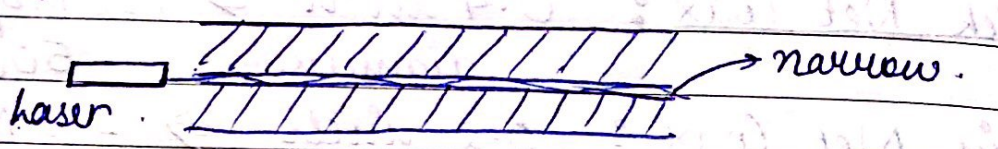
↳ Critical angle.

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right).$$



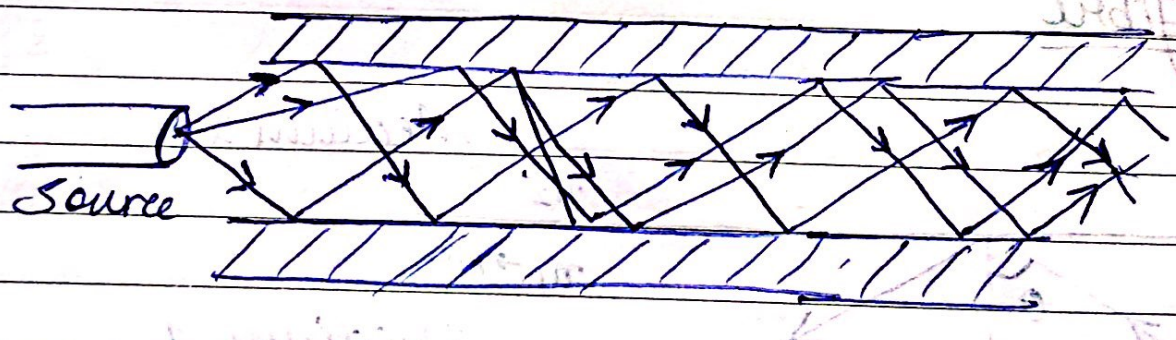
Q. Types of Optical Fibres :

(a) Single-Mode Fibre :-

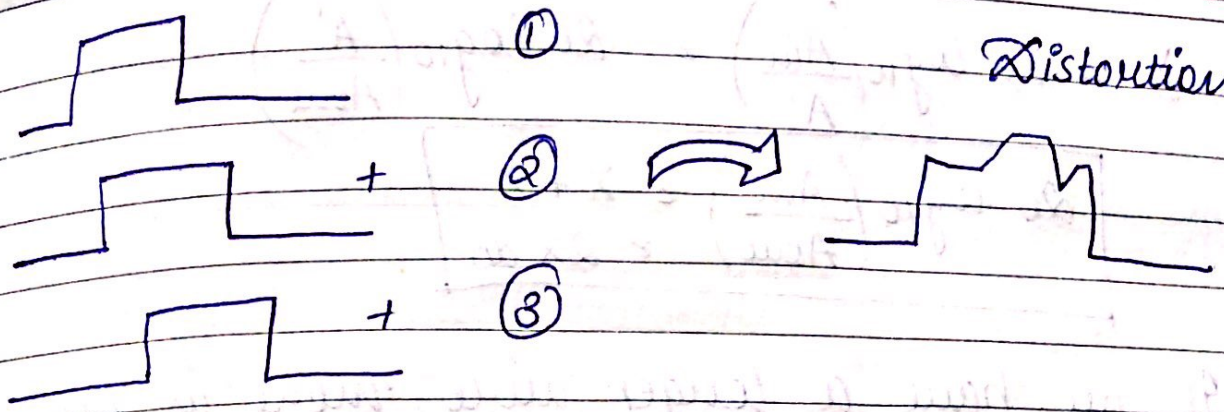


- Narrow enough to let single ray to pass.
- Single Ray passes through.

(b) Multi-Mode Fibre :- (Cheaper)

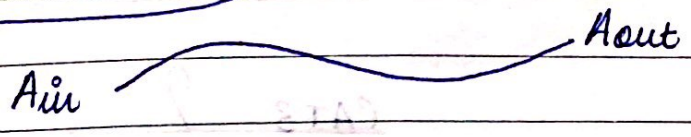


We might assume that this is much better since more transmission is possible.
But when multiple rays with different time lags, distortions might occur.



Quality of Wire/Cable

Attenuation



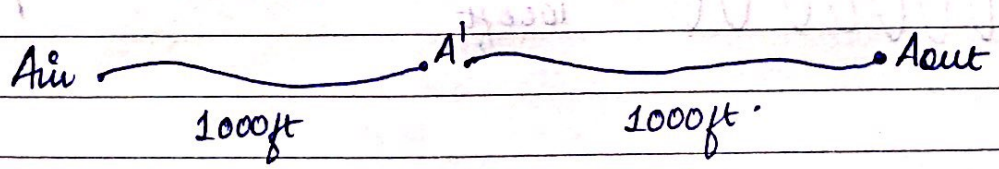
$$\text{Attenuation (in dB)} = 10 \log_{10}\left(\frac{Power_{in}}{Power_{out}}\right)$$

$$= 10 \log_{10} \frac{A_{in}^2}{A_{out}^2}$$

$Power \propto A^2$

$$\boxed{\text{Attenuation} = 20 \log_{10} \frac{A_{in}}{A_{out}}}$$

Example:



Sol^n:

⇒ Total Attenuat^n = 2X dB

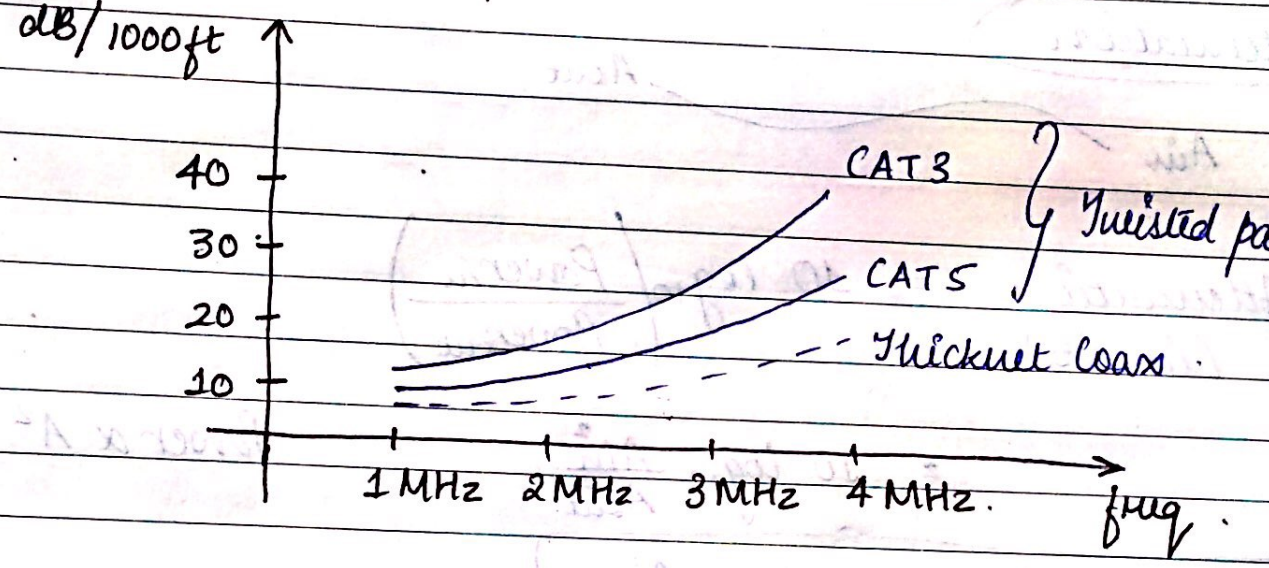
MESSAGES

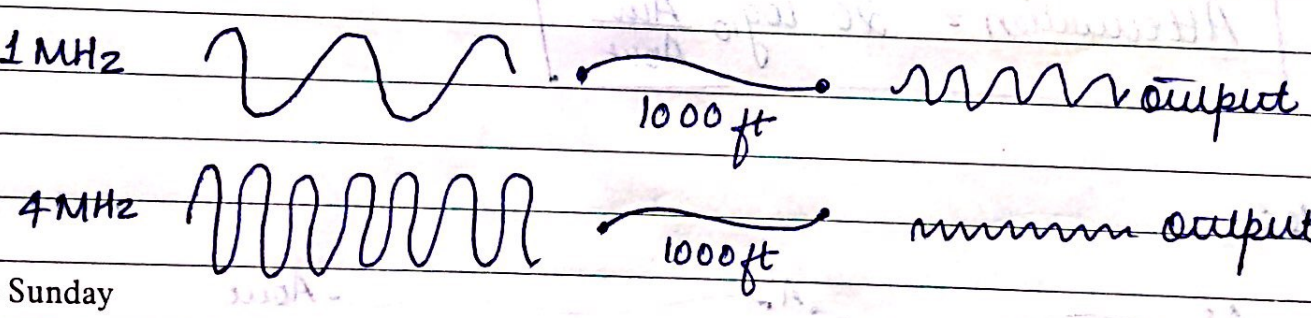
$$X = 20 \log_{10}\left(\frac{A_{in}}{A'}\right) = 20 \log_{10}\left(\frac{A'}{A_{out}}\right)$$

$$\boxed{20 \log_{10}\left(\frac{A_{in}}{A_{out}}\right) = X + X = 2X \text{ dB}}$$

→ If we have a longer wire, more is the attenuation.

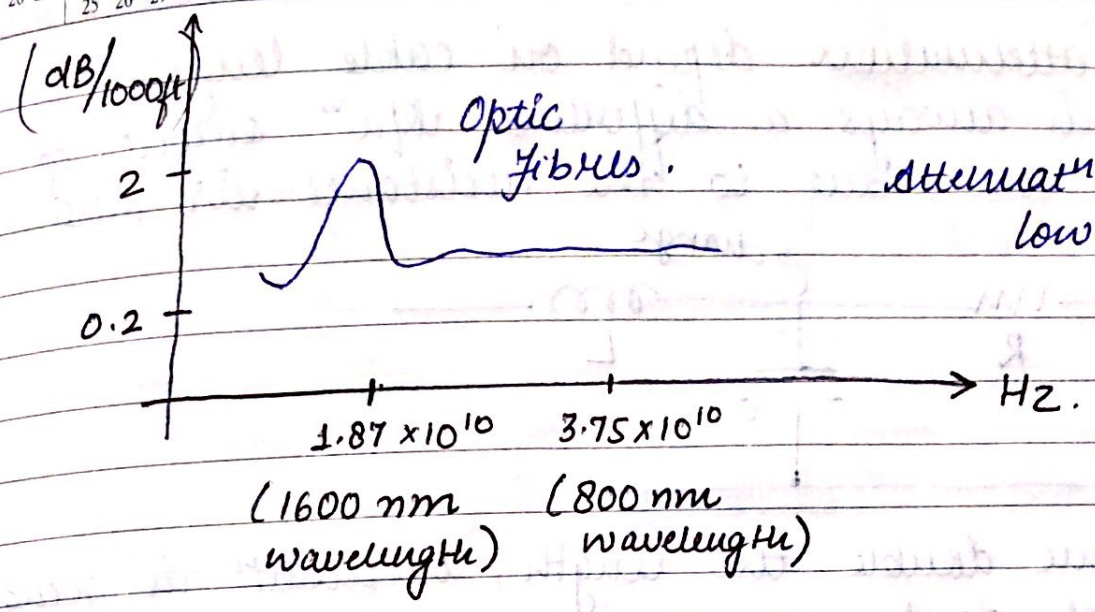
⇒ Graphical Comparision





→ Higher the frequency, higher is the attenuation.

Thumb Rule: Use higher frequency to get higher data rates.



Attenuatn very low.

→ As per record, a lab was able to attain 255 Tbps.

17/08/2016

Q Does attenuation depend on amplitude?

→ Ain ~~~ Aout Ain/Aout

$$\boxed{X = 20 \log_{10} \frac{A_{in}}{A_{out}} \text{ dB}}$$

⇒ Attenuatn doesnot depend on Ain, but ratio Ain/Aout. If Ain doubles, Aout doubles.

⇒ Ratio of amplitudes at input & output

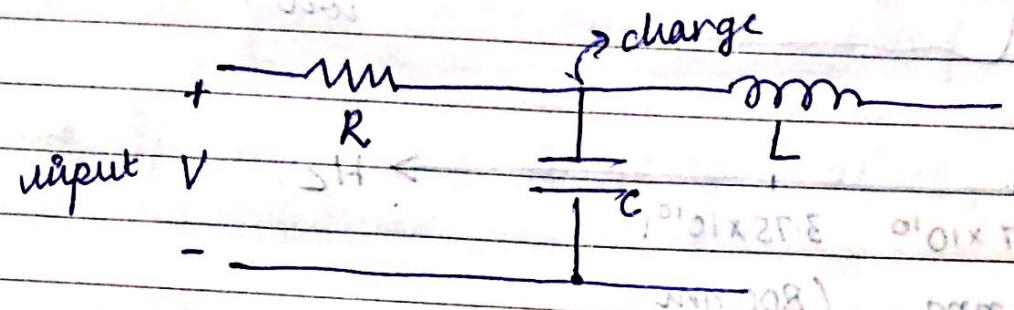
Q Does attenuation depend on frequency?

→ Yes.

(Graph ↑)

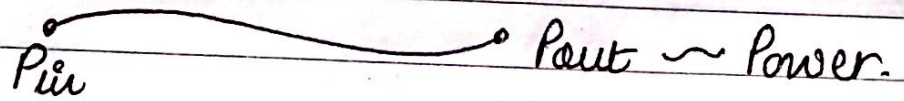
Q Does attenuation depend on cable length?

→ There is always a difference b/w output & input end., due to the resistance in wire.



If we double the length, attenuat^n is going to get <u>double</u> on the dB scale.

Example:



(i) Suppose $P_{out} = \frac{1}{2} P_{in}$.

→ Attenuat^n $= 10 \log_{10} \frac{P_{in}}{P_{out}} \approx$ 3 dB

(ii) $P_{out} = \frac{1}{4} P_{in}$

→ Attenuation $= 10 \log_{10} \frac{P_{in}}{P_{out}} \approx$ 6 dB

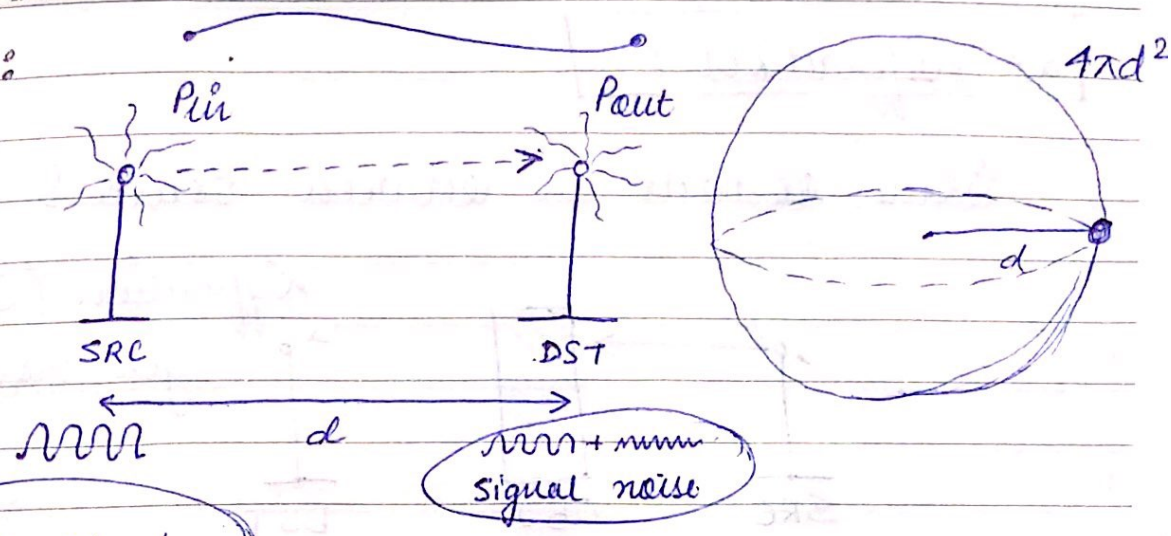
(iii) $P_{out} = \frac{1}{8} P_{in}$

→ Attenuation $= 10 \log_{10} \frac{P_{in}}{P_{out}} \approx$ 9 dB

(iv) $P_{out} = \frac{1}{10} P_{in}$

→ Attenuation $= 10 \log_{10} \frac{P_{in}}{P_{out}} \approx$ 10 dB

Wireless :

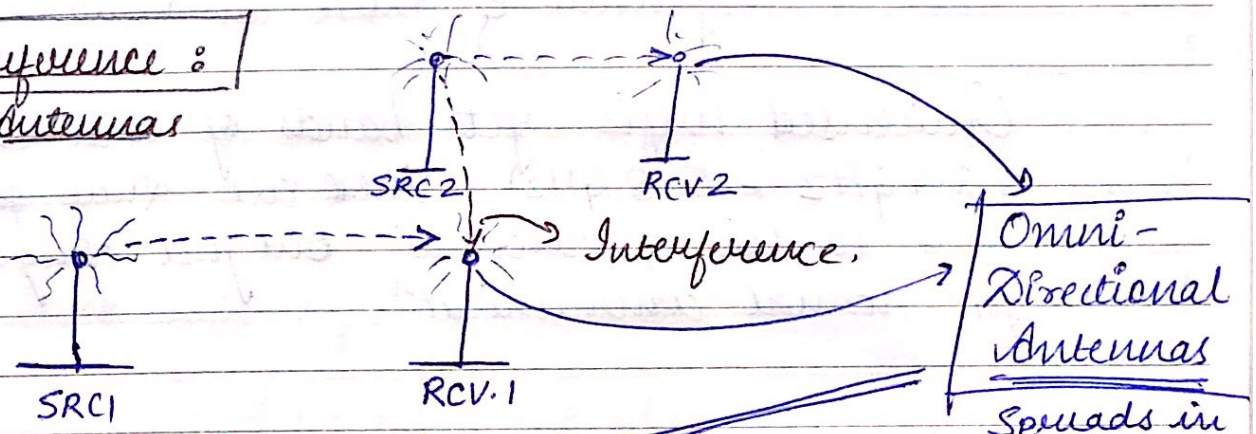


$$\frac{P_{out}}{P_{in}} \propto \frac{1}{d^2}$$

* Other Issues

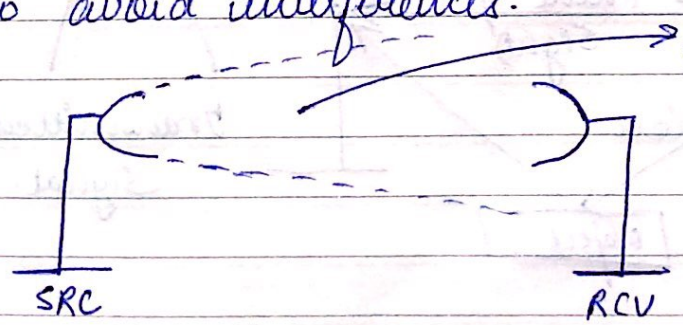
1) Interference :

@ Antennas



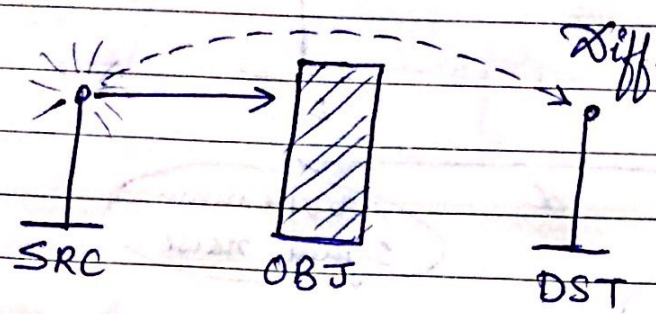
Sol^n (b) Directional Antennas -

We can use direct^nal antennas to avoid interferences.



2) Diffraction :

Some obstacle in between source & destination.



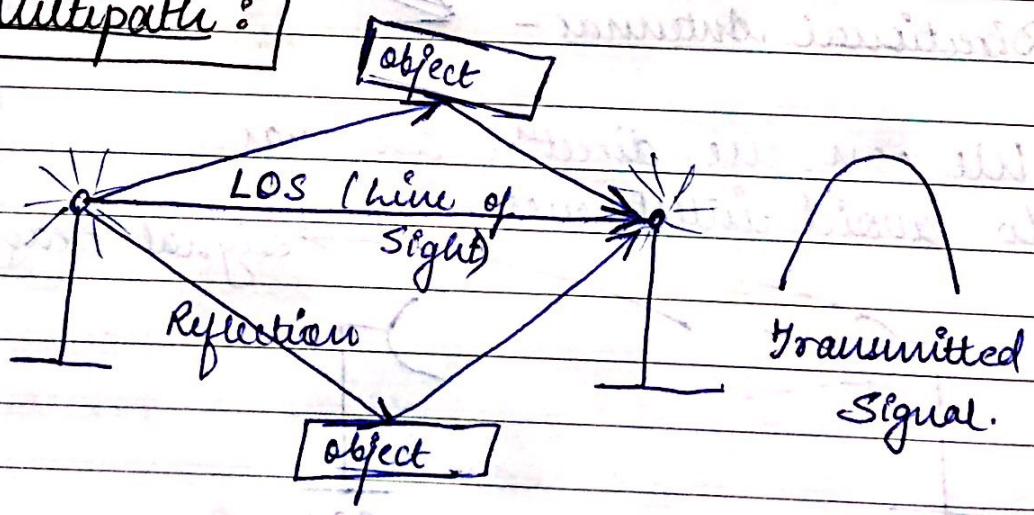
Diffraction (Signal goes around objects).

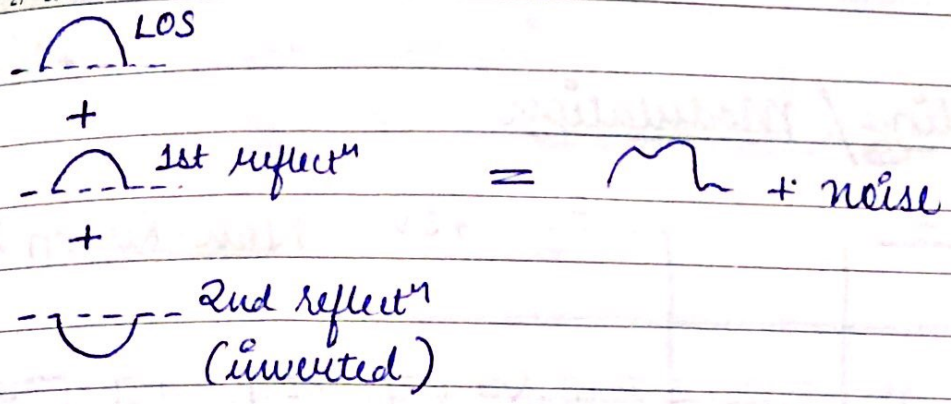
@ Frequency : lower frequency diffract more easily.

⇒ lower freq. bands are much more expensive & more in demand !.

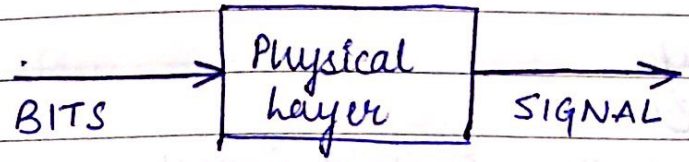
Unlicensed Wifis get bands of around (2.4 GHz - 5.8 GHz). These are quite poor due to lot of attenuatn. But just okayish for normal communicatn.

3) Multipath :





SIGNALLING / MODULATION

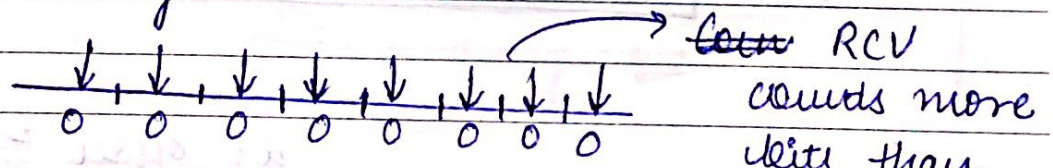


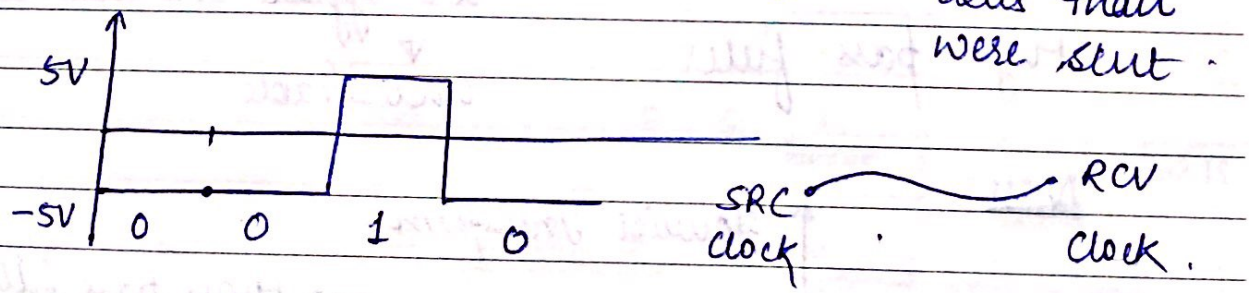
- Wired Media:

1) Non-Return to Zero (NRZ)

Problems:

@ Clock Recovery:

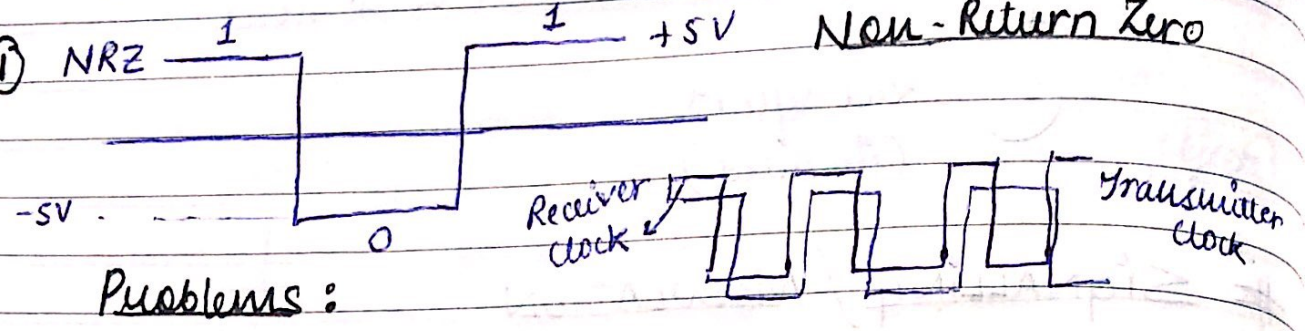




19/08/2016

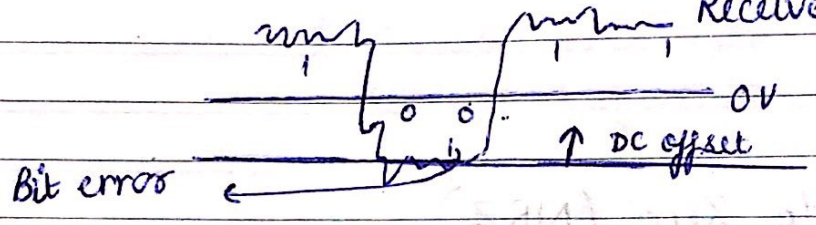
Signalling / Modulation

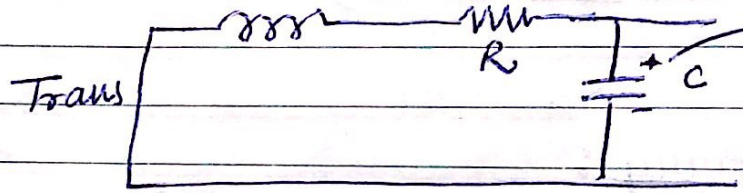
① NRZ — Non-Return Zero



Problems :

ⓐ Clock Recovery
ⓑ Baseline Wander





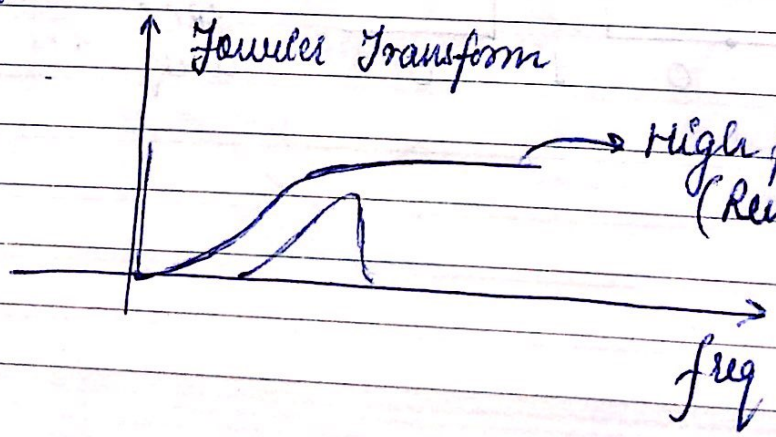
→ Non-zero voltage possible even if transmitted signal is zero.

d.c. offset
↓
undesirable

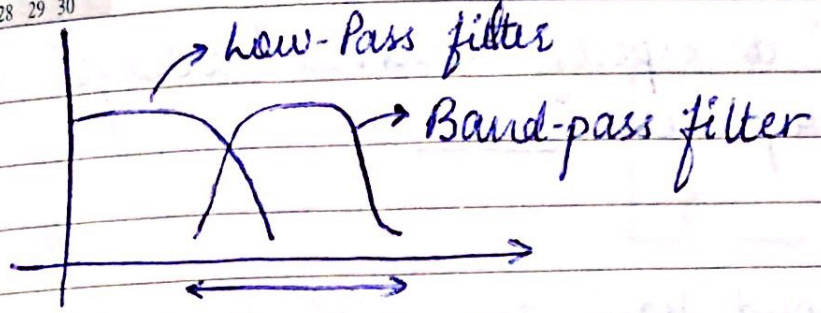
High-pass filter.

21 Sunday

Note:

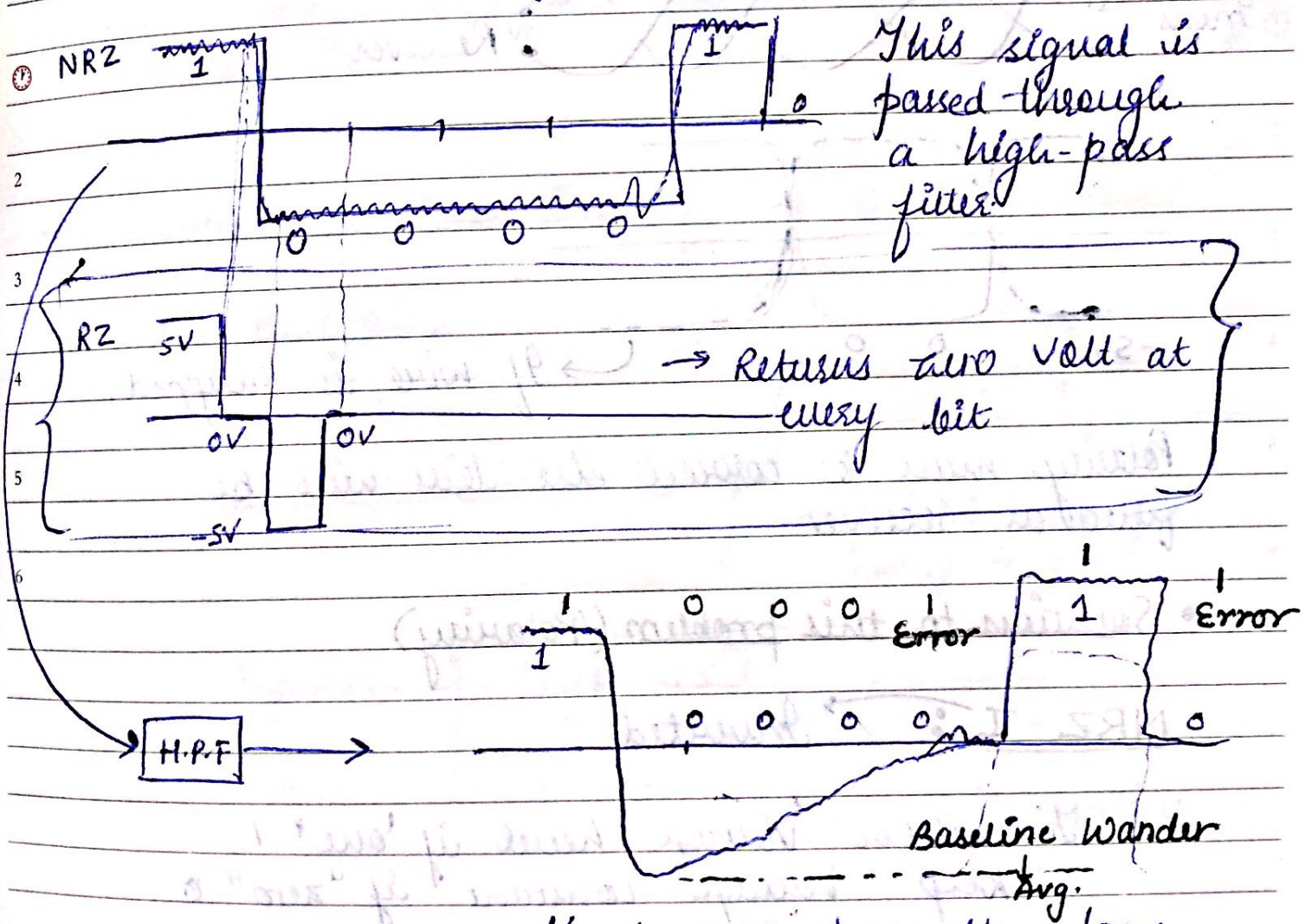


→ High pass filter (Remove low-frequency component)



Band pass filter clears everything outside low-pass filter.

Consider a "NRZ" signal!

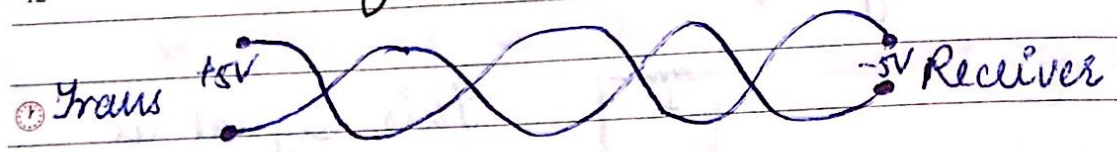


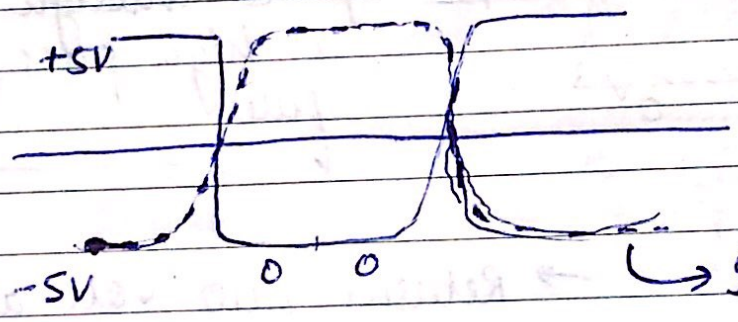
It doesn't pass the low voltage (when 0)

"Reciver" expects observed "average" of signal to represent "Zero".

(In the second half, the high pass filter has shifted up and hence the entire signal henceforth will shift up)

© Polarity





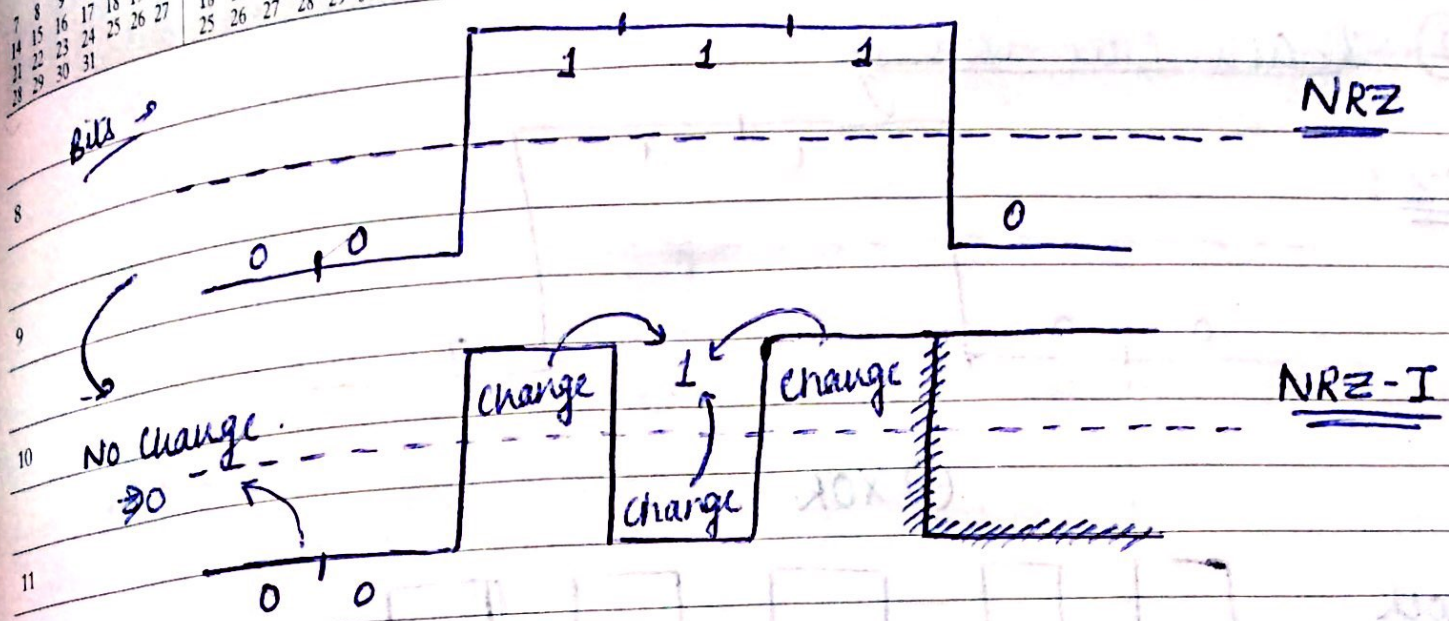
→ If wire is swapped.

Polarity must be correct else bits will be filled at reciver.

- Solution to this problem (Polarity)

NRZ - I : → Inverted

Transition Voltage hence if "one" 1
Keep Voltage constant if "zero" 0



For 1 bit, change ⇒ ✓ But at 0's, clock recovery problem ☹.

→ Solutions to Clock Recovery & Baseline Wander

① 4B/5B Coding

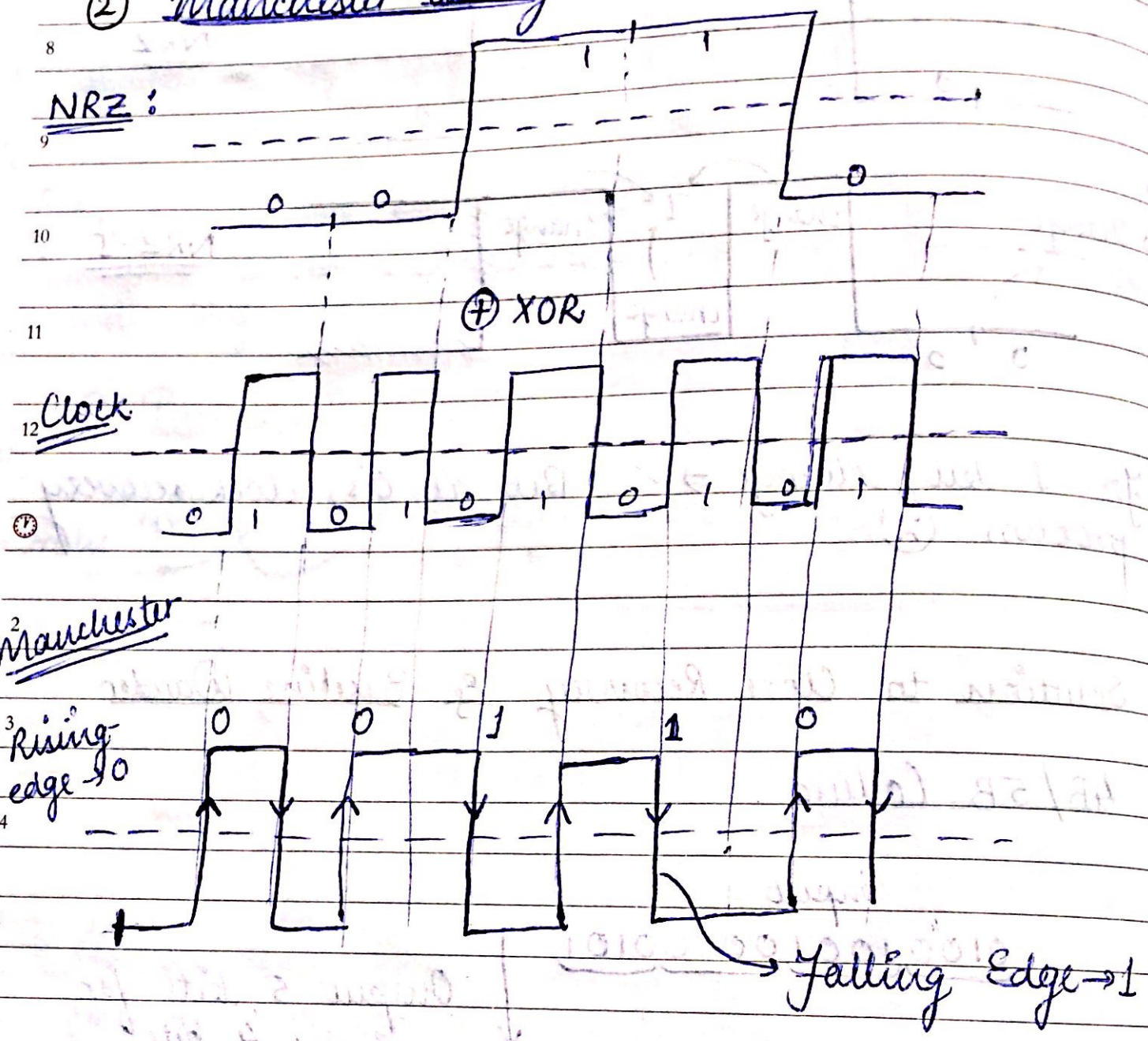
Input
0100 1001 0000 0101

↓ Output 5 bits for every 4 bits

Input (4)	Output (5)
0000	01010 → Atmost 2 Consecutive Zeroes or Ones.

4B/5B Coding with NRZ-I used in 100Mbps Ethernet

② Manchester Coding



> We need to know when bit begins. Accordingly, falling edge → 1 or 0.

> Solved the clock recovery problem & Baseline Wander (coz the signal is continuously transitioning b/w 0 to 1) ✓

> Polarity must be correct!

☺

Manchester Coding is used in "ETHERNET 10 BASE-T"

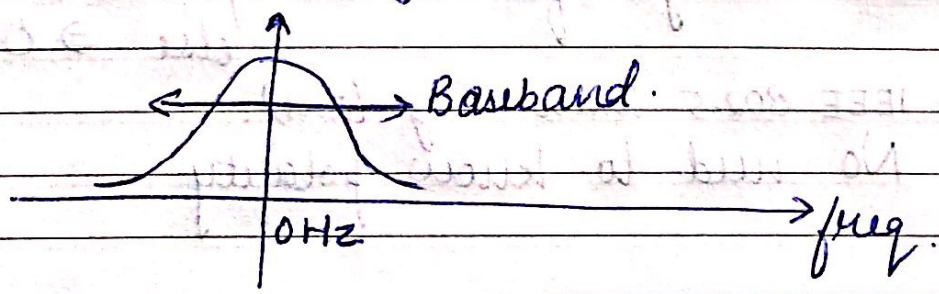
(IEEE 802.3 Standard)

10 BASE-T

- 10 Mbps
- Baseband Signalling
- Twisted pair

100 BASE-F

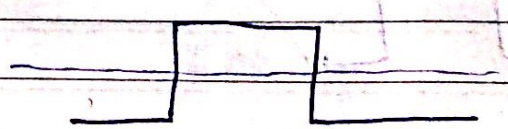
- 100 Mbps
- Baseband Signalling
- Fibre Optic



23/08/2016

0 or 1

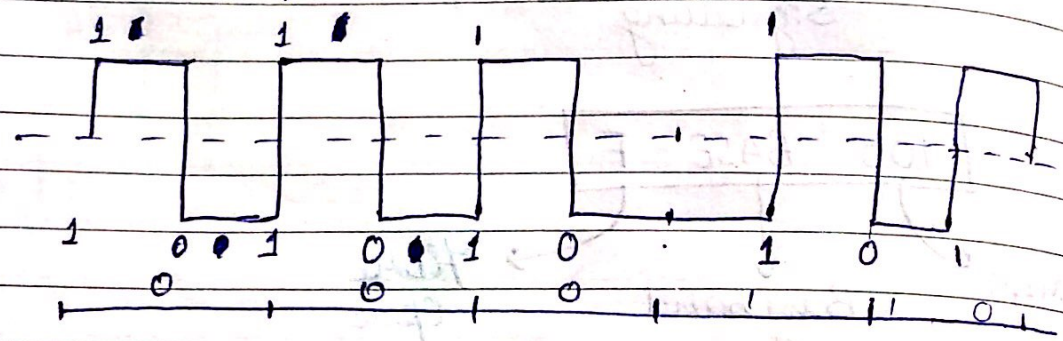
Rising edge → 0
Falling edge → 1.
(Used in 10 BASE-T).



Differential Manchester Coding

bit = 1 ⇒ 1st half of bit period. Same voltage as last half of previous bit period.

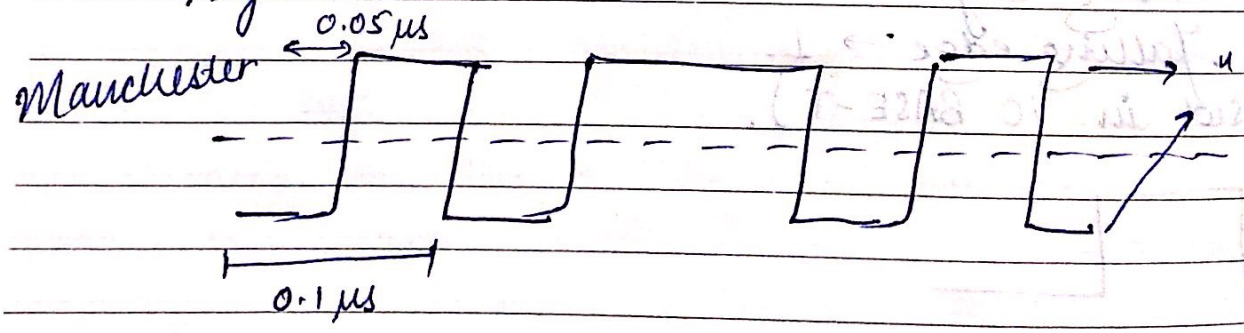
bit = 0 ⇒ 1st half of bit period, opposite of last half of previous bit



Const. voltage for 1 bit period ⇒ 1
else ⇒ 0.

(Used in IEEE 802.5 token ring lans).
No need to know polarity

Baud Rate: Max. number of distinct symbol changes made to the transmission medium per second in a digitally modulated signal.

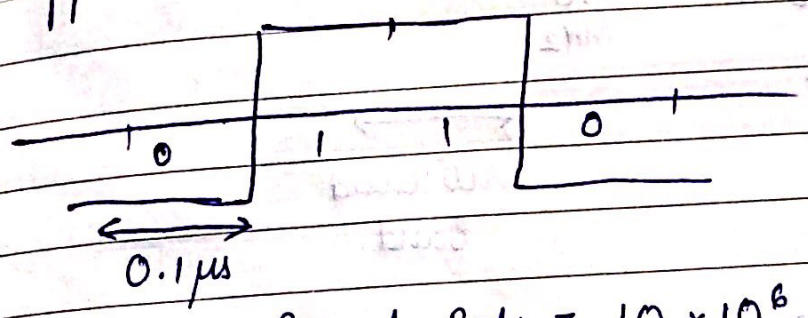


Baud Rate $= \frac{1}{0.05 \times 10^{-6}} = 20 \times 10^{6}$ symbols/sec.

Bit rate $= 10 \times 10^{6}$ symbols/sec

NRZ ?

Suppose bit rate = 10 Mbps

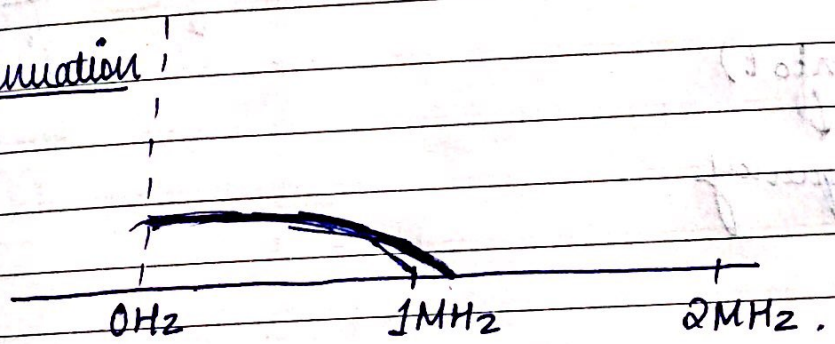


Baud Rate $= 10 \times 10^{6}$ symbols/sec.

Eg:

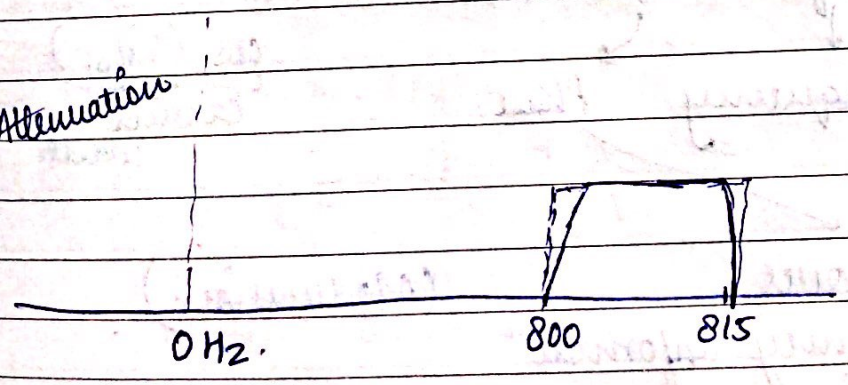
(1)

Attenuation

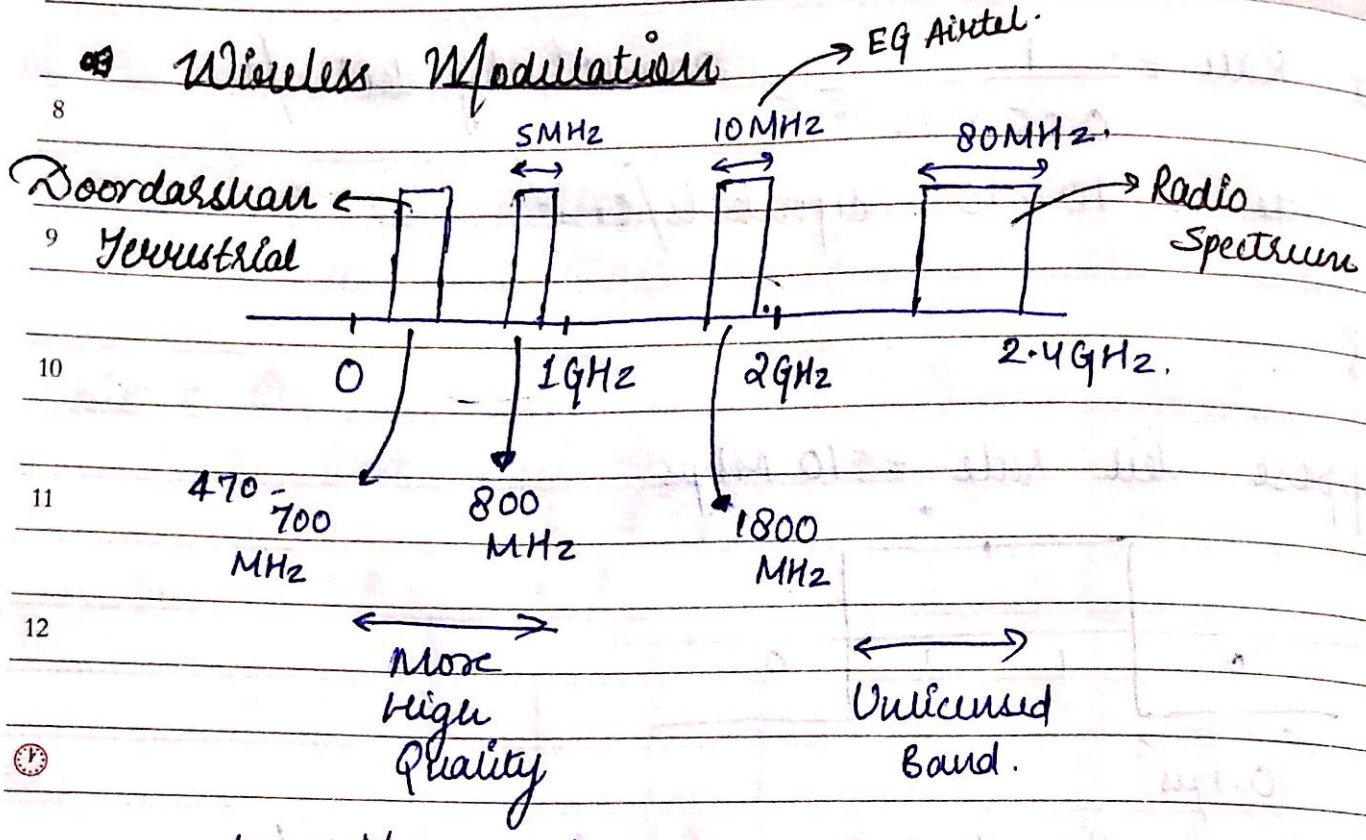


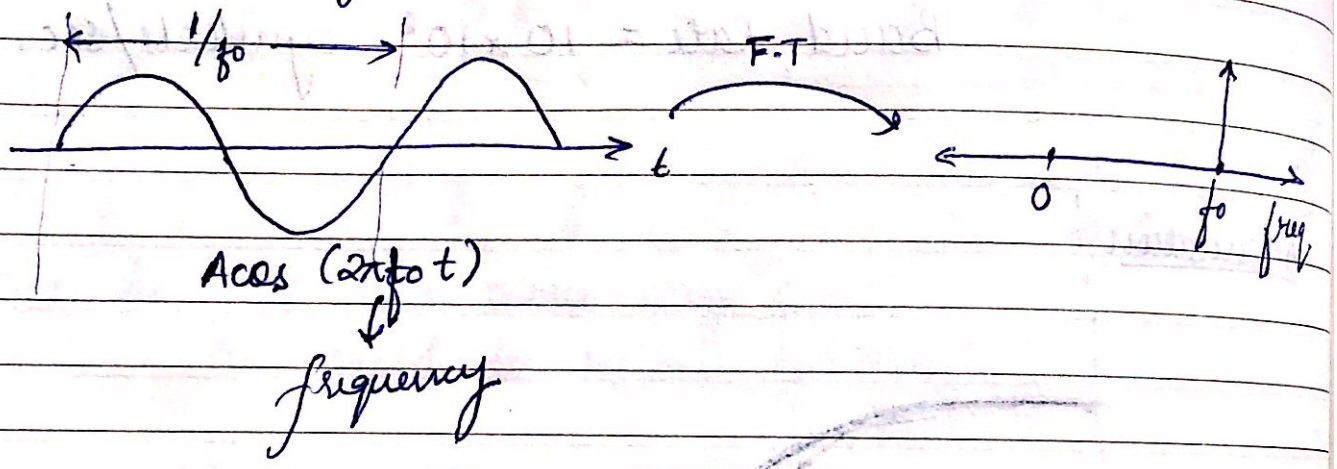
(2)

Attenuation



Wireless Modulation





* $A \cos(2\pi f_0 t + \phi)$

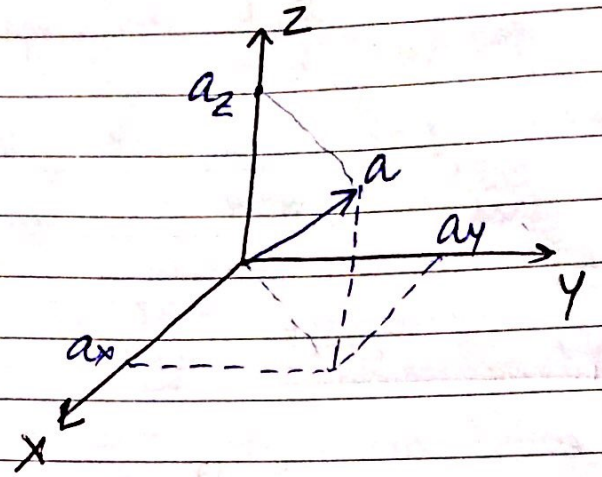
Amplitude, frequency, Phase.

$\underbrace{\cos(2\pi f_0 t)}_{\text{carrier wave}}$

Modify over time to convey information to receiver. (Modulation).

Signal Vector Space

@ Helps visualise, analyse performance of modulation schemes.



3-D Vector Space

- $\underline{a} = (a_x, a_y, a_z)$

$$\underline{a} = a_x \hat{i} + a_y \hat{j} + a_z \hat{k}$$
$$= a_x \hat{e}_x + a_y \hat{e}_y + a_z \hat{e}_z$$

unit vector in x

$|\hat{e}_x| = 1$

- $\hat{e}_x \perp \hat{e}_y \perp \hat{e}_z$ → Basis Vectors
- $a_x = \langle \underline{a} \cdot \hat{e}_x \rangle$

Dot Product

- Signal, $s(t) = \sum \underbrace{(\ )}_{\text{coefficients}} \underbrace{e_{x,y,z}}_{\text{Basis Vectors}}$

- Fourier Basis Vectors

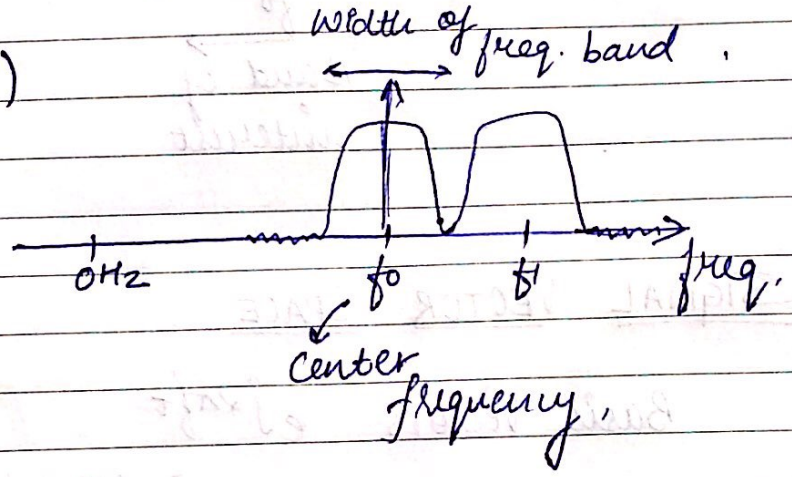
$$e^{j2\pi f_0 t} = \cos(2\pi f_0 t) + j\sin(2\pi f_0 t).$$

Wavelets.

(b) Can write any time signal as linear combination of Fourier Basis Vectors (sine waves).

Wireless Modulation 24/08/16

$A\cos(2\pi f_0 t + \phi)$



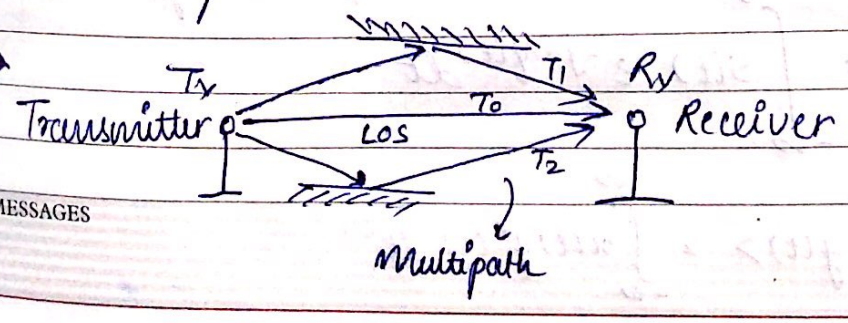
Modify

$$\boxed{A\cos(2\pi f_0 t + \phi)}$$

→ Phase Modulation

→ Frequency Modulation

→ Amplitude Modulation

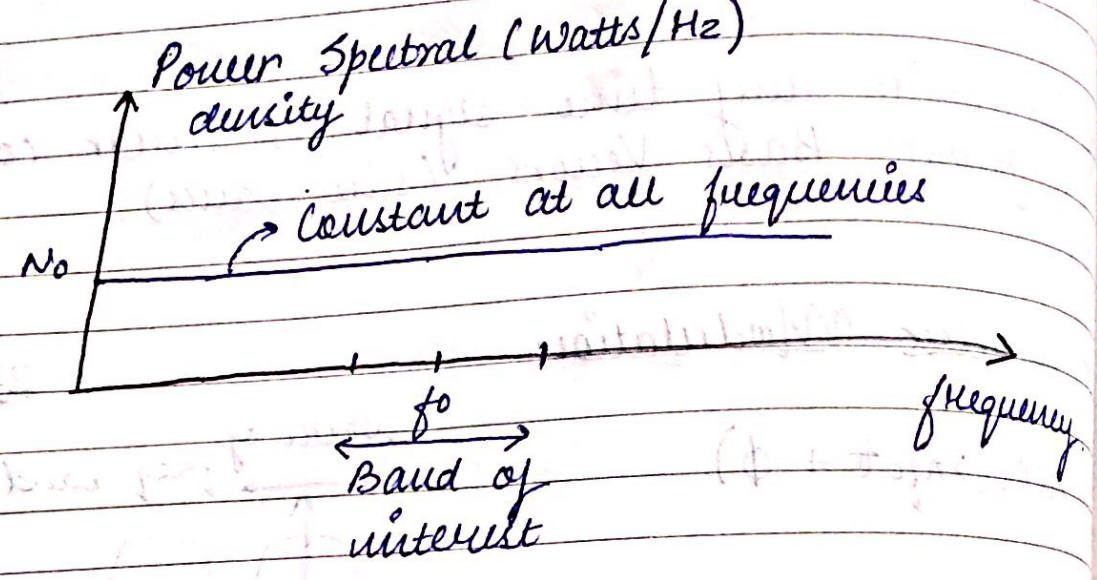


delays on diff. paths

Rx (Receiver) gets $a_0 s(t-t_0) + a_1(t-t_1) + a_2 s(t-t_2) + \dots + n(t)$

Thermal noise

Thermal Noise



SIGNAL VECTOR SPACE

Basis Vectors $e^{j2\pi ft}$

$= \cos 2\pi ft + j\sin 2\pi ft$

$s(t) = (\ )e^{2\pi f_0 t} + (\ )e^{2\pi f_1 t} + \dots$

weights

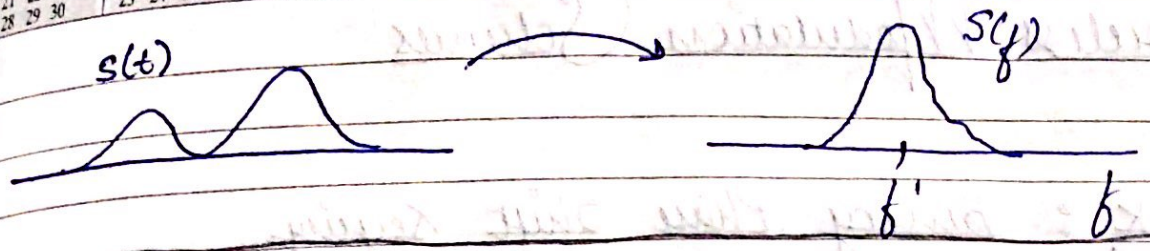
$\underline{a} = a_x\hat{e}_x + a_y\hat{e}_y + a_z\hat{e}_z$

$a_y = \langle \underline{a} \cdot \hat{e}_y \rangle$

$S(f) = \langle s(t), e^{j2\pi ft} \rangle = \int_{-\infty}^{\infty} s(t)\, e^{-j2\pi f(t)}\, dt$

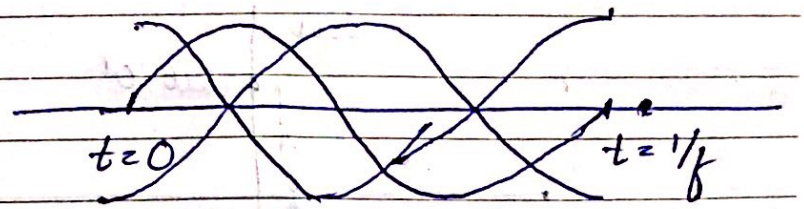
Fourier Transform

$\langle x(t), y(t) \rangle = \int_{-\infty}^{\infty} x(t) y^*(t)\, dt$

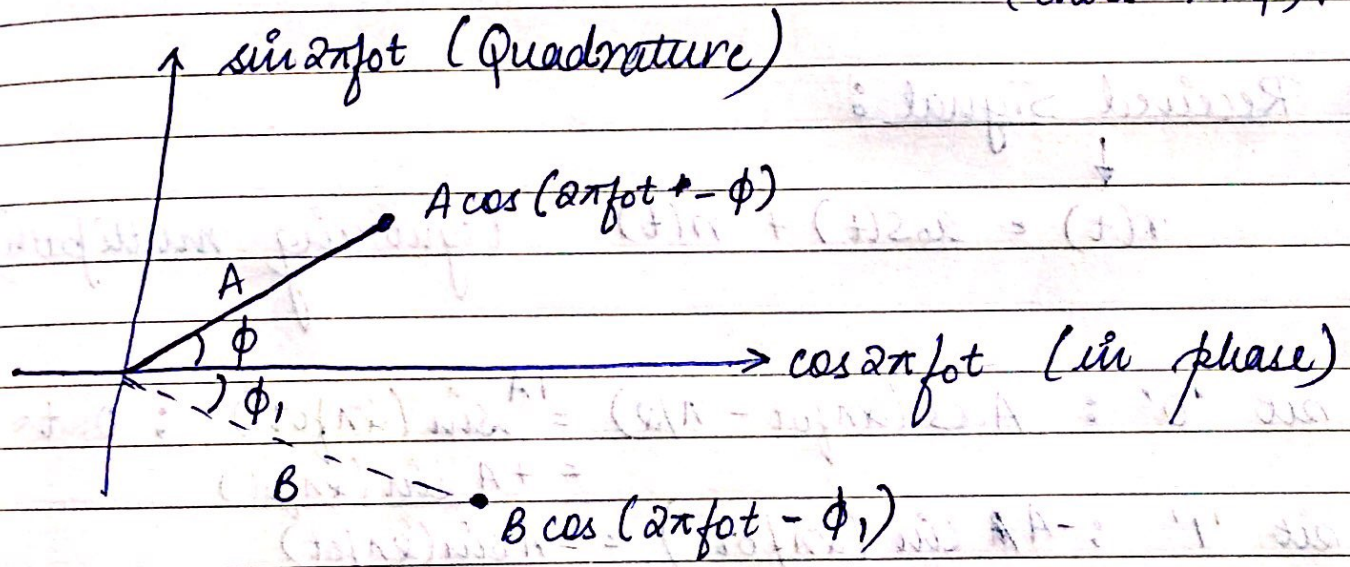


* $A\cos(2\pi f_0 t + \phi)$; $0 \le t \le 1/f_0$

focus on carrier frequency



Different signals which Tx can send (chose A, ϕ).

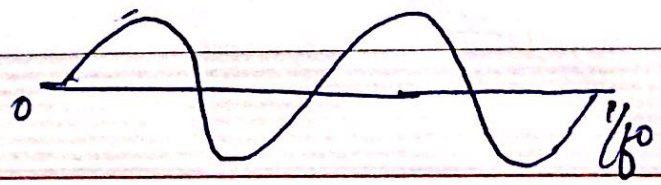


Sunday 06

Q Are $\sin(2\pi f_0 t)$ and $\cos(2\pi f_0 t)$ orthogonal to each other?

→

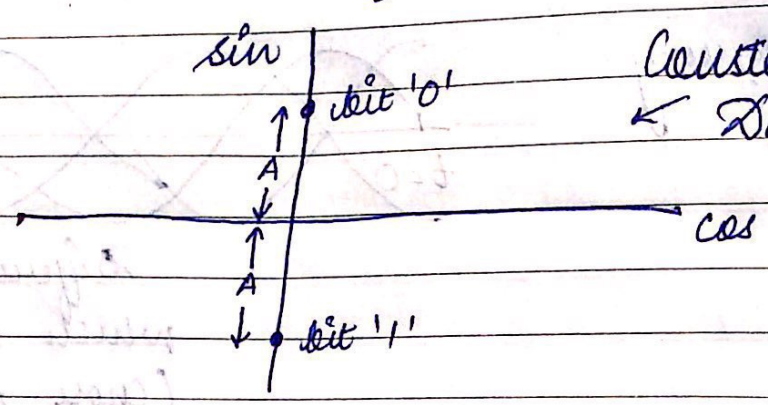
$$\langle \sin(2\pi f_0 t), \cos(2\pi f_0 t) \rangle = \int_0^{1/f_0} \underbrace{\sin(2\pi f_0 t)\cos(2\pi f_0 t)}_{\frac{1}{2}\sin(4\pi f_0 t)}\, dt$$



Wireless Modulation Schemes

① BPSK : Binary Phase Shift Keying

bit 0 : $A\cos(2\pi f_0 t - \pi/2)$
bit 1 : $A\cos(2\pi f_0 t + \pi/2)$



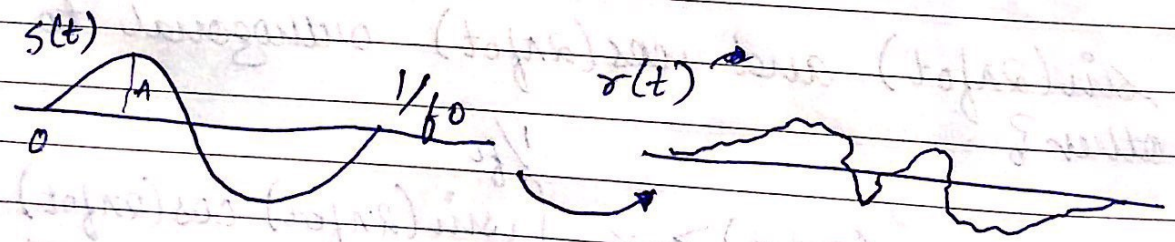
Constellation Diagrams.

* Received Signal :

$r(t) = a_0 s(t) + n(t)$ (ignoring multipath)

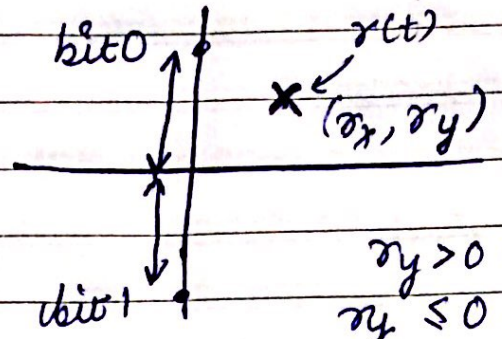
bit '0' : $A\cos(2\pi f_0 t - \pi/2) = +A\sin(2\pi f_0 t)$; $0 \le t \le 1/f_0$
$= +A\sin(2\pi f_0 t)$

bit '1' : $-A\sin(2\pi f_0 t) = -A\sin(2\pi f_0 t)$



We want to map this signal to a point in the vectorspace.

Say, if we mask →



→ Since closer to +Y axis, bit '0'. If below x axis, bit '1'.

$r_y > 0 \Rightarrow 0$
$r_y \leq 0 \Rightarrow 1$

$$r_x = \langle r(t), \cos(2\pi f_0 t) \rangle$$
$$r_y = \langle r(t), \sin(2\pi f_0 t) \rangle$$

$$r_x = \int_0^{1/f_0} r(t) \cos(2\pi f_0 t)\, dt.$$