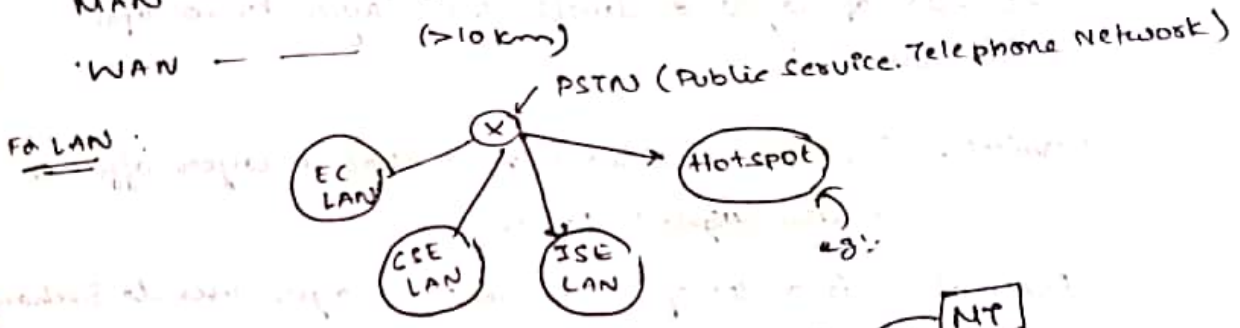
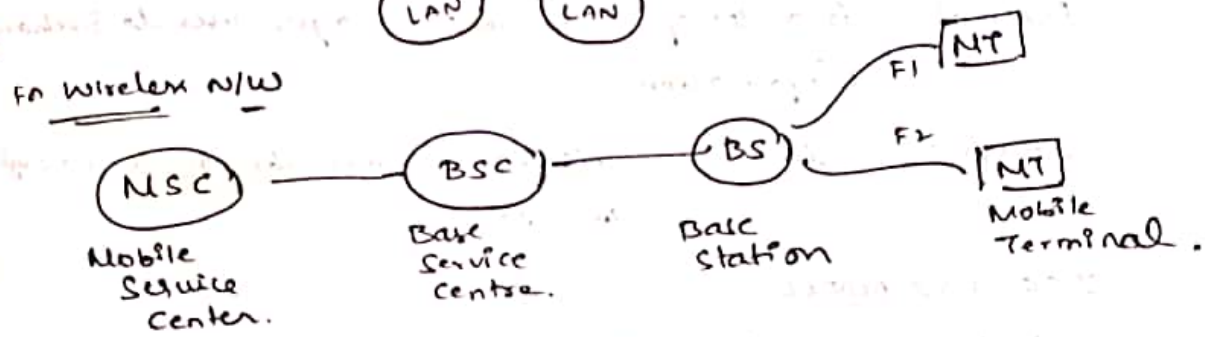
Computer N/Ws

* InterConnection of Computer and Other devices (Router, Switches, etc)
* Internet:- Network of Network / Interconnection of Networks.

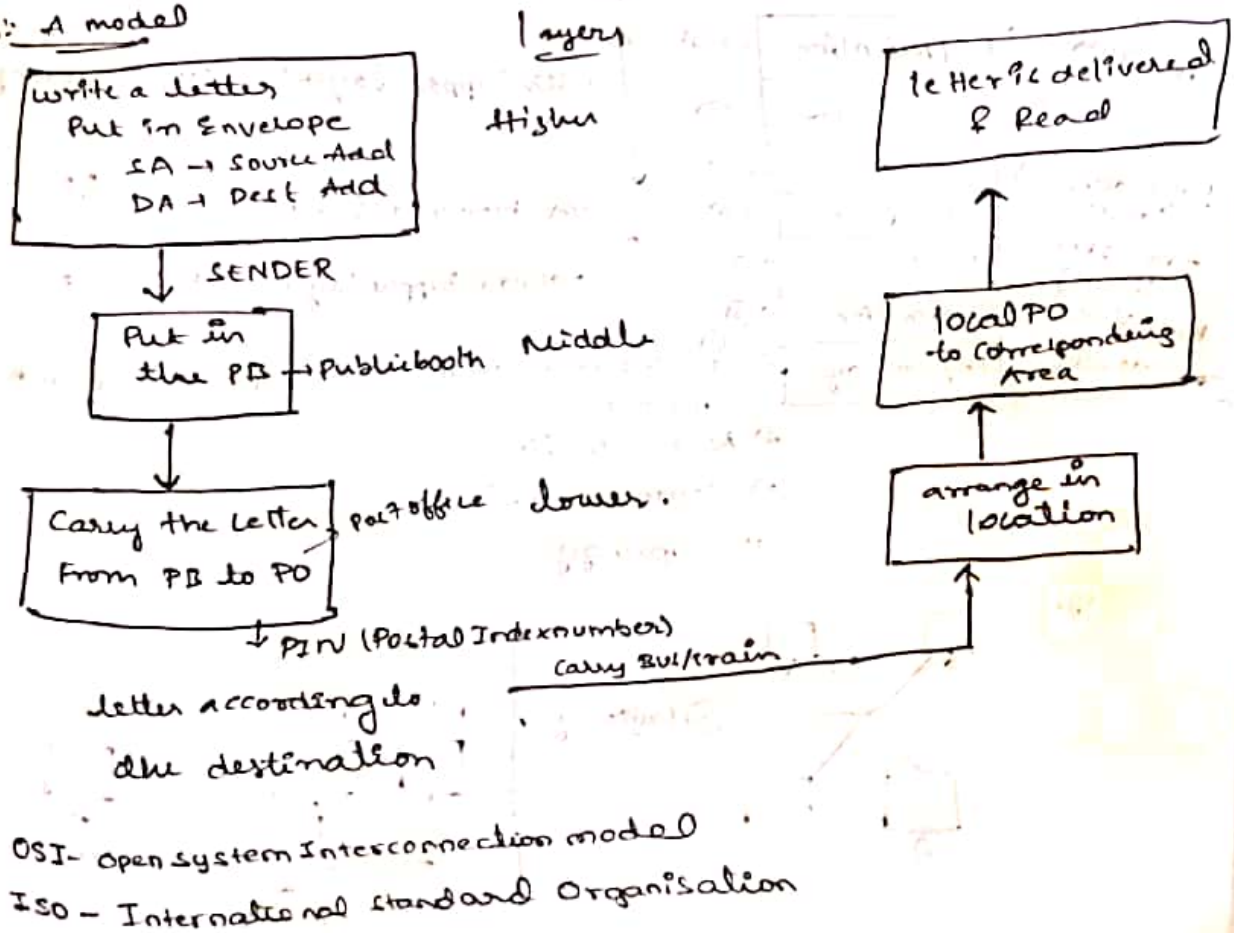
eg: Network.

	Range
PAN –	10ft
LAN –	50ft
MAN ——	50ft - 10km
WAN — ——	(>10 km)





eg: A model



OSI - Open system Interconnection model

ISO - International standard Organisation

10/3/22

Layering:

To break up the communication task into sperate components and activities.

Advantages:

To reduce design Complexity: Networks are siganised as a services of layers & levels each layer build upon one below it.

Services:-

set of actions/work that a layer offers to another (higher) layer

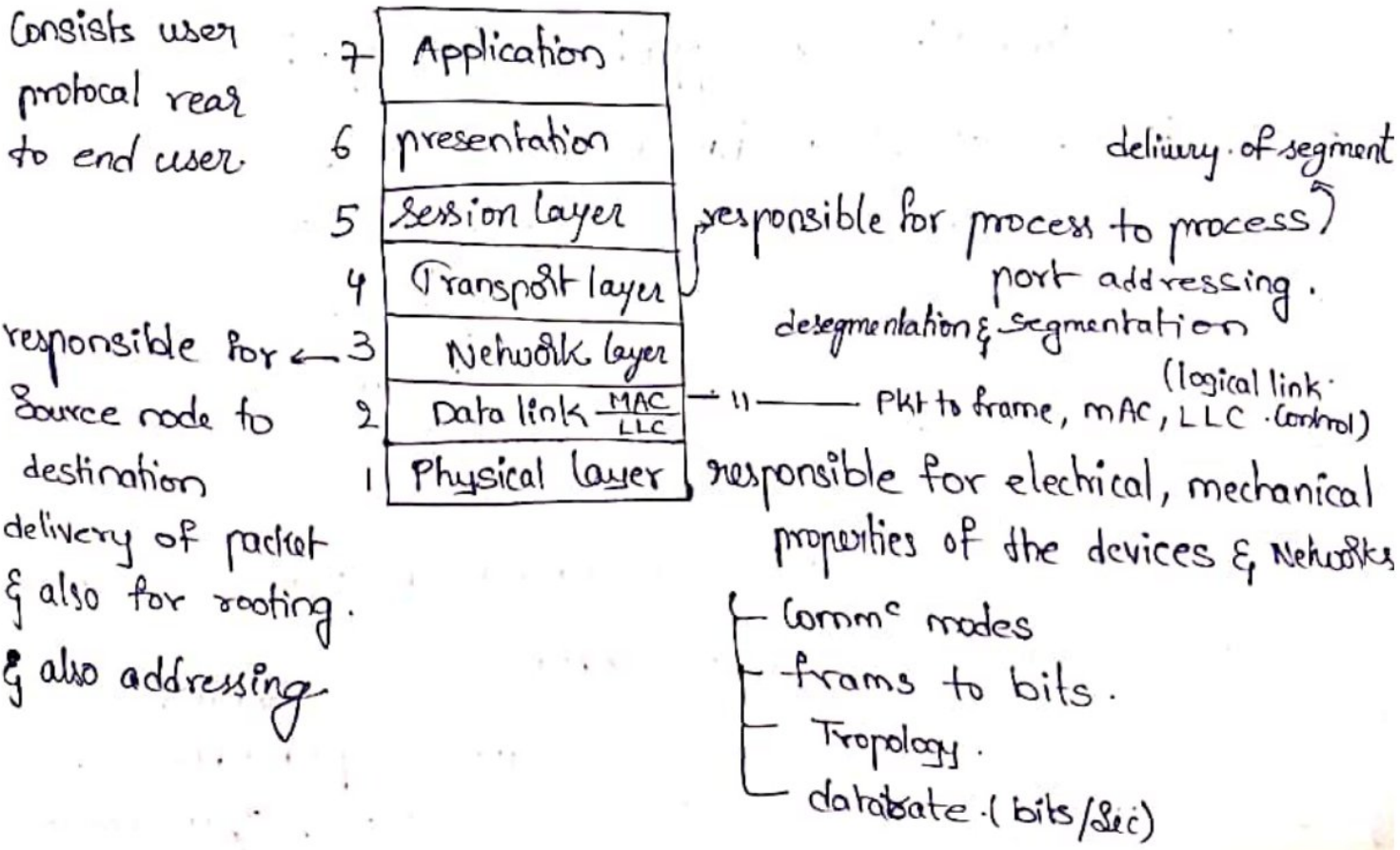
protocol:-

set of rules that layer uses to exchange information.

Inkrface:-

Commᶜ Btw the layers high. Comᶜ can be Hardware & Software.

ISO-OSI Reference model (7 layers)



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MAC (media access control layer)

TDMA
FDMA } protocals
CDMA

LLC (responsible for node to node Conversion.
packet to frame Conversion)

5) session layer responsible for establisment of session
maintain entire session
& terminating session

6) presentation layer —"— syntact & scematic of information to be presented at application layer.

⇒ 7,5,6 → user Support layers.
1,2,3 → network support layers.
4 → link B/w user Support & N/w Support layer

→ Information in 7,5,6 is known as message.

—"— V/R/3 4 —"— Segment
—"— 3 —"— packets
—"— 2 —"— Frames
—"— 1 —"— bits.
stream.

→ address in 7,5,6 layers is known as user specific address

Eg:- sjce.ac.in , IISc.ernet.in.

—"— 4 —"— port address. (16 bit)
—"— 3 —"— IpV4 / IpV6 (32/128)
MAC/link / Ethernet

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ISO-OSI reference model

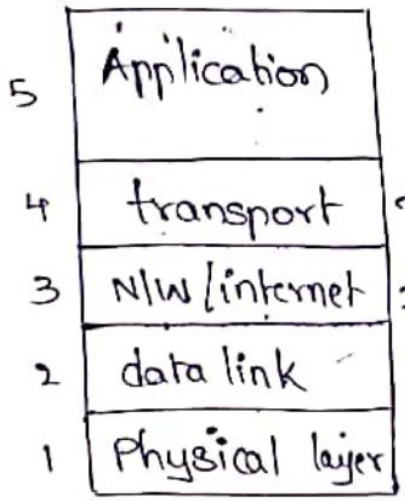
11/3/22

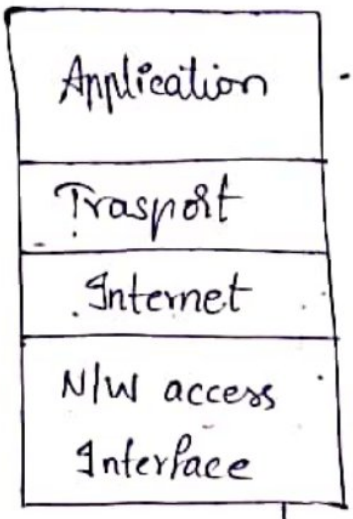
open System → Set of protocals that allows 2 diff Sys to Communicate regardless of underlying network architechure.

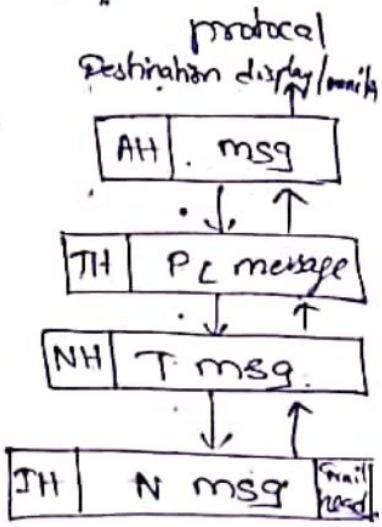
ISO → organization. (Sets the std for Commᶜ protocals).

OSI → It is a module model but not a protocal.
It is model for understanding and designing a N/w architechure which is flexible, robust and interopersible.

TCP/IP protocal Suit (Transmission Control protocal / Internet protocal)

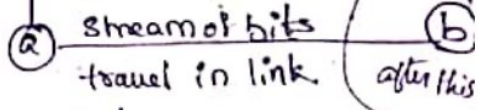






Based on Text Book

on General Basis.



encapsulation & decapsulation :-

↳ process of Converting application layer message into transport level (low level information) (high level information)

↑
↑ in above fig
↑ is decapsulation

draw again beside it same diagram with opp direction

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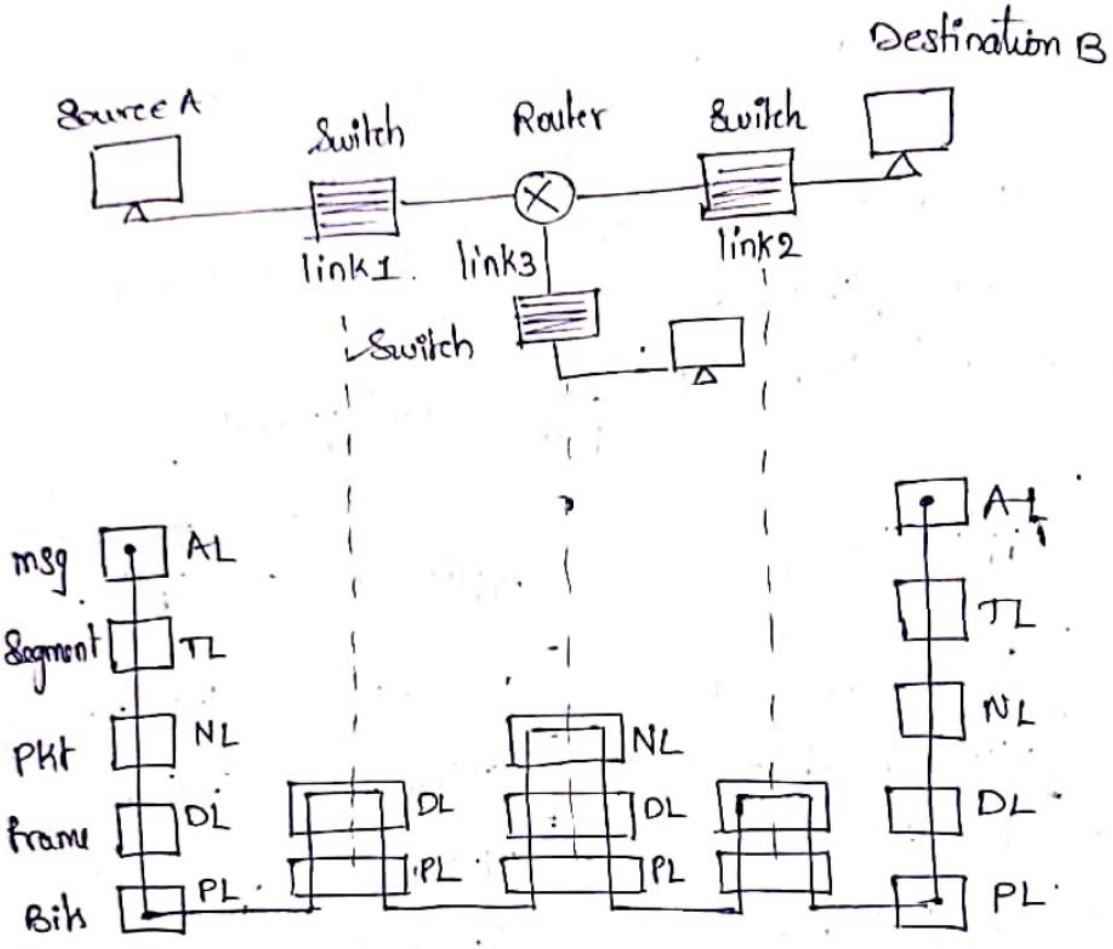
~~TCP/IP~~

~~Connection~~

TCP/IP

Communication through Internet :-



Comparision of OSI model & TCP/IP model :-

1)

	ISO-OSI
7	Application
6	Presentation
5	Session
4	Transport
3	network
2	Data
1	physical

Application	
Transport	
N/W / Internet	
Datalink	N/W access Layer
physical	

Scanned with CamScanner

2) open Sys interConnection	2) protocal model (Transmission control protocal / Internet protocal)
3) protocal independent standard	3) TCP/IP model depends on Std protocal.
4) It act as an interaction gateway B/w user & N/w	4) It is a Connection Oriented protocal that assign the N/w hosts over the internet.
5) OSI model is Created first then protocals are developed that fit the N/w architechture	5) protocals are developed first then built on TCP/IP modle.
6) Provides the QOS;	6) doesnot provide QOS.
7) Represents defines administration interfaces & data Conversion	7) doesnot mention the Services interfaces & Protocals.
8) protocal of OSI module are better unseen and Can be returned with another appropriate protocal quickly.	8) protocals are hidden. & not Can't fit a new protocal stack.
9) involve with more layers hence Complexe.	9) less layers, simpler protocals stack.
10) uses horizantal approach for analysis.	10) uses vertical approach for analysis.

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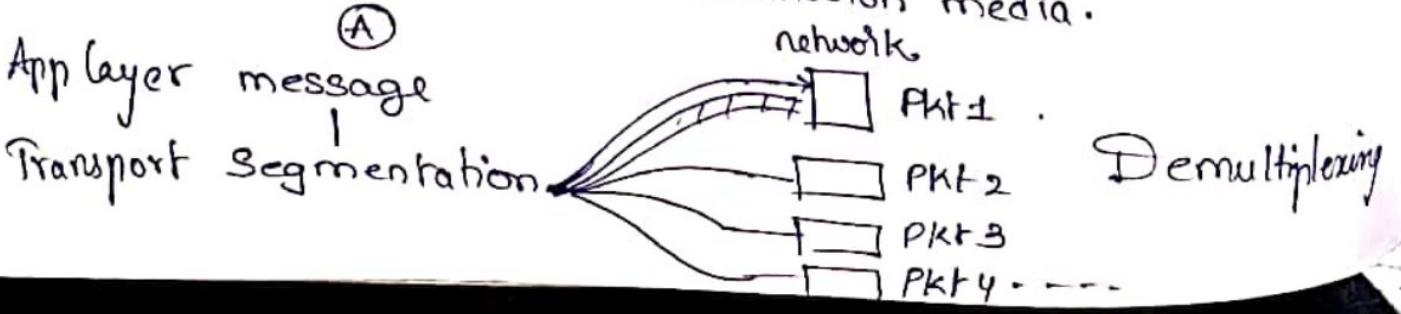
Similarities B/W ISO-OSI model & TCP/IP model :-

1) both uses layered architecture.
2) both are logical models.
3) both the models defines the std for Networking & protocols
4) both the models provide the frame work for creating & implementing networking std's & 'devices'.
5) both the models divide the N/w comm^c. process into making their layers.
6) In both models manufacturer allows making set's, devices and N/Wing Component that can work independently.
7) In both the models a Single layer defines a particular ~~personality~~ functionality and set the std for that layer
8) both the models simplify their 'troubleshooting process' by dividing the layers Complex fun^c into simpler Components of layer.

Multiplexing & Demultiplexing :-

Converting segment into transportable packets.
process of combining & converting packets into segment
many → one

Demultiplexing is process of converting segment into packets which are suitable for transmission media.



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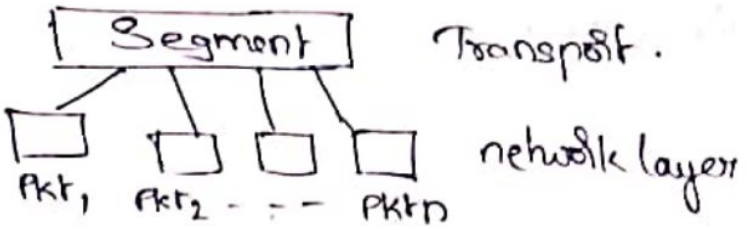
(R)
Receiver



Addressing :-

Address : unique bit pattren of alphabet of strings assigned to each system. assigning this is called bits addressing.

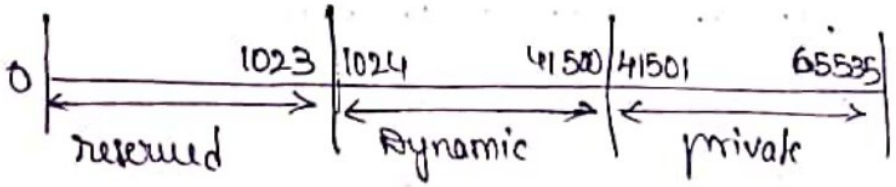
Application	→ user Specific address
Transport	→ port address.
Network	→ logical address / IP address.
N/W acess layer	

* user Specific address is unique address representing a Organization of institute or person.

Eg:- www.sjce.ac.in, (email), ...

this address can be used for Sending & receiving text msg it can't be used for universal Comm^c. even though its address is unique address.

* port address: is 16 bit address assigned by authority



http - (80)
FTP - (20-21)
port number ↑

→ it is unique address assigned for protocals. SNTP → 20

IANA (internet assigned number authority).

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Partially Qualified domain names

fully ——"——

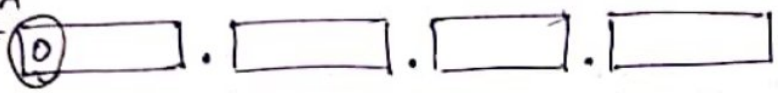
IP address : 32 bits number represented by doted decimal number. this is universal number.

Representation : a.b.c.d

Eg : 192.10.8.2

classful addressing

class A



if most significant bit is 0 then it is called classful addressing

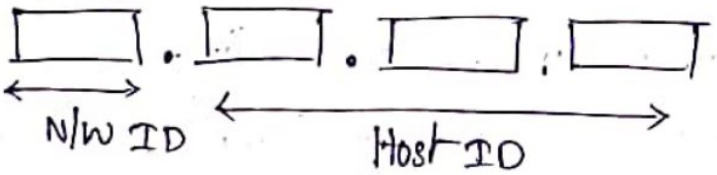
00000000 00000000 00000000 00000000

0 . 0 . 0 . 0

01111111 11111111 11111111 11111111

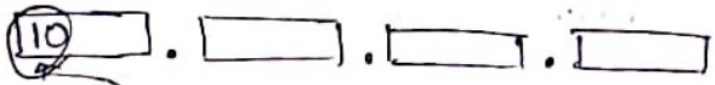
127 . 255 . 255 . 255

any number B/w 0 to 127 is under classful address.



2^{24} devices can be addressed

class B



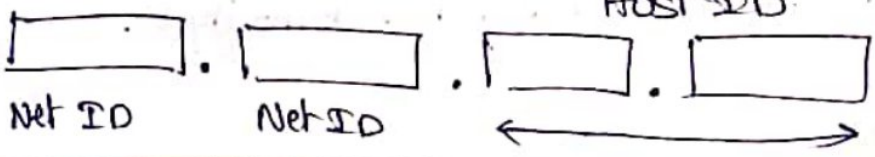
↳ starts with 10.

10111111 . 11111111 . 11111111 . 11111111

191 . 255 . 255 . 255

10000000 00000000 00000000 00000000

128 . 0 . 0 . 0



2^{16}.

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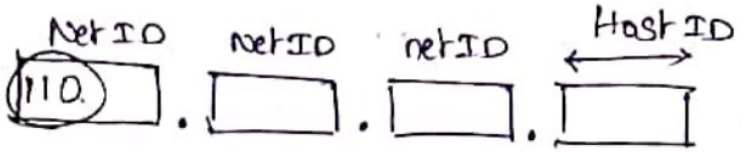
class C :



11000000 . 00000000 . 00000000 . 00000000

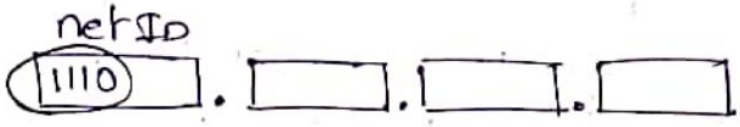
192 . 0 . 0 . 0

223 . 255 . 255 . 255

$2^8 = 256$ in each N/w we can address 256 devices.

→ one sender & one receiver, one-to one Commⁿ.
(Source) (desination)

class D :-



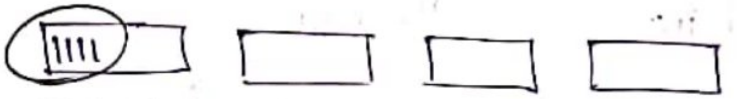
11100000 . 00000000 . 00000000 . 00000000

224 . 0 . 0 . 0

11101111 . 11111111 . 11111111 . 11111111

239 . 255 . 255 . 255

class E :- not used for any applications.



11110000 . 00000000 . 00000000 . 00000000

240 . 0 . 0 . 0

11111111 . 11111111 . 11111111 . 11111111

255 . 255 . 255 . 255

→ I Can't change IP number but can host number.

Subneting :- process of dividing largerth N/w into smaller N/w.

Superneting :- creating a larger N/w. used in router to decrease the RT

IP → classful addressing

A – 0-127
B – 128-191 } unicast
C – 192-223
D – 224-239 — multicas
E – 240-255 — reserved.

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2^3 = 8 Subnets 198.16.8.0

2^2 = 4 Subnets 198.16.8 bbbXXXXX

2^1 = 2 Subnet.

18/3/19

classless addressing.

prefix notation or CIDR notation.

$$\text{addresses in a N/w} \propto \frac{1}{\text{prefix}}$$

126.1.1.10/8 → no. of bits in N/w.

here 8 bits intidates Net Id & 32-8 bits indicates host Id.

Subnet mask :-

129.2.10.1/22

10000001 00000010 00001010 00000001

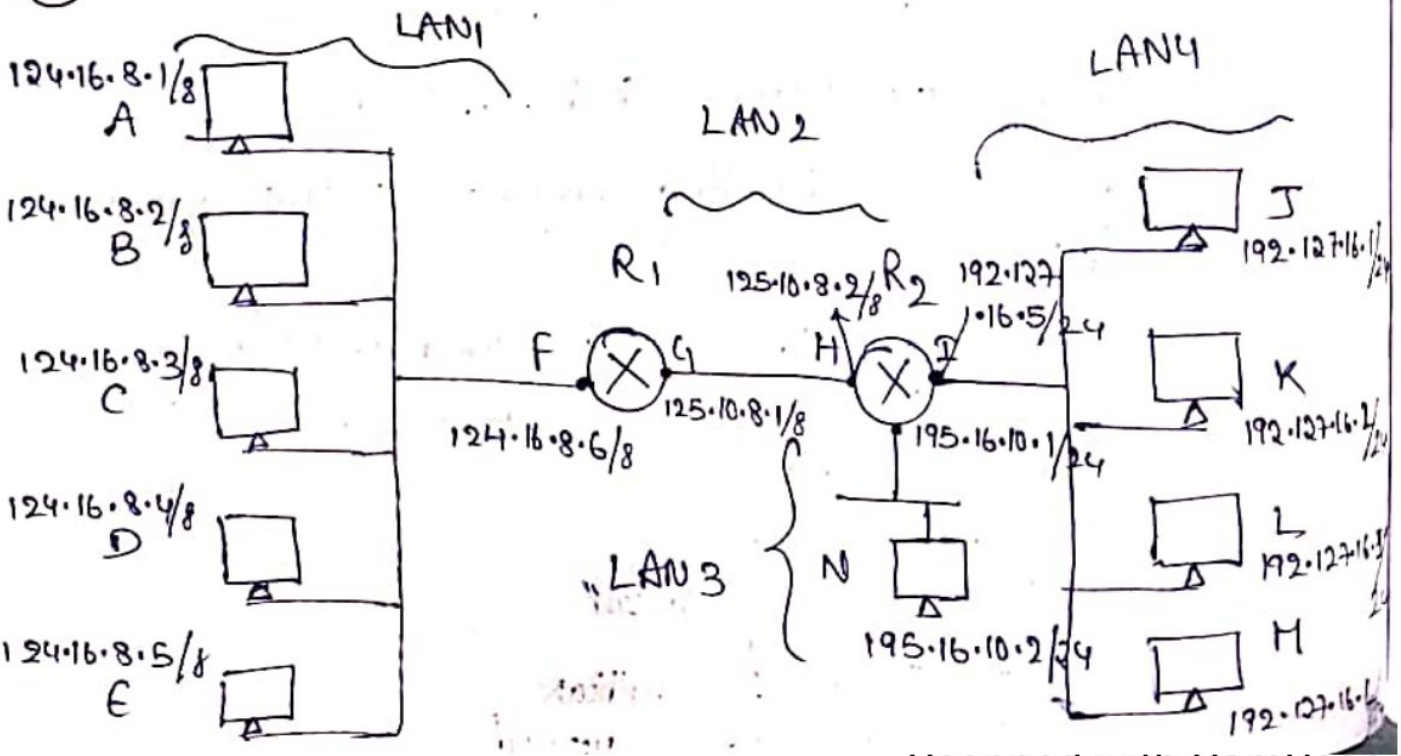
netID HostID

255.255.252.00 → subnet mask.

↓

and of & data & sent it.

(1)



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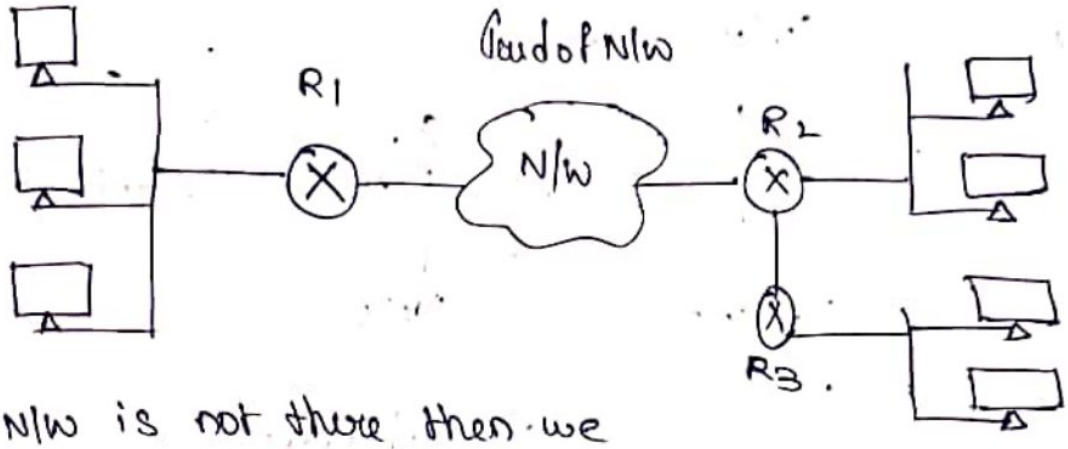
① Identify no.of Segments & networks.

4 N/ws in given fig (LAN1, 2, 3, 4).

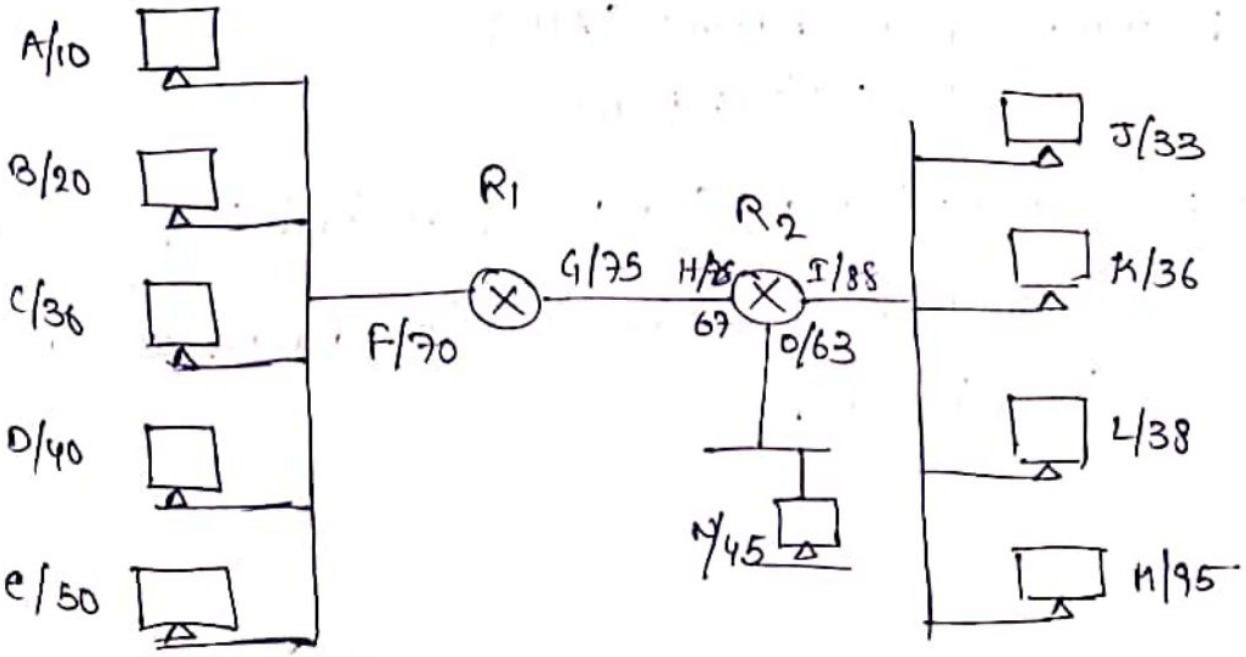
② Identify nodes & allocate IP addresses.

②



→ if N/w is not there then we Can say 6 N/w's but we Can't say how many no.of N/w's we have in clould of N/w.

③ there is HTTP Sesion B/w host A & to host M write a Data graph at diff point of N/w (refer ①).
Assume all alphabets denotes IP. address. & numbers indicate (mac address.of, link address)



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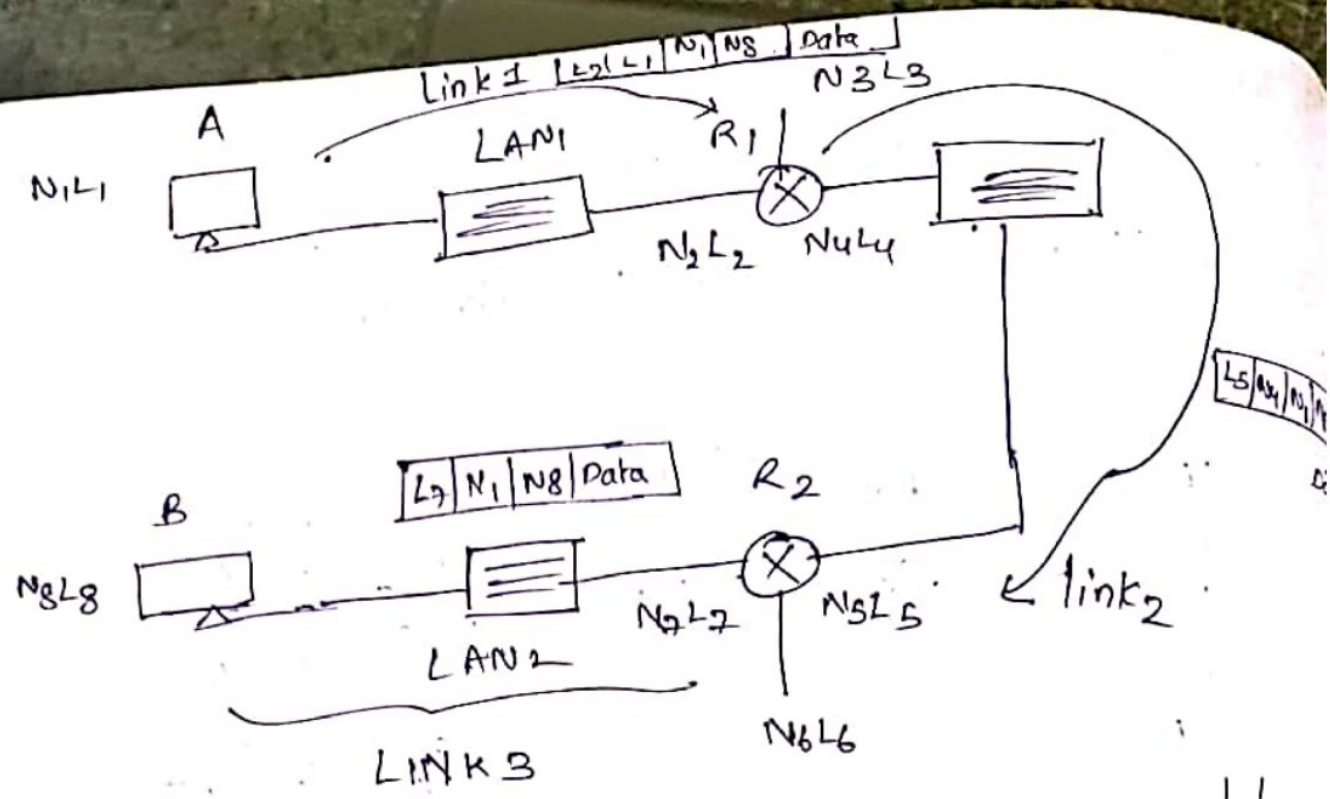

Link layer address :- (NIC) 48 bit address. 21/3/22

A6 : f2 : f3 : AB : BC : BE

FF - broadcast

10100110

0 - unicast

1 - multicast

unicast address — 1 source
1 destination

least Significant "bit"

the first bit of the most Significant "byte" gives info about unicast & multicast.

Framing — fixed frame (ATM)
— variable frame

broadcast — many to many (any one can send to anyone)

Source will always be unicast, destination can be unicast, multicast, broadcast address.

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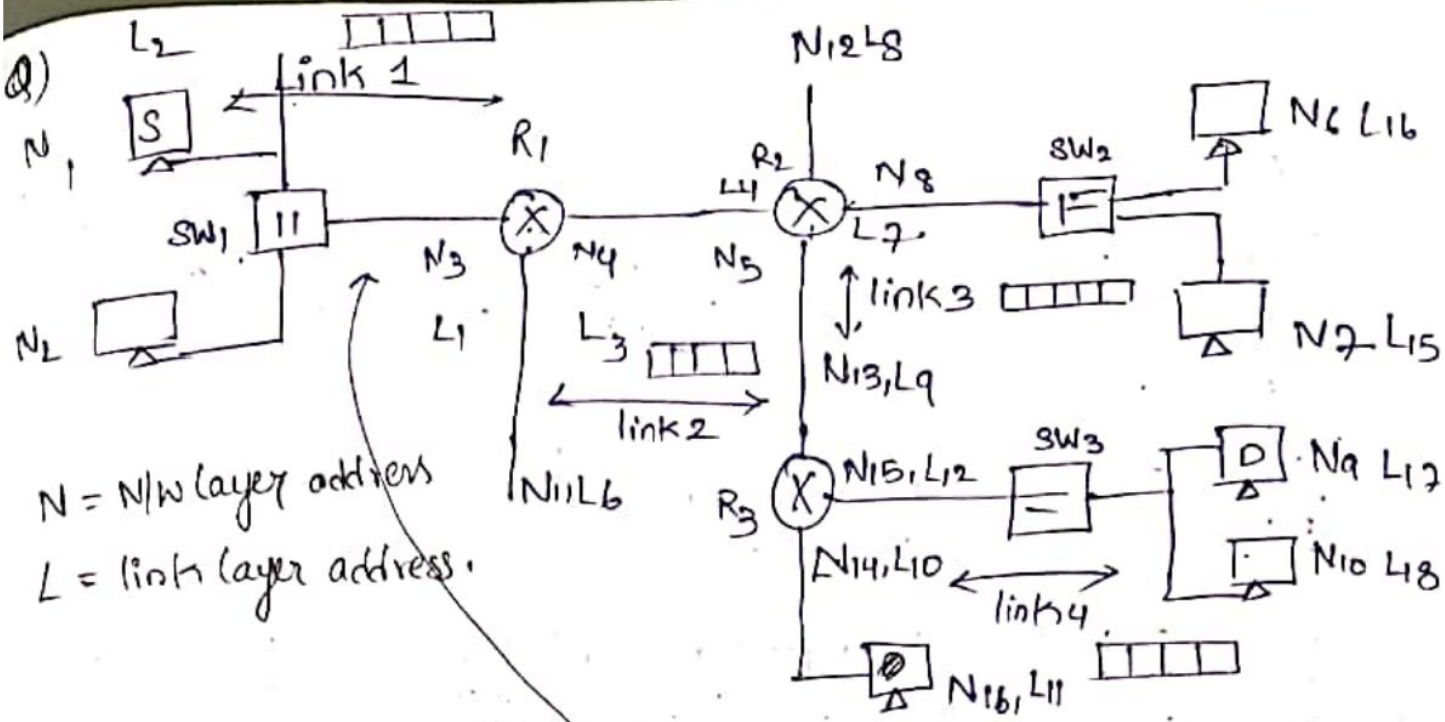
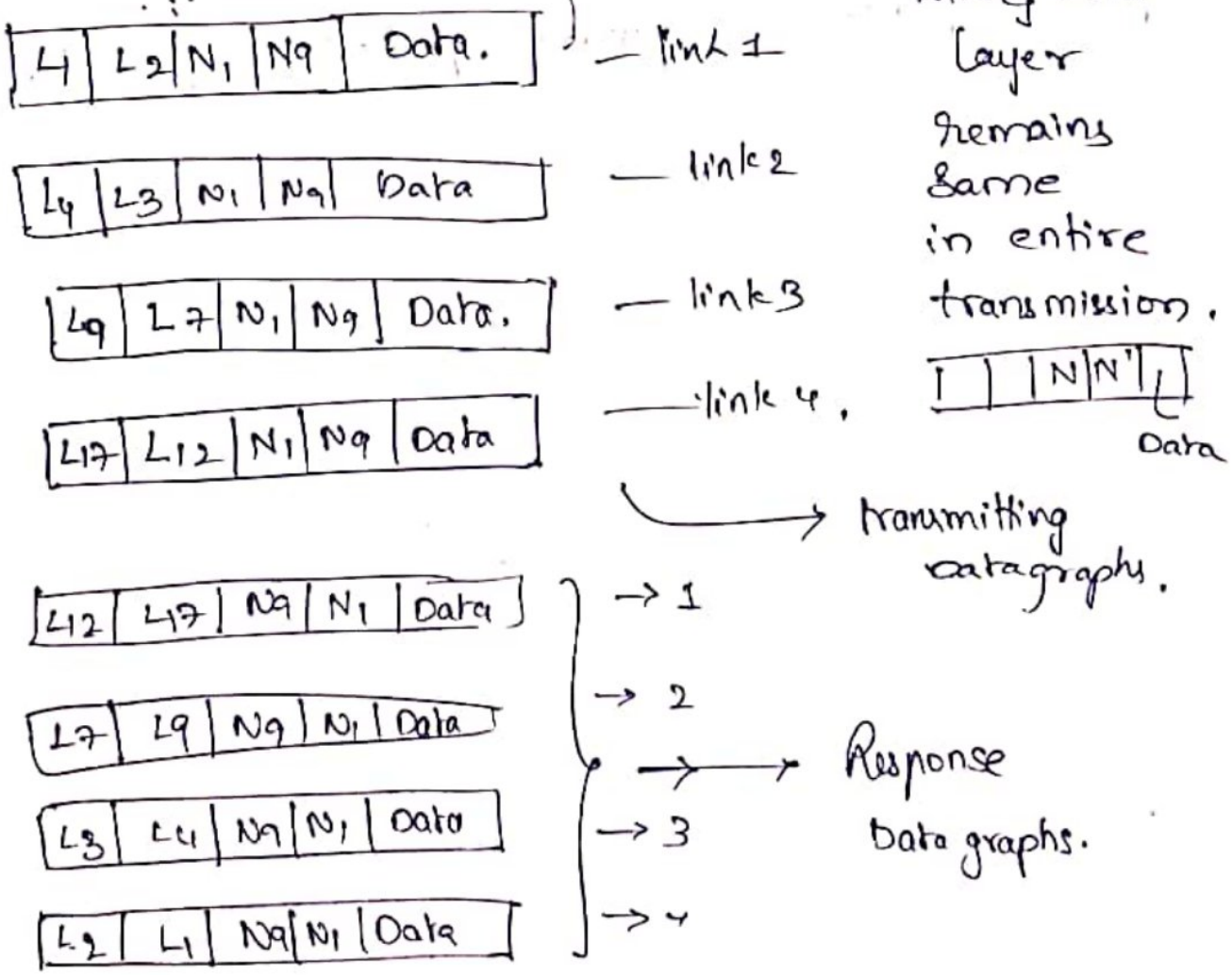
Q)



There is an HTTP Section B/w. S & D.
write the Data graph at diff links layer. and N/w layer.



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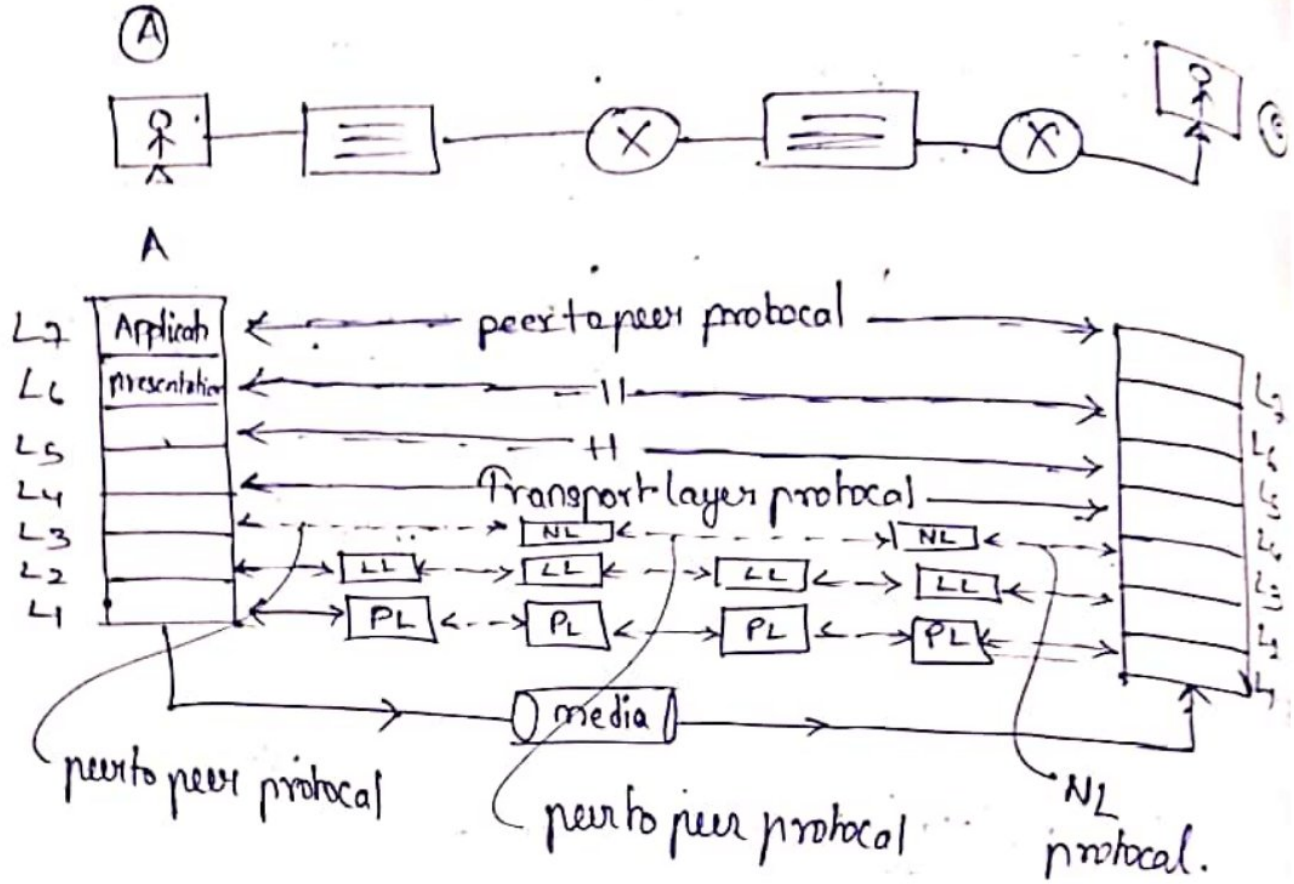
Peer-to-Peer communication : a, peer to peer protocol



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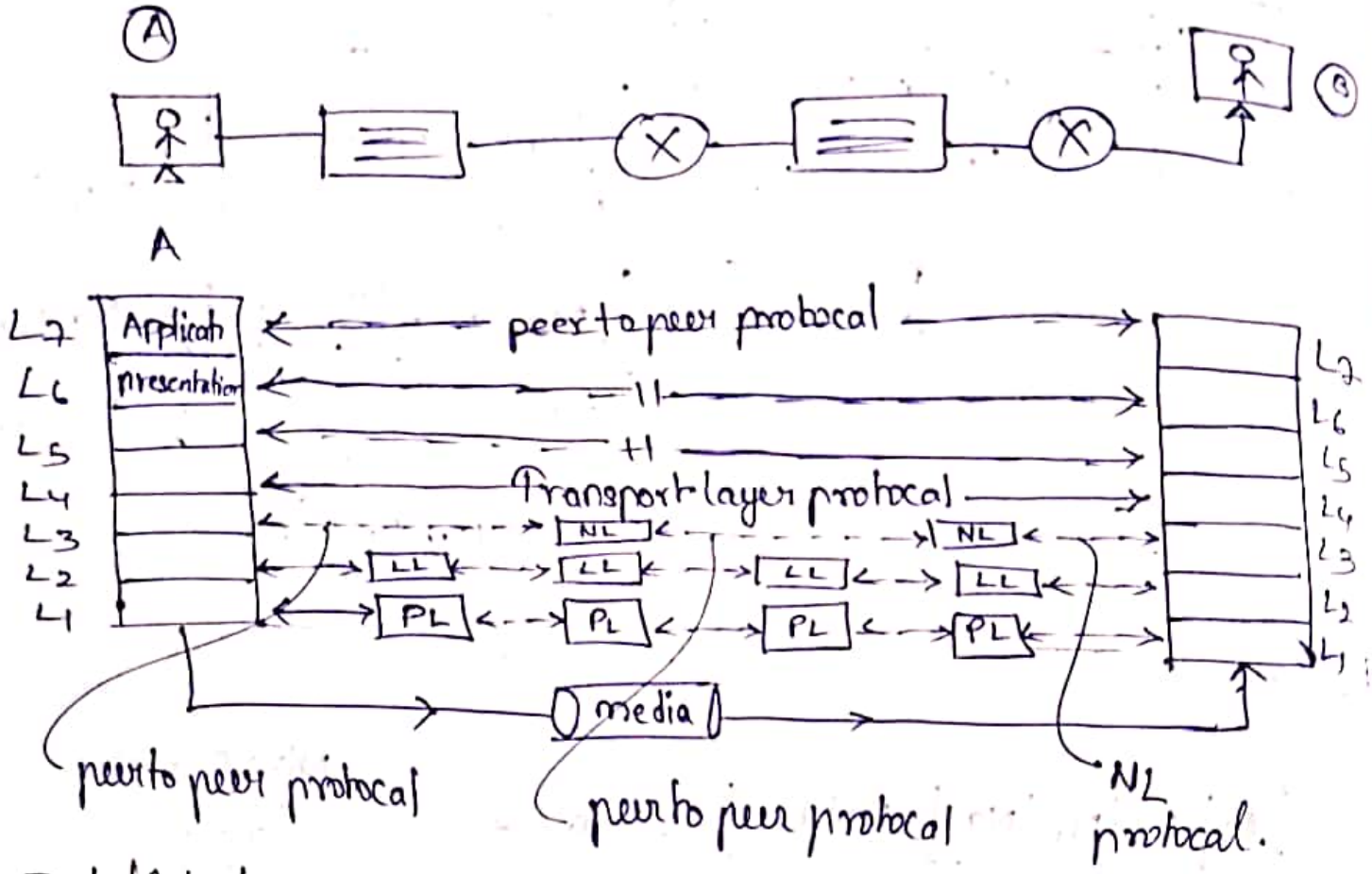
Peer to Peer communication : Q. peer to peer protocol



Datalink layer

Physical layer and datalink layer are territories of networks that make up the internet.

Data link layer and physical layer provide a services to upper 3 layer of TCP/IP protocal suit.

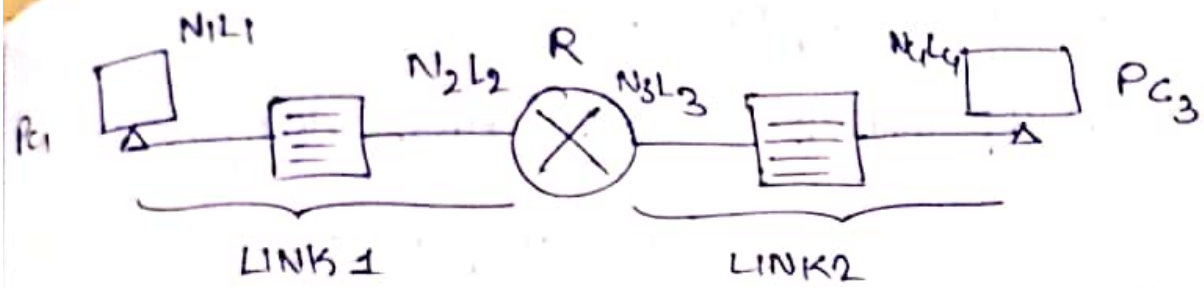
physical layer provide a services to datalink layer and data link layer use the services.

Datalink layer → Framming, Flow Control (management of data flow b/w nodes in n/w), Error detection

Addressing of frames, Congestion control

→ node to node delivering of frames

→ how to share media among several users / devices.



Two types of links

① point to point link

② Broad Cast link.

point to point link: Link is dedicated B/w two devices.

Eg:- chat using telephones.

Broad Cast link: Shared B/w several pairs of end devices.

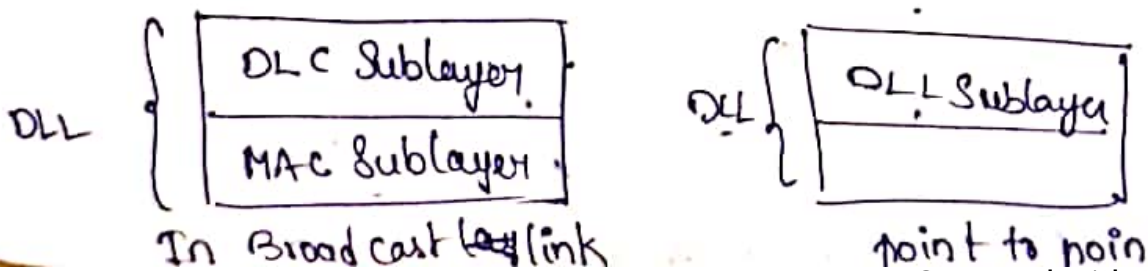
Eg:- Cellular Commⁿ (mobile commⁿ).

→ Can be wired or wireless.

Data link layer — Digital link Control (DLC)
— media access control (MAC)

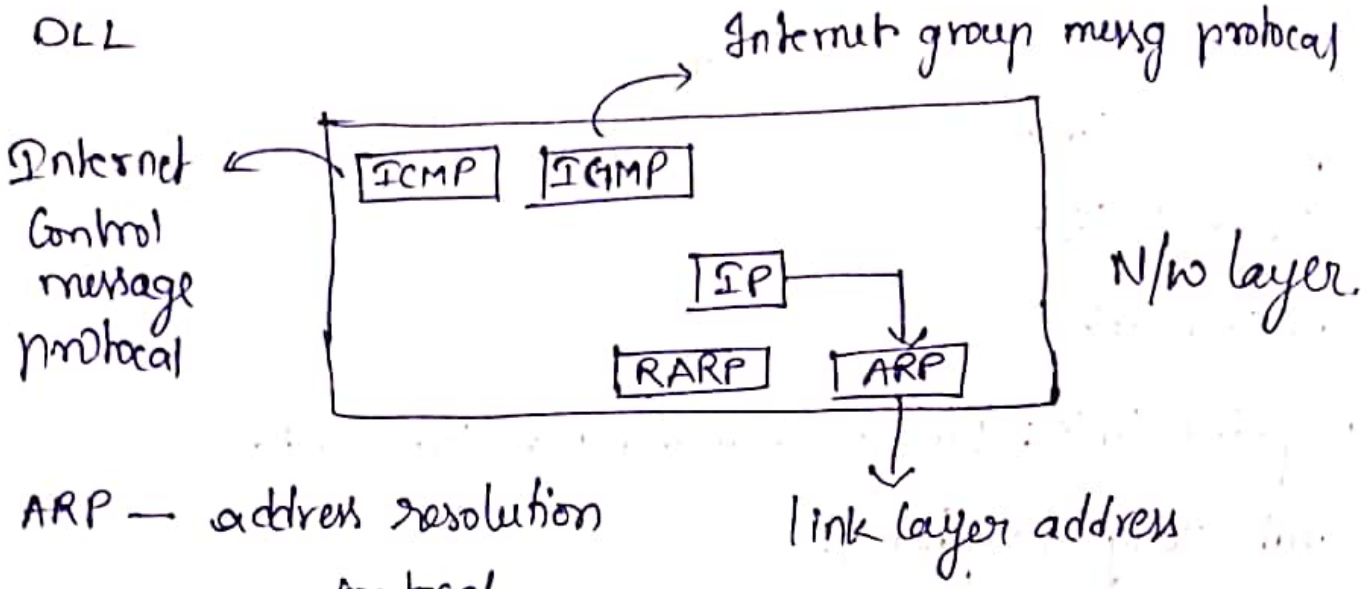
→ DLC deals with flow Control, error Control, Congestion control, framming and node to node ~~dealing~~ delivery of frames, Deals with issues related with both, point-point link & Broad Cast link.

→ how to share data rate/Bw of media B/w several devices in broad Cast link.



ARP : It is N/w layer protocal.

→ it maps an Ip address to Link address and pass it to OLL



ARP — address resolution protocal

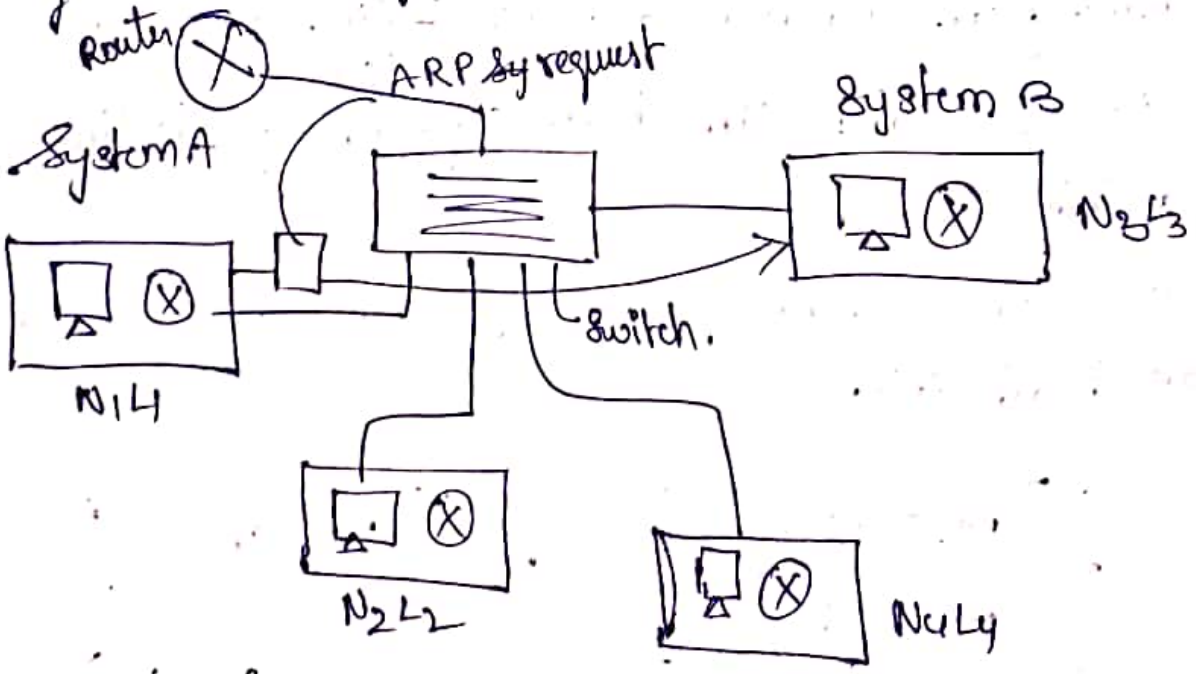
RARP — Reverse resolution protocal.

ARP requests Contains

→ IP and link layer address of Source

→ IP address of destination.

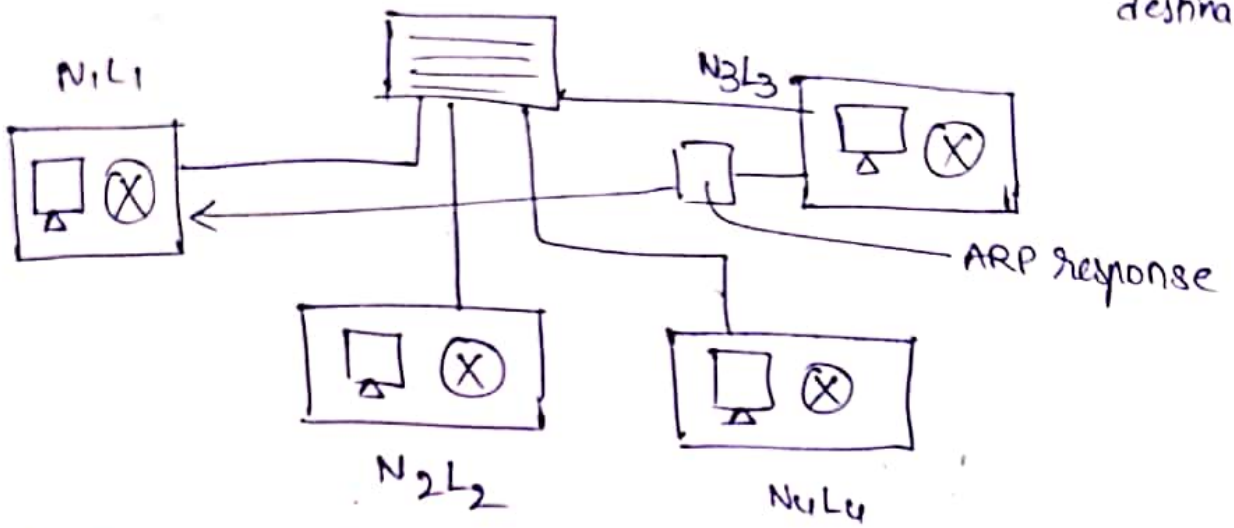
Equating on Link layer address is broad cast on LAN/WAN,



ARP request is Broad Cast message

ARP looking for link layer address of a node with IP address

Source (N_1L_1, N_3) destination



here ARP response is point to point message

Frame Size :-

① Fixed Size Frame

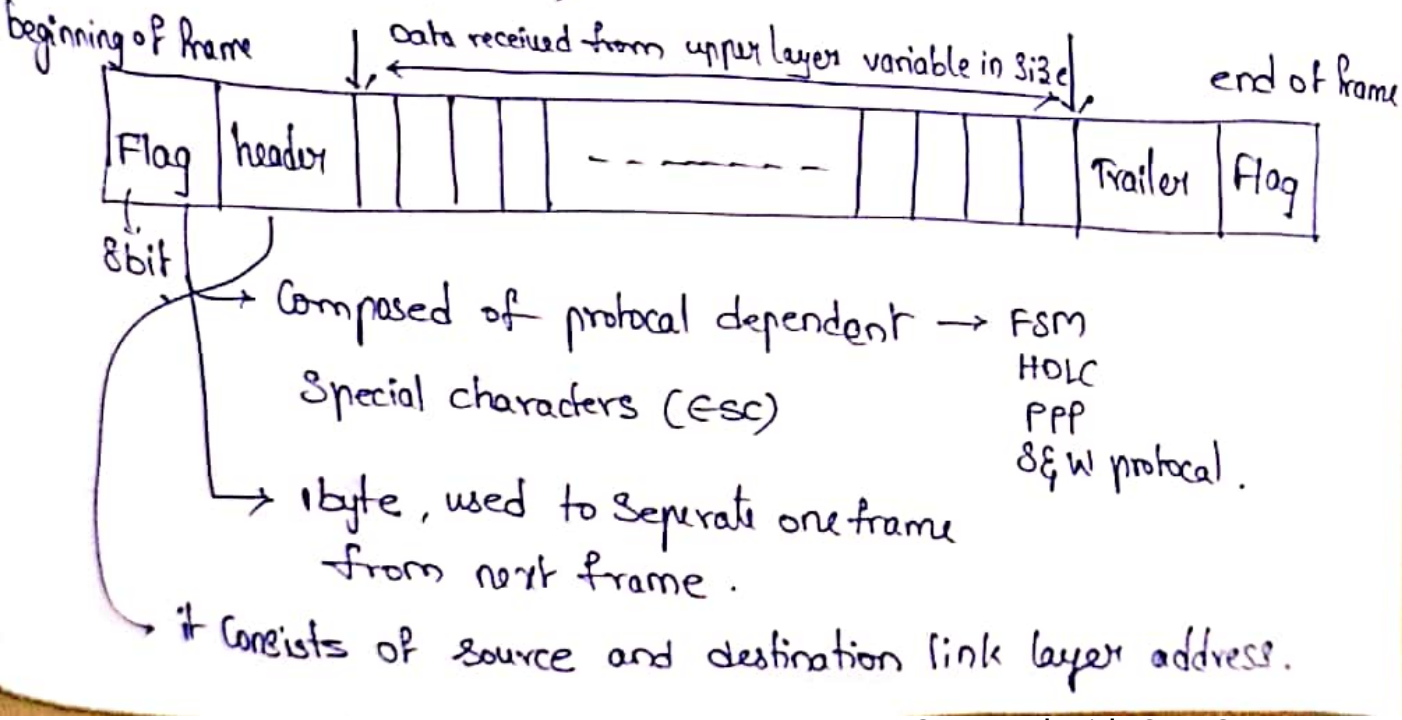
we need not define the boundary of frame. Size itself used as delimiter

Eg:- ATM, (asynchronous N/w. transfer mode N/w)

② Variable Sized Frame

we need to define the (boundary) start & end of frame

Eg:- used in local area N/w. (LAN)



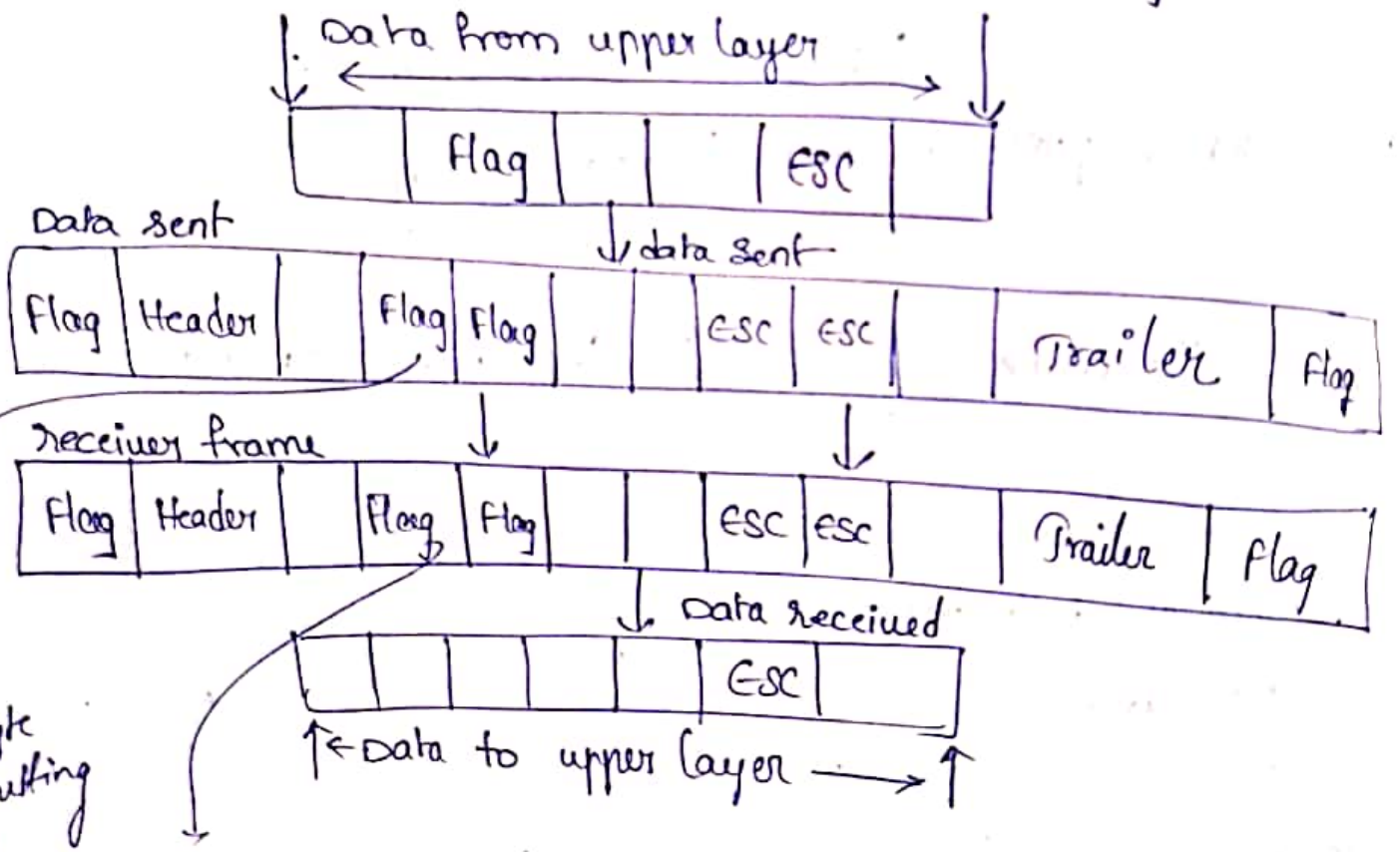
~~Carries (Trailer is)~~

~~error detection redundant bits & multip~~

Trailer Carries error detection, redundant bits & multiples of

Framming
- bit Oriented.
- character Oriented

above shown fig is "character Oriented Stuffing"



Byte Stuffing
↓
adding special char to Data byte of frame

Deshuffing: Removing data from received frame (Special char)

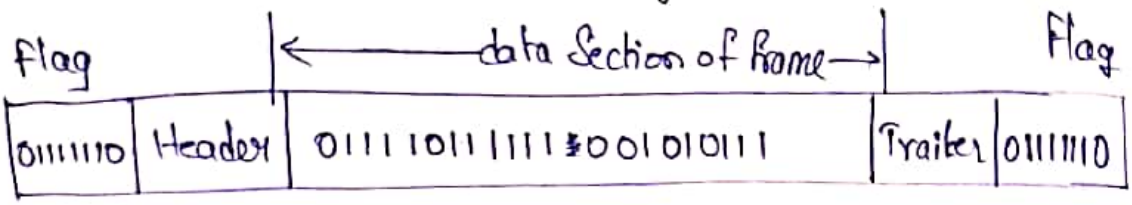
→ This entire thing is char Stuffing.

→ All bytes in above diagram are ASCII char

char° Stuffing & byte Stuffing :-

Process of adding one extra byte of char° wherever there is flag & esc in data Section of Text of frame.

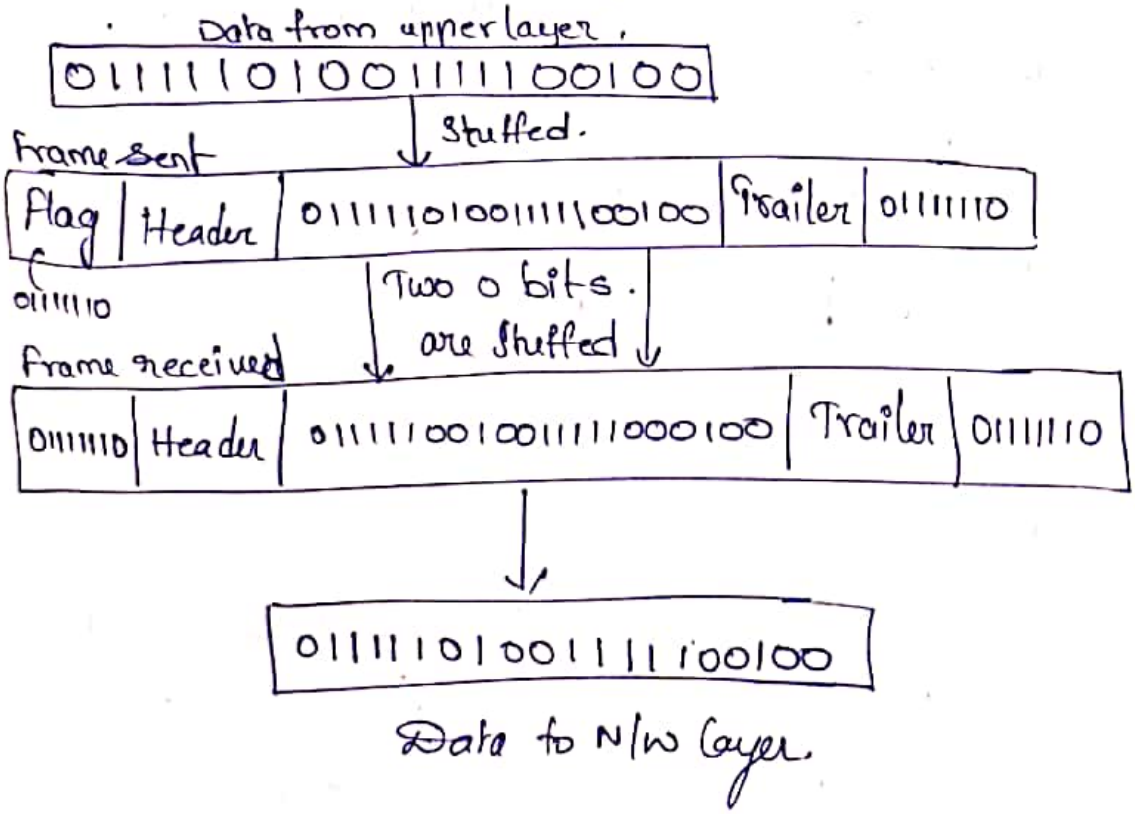
Bit Stuffing (Bits Oriented framing).



→ The delimiters are used to define beginning and end of frame (Flag = 01111110)

→ if the flag patteren (01111110) appears in data Section. then one extra bit is added after the pattern. this means after Consecutive 5 ones, two bits are added in data Section.

→ it is process of adding one extra zero whenever flag pattren is present in the data Section., so that receiver doesnot mistake the flag pattren is Called. bit Stuffing.

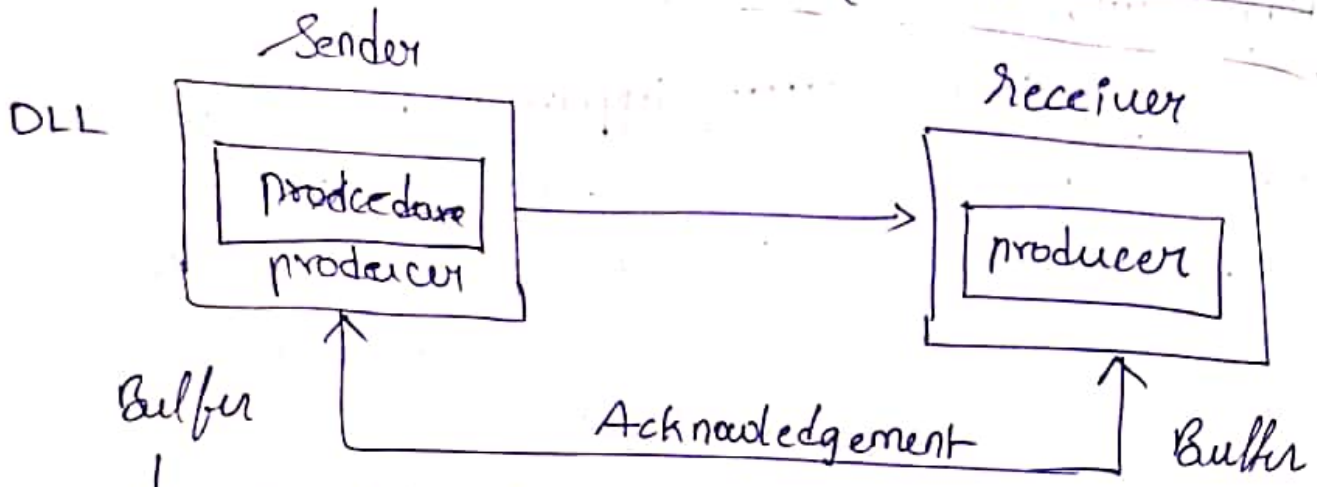


Flow Control and Error Control :-

Process of managing the rate of data transmission B/w two nodes or more nodes to prevent fast Sender with slow receiver.

It is set of protocal/ ~~protoc~~ procedure used to restrict amount of data. Sender can send before receiving acknowledge

→ Services provider by DLL | protocal



↳ Set of memory location that can hold packets at receiver and sender suppose if receiver buffer is full then it should acknowledge to sender by not pushing packet/frames.

error Control :-

It is process of checking correctness of frame B/w the two nodes in a link.

In data link layer CRC (Cyclic redundancy check) is added to frame header by sender & check by receiver.

In receiver used 2 methods to check correctness of frame

i) After receiving frame if frame is ~~corrected~~ corrupted it is simply discarded. else frame is sent to upper layer (N/W layer) → first method

ii) in this case sender doesn't know the correction of frame that was sent.

ii) After receiving frame if frame is corrupted simply discard the frame & inform the sender. else if frame is not corrupted deliver to N/W.

at any chance receiver will not deliver corrupted frames to upper layer.

→ This is node-node flow control & error control. (in data link layer).

→ in transport layer flow control & error control are from (source to destination).

→ Service provider by DLL :-

Connection less.

→ frames are send via any node.

→ frames are not numbered/ordered.

→ If receiver receives frame just sent to upper layer.

Connection oriented.

→ Connection is established before sending frame.

→ All frames are numbered and delivered to upper layer.

→ if receiver receives the out of order (OOO) frames it will be buffered & sent to upper layer once. OOO frame received

Protocols :-

→ FSM (finite space machine)

→ Simple protocol.

both protocols Assumes channel/ media is noiseless.

Stop & wait
Go Back N
SR
} channel is noisy

not in syllabus.

→ HDLC
→ PPP } Bit oriented protocol.

Protocols :-

→ FSM (finite space machine)

→ Simple protocol.

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Stop & wait
Go Back N
SR
} channel is noisy

not in syllabus.

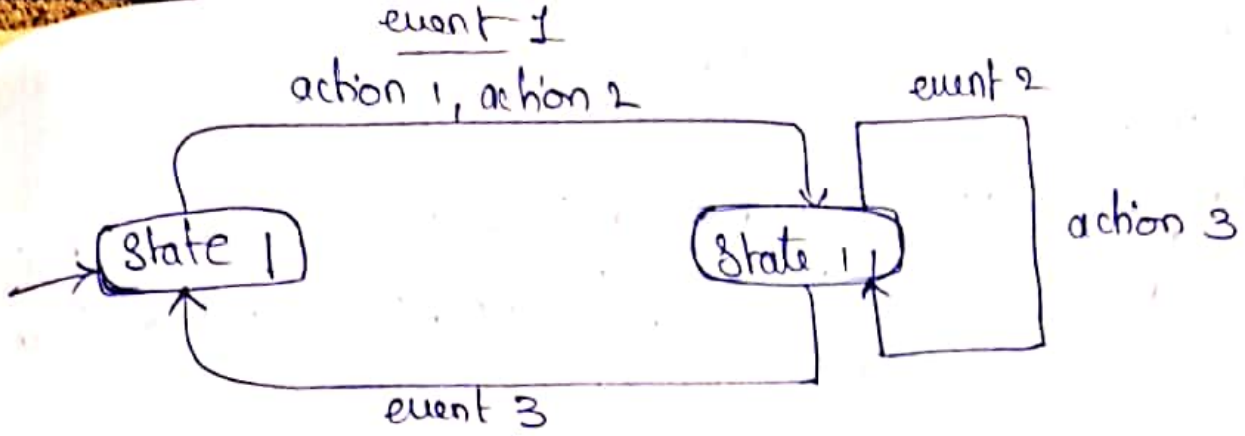
→ HDLC
→ PPP } Bit oriented protocol.

31/3/22

4 protocals in DLL to deals with flow control, error Contro

1) Simple protocal → Simplex Communication. (Simpler channel)
2) Stop & wait protocal → Duplex Channel.
ARQ (Automatic repeat request)
3) go back N protocal with ARQ → Duplex channel
4) Selective repeat ARQ → Duplex channel

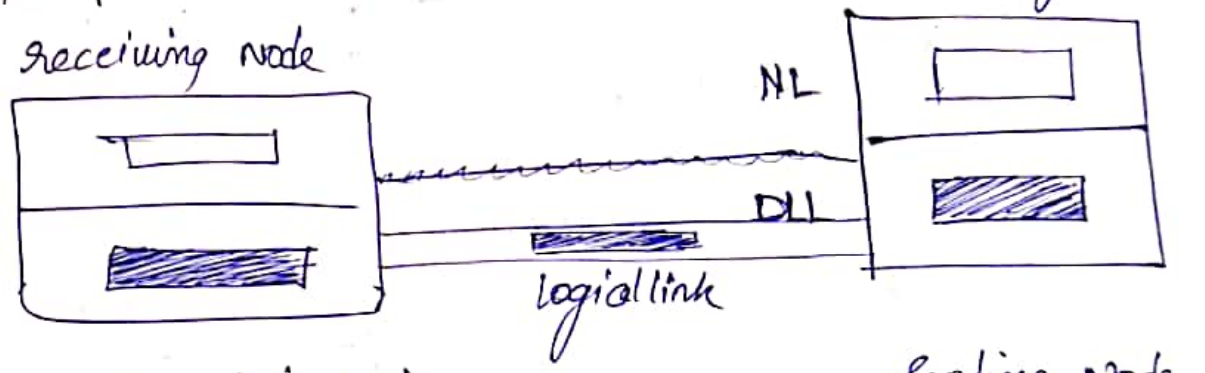
FSM :- (Finalize state machine)
└ It has fixed no. of states machine with finite number of states. any machine is always in one state until an event occurs.

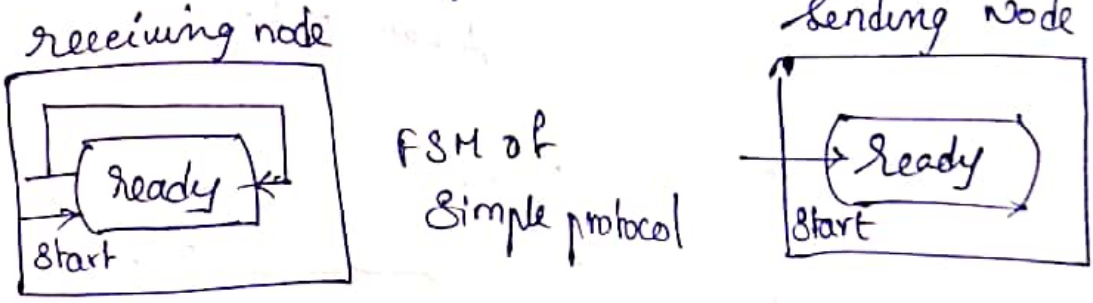


FSM with 2 States
3 actions
3 events

→ when event 1 occurs action (1, 2) occured.
→ if event 2 occurs action 3 occures..

Simple protocol :-





packet comes from NL event makes a frame & sent it → action 2

↓ action 1

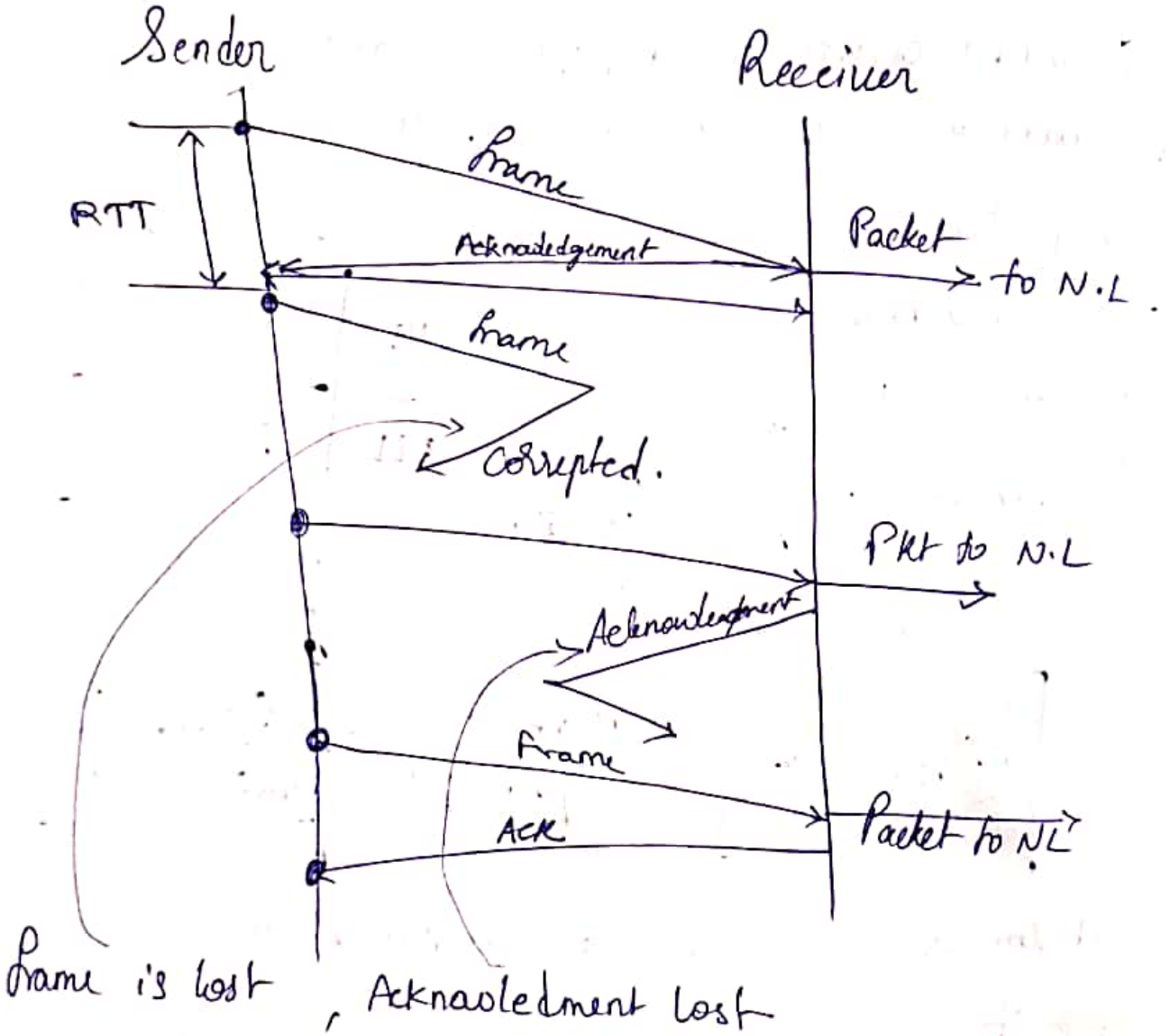
frame is arrived delivered to NL.

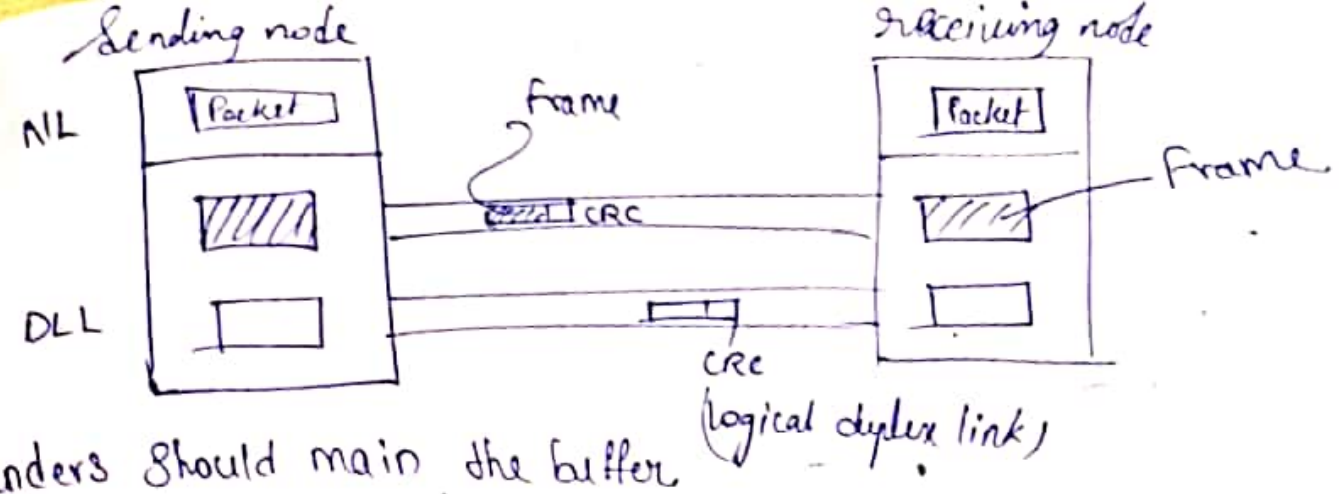
Data link layer at sender gets a packet from N/w layer make a frame out of it & sends the frame.
D.L.L of receiver receives the frame extracts packet from frame & deliver to NL.

D·L·L of Sender & Receiver provides the transmissions services for N·L.

Simple protocol is designed for noiseless channels. hence it is not used for error control. ideally, we will not find noiseless channel in practice.

* Stop & wait protocol: is used for noisy channel & Simple protocol is basis for understanding stop & wait protocol





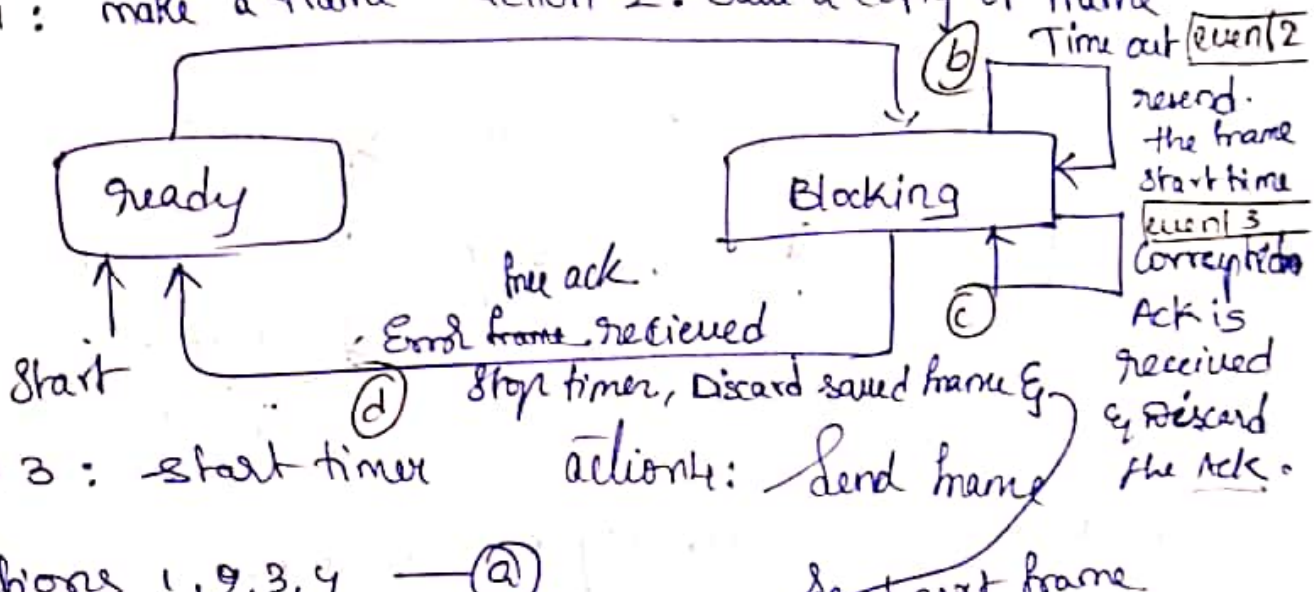
(logical duplex link)

Senders should main the buffer

Buffer : Timer.

event: packet is received from NW layer.

action 1: make a frame action 2: Save a copy of frame



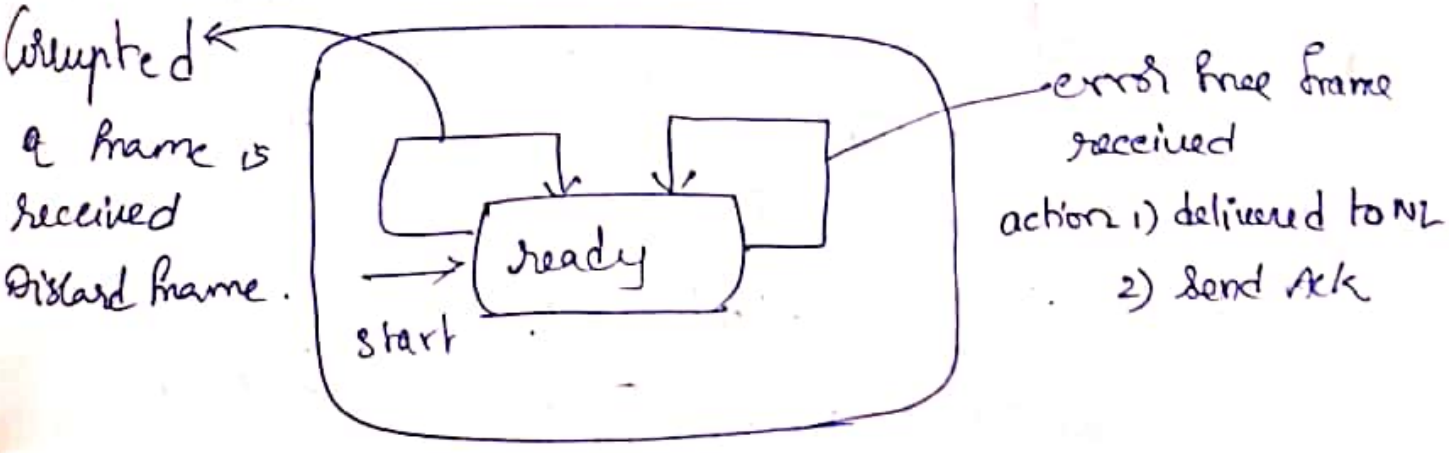
action 3: start timer action 4: Send frame

all actions 1, 2, 3, 4 — (a)

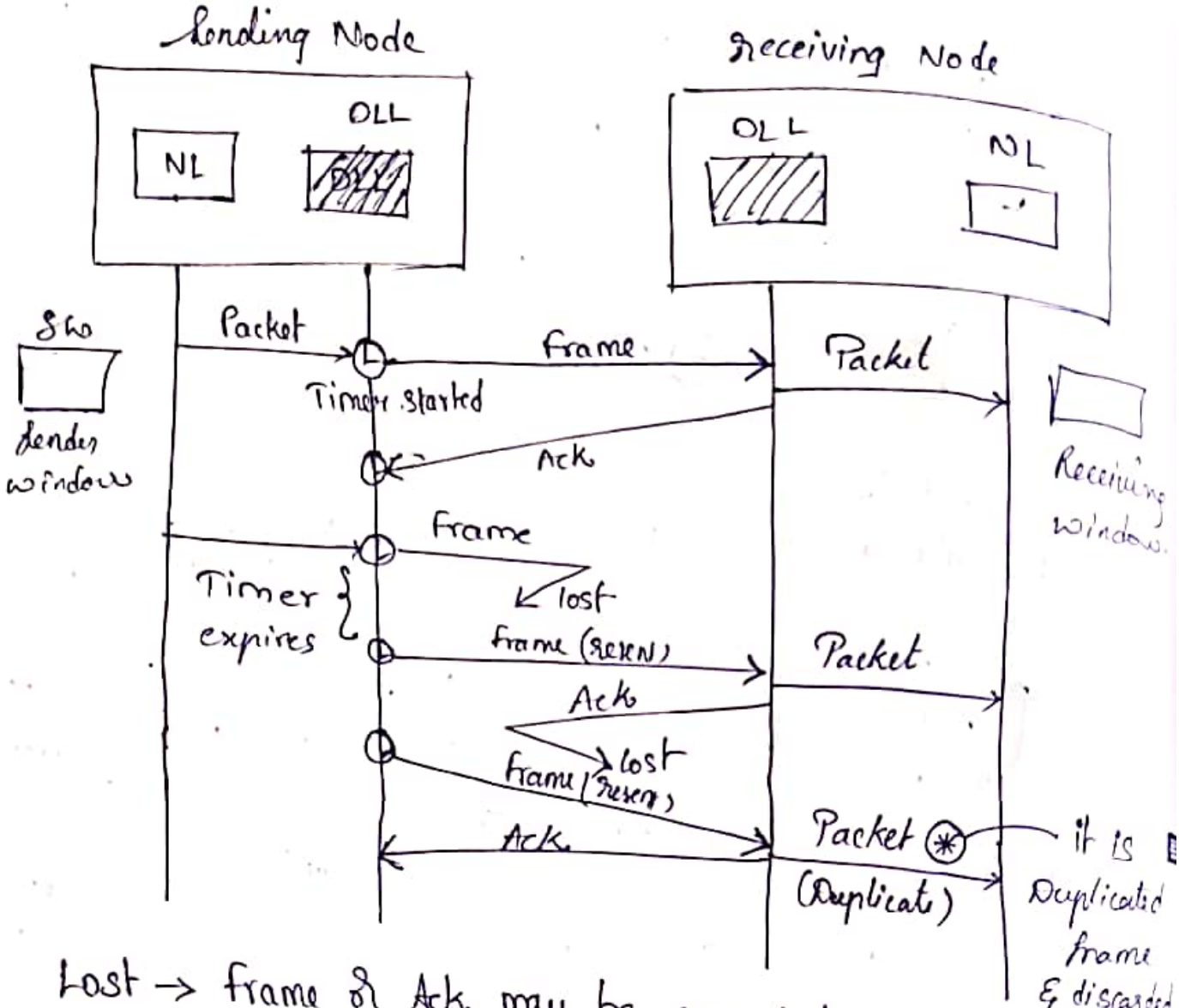
Send next frame

Sending Node FSM

Received FSM



Flow Diagram of Stop and wait :-

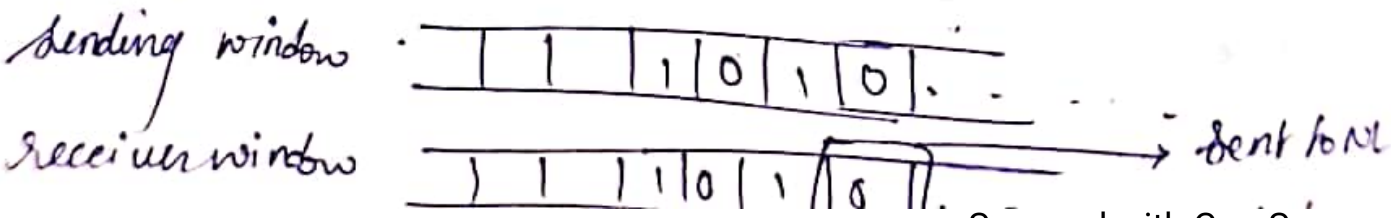


Lost → frame & Ack may be corrupted.

Sequence numbers in module 2 ~~contains~~ Arithmetic

0 1 0 1 0 1 0 1 - - - - - - - -.

both Sender & receiver window uses Sliding window protocal. when sender sends one frame ~~at a~~ wait for acknowledgment. before sending the next frame at a time



efficiency: of start and stop protocol is measured using B·W delay product.

→ stop and wait protocol is inefficient because of channel thick & long. (long means thick means channel with high B·W · long means (round trip) is large // long.

⇒ B·W delay product is measure of no. of bits, sender can transmit through the channel while waiting for ack from receiver.

Q) Assume that in stop & wait protocol the B·W of link is 1mbs, and 1 bit take 20ms to make a round trip what is the B·W delay product. if 1ys data pckts are 1000 bits in length. what is the link utilization %.

Sol B·W delay product = BDP = $(1 \times 10^6)(20 \times 10^{-3})$ 1Mbs.

$= 20{,}000$ bits.

Link utilization percentage = $\frac{1000 \text{ bits}}{20{,}000 \text{ bits}} \times 100$

$= 5\%$

This means that only channel is used for 5% and around 95% of time channel capacity is wasted.

Q) In stop & wait protocol the B·W of link is 100 Mbps 1 bit takes 25·5 msec to make a round trip what is BW delay product If the 1ys data 10K bits what is link utilization percentage

Sol B·W delay product = $100 \times 10^6 \times 25.5 \times 10^{-3} = 25.5 \times 10^5$ bits

Link utilization percentage $= \frac{10 \times 10^3}{25.5 \times 10^5} \times 100$

$= \frac{10}{25.5}$

$= 0.392\%$

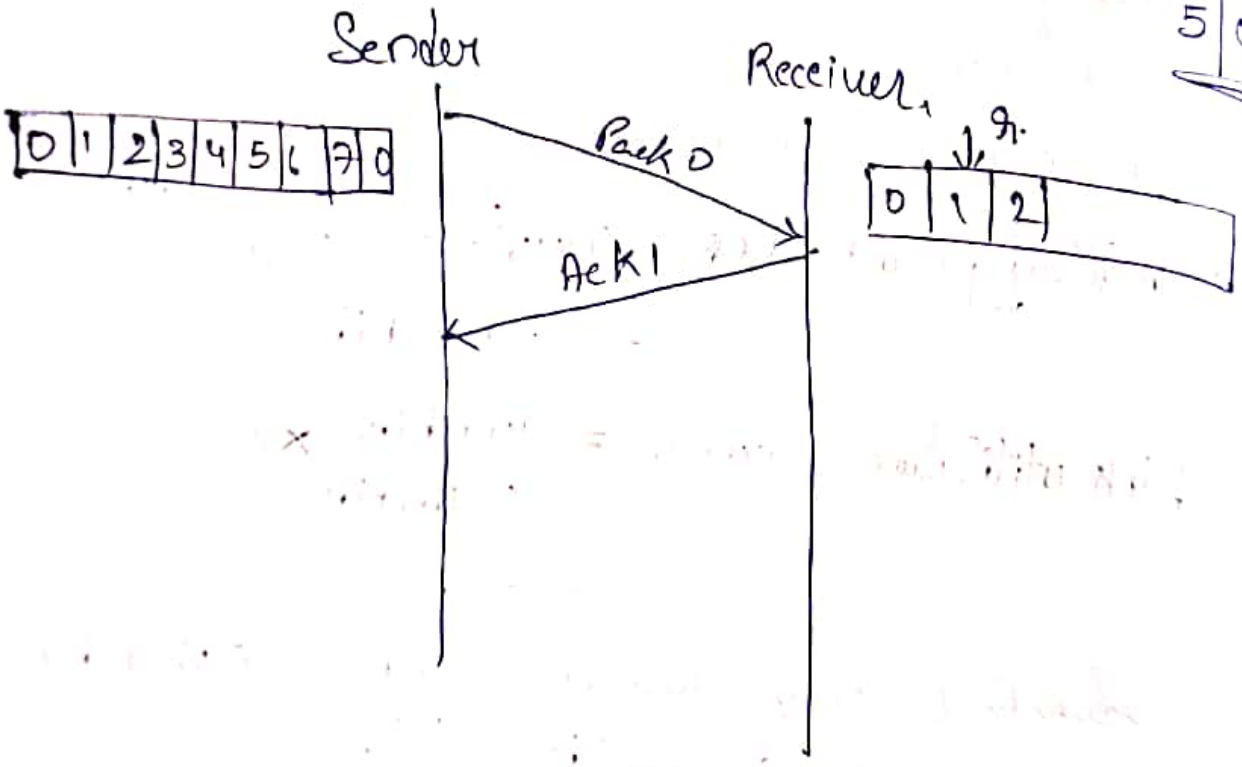
Go back N Protocol :-

→ multiple frames can be sent in GBN protocol

→ sending window $2^m - 1$ (size) | receiver window 1 (size)

→ Sliding window protocol.

5 | 9 | 22

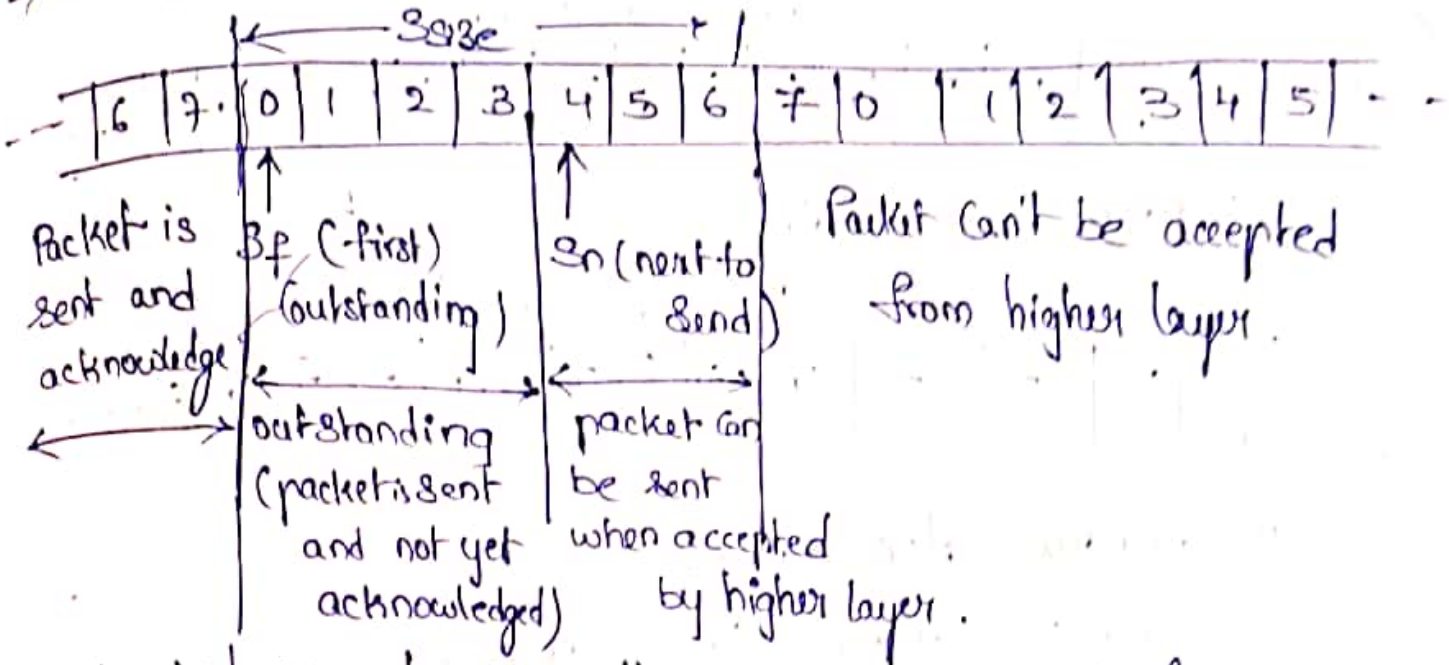


* Sequence numbers are modulo 2^m.

where m = size of sequence number field in bits.

→ the send window is an "imaginary box" covering sequence number of the data packet that can be sent.

∴ max size of send window is $2^m - 1$



Send window at any time divides possible sequence into 4 regions.

Region 1 :- packet is sent & acknowledge

Region 2 :- outstanding packet it means packet is already sent but not received acknowledgment

Region 3 :- the packet can be sent provided there is request from higher layer.

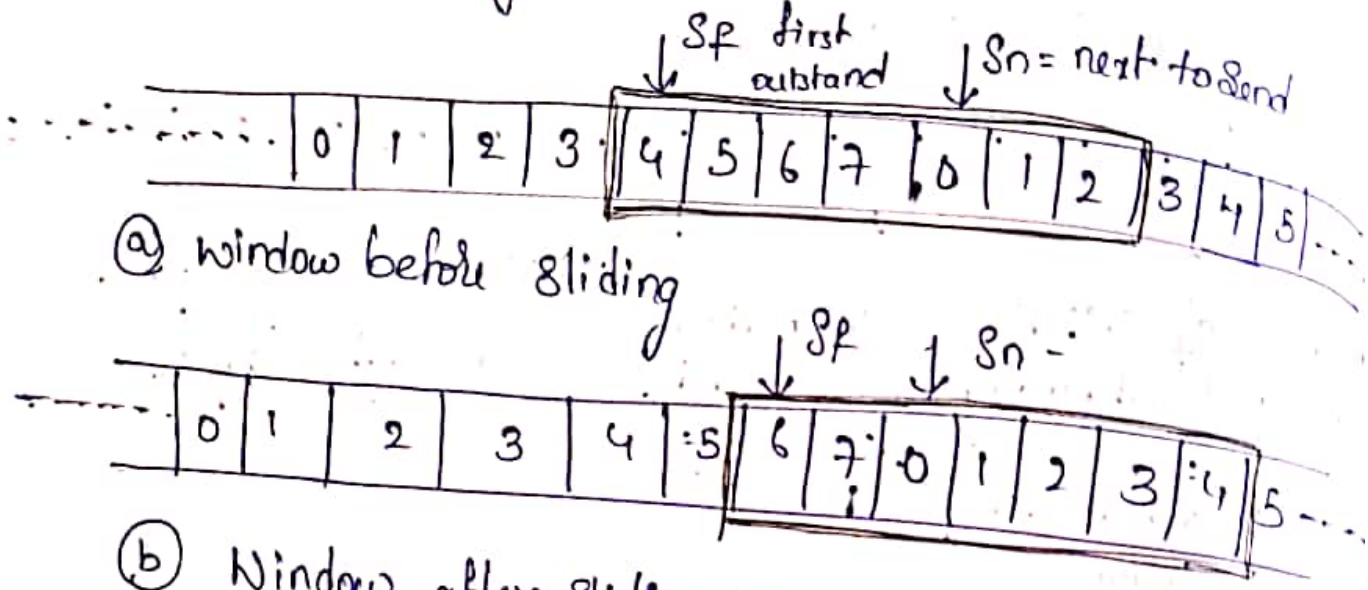
Region 4 :- packet can't be accepted from higher layer. because previous packets are not

Sf = Sequence number of first outstanding packet

Sn = ——— ——— that will be assigned to next packet "to be sent".

S_{size} => Send window size it indicate size of send window. it is fixed.

Send window can slide one or more slots to the right when an acknowledgment arrives from receiver.



(a) window before sliding

(b) Window after sliding.

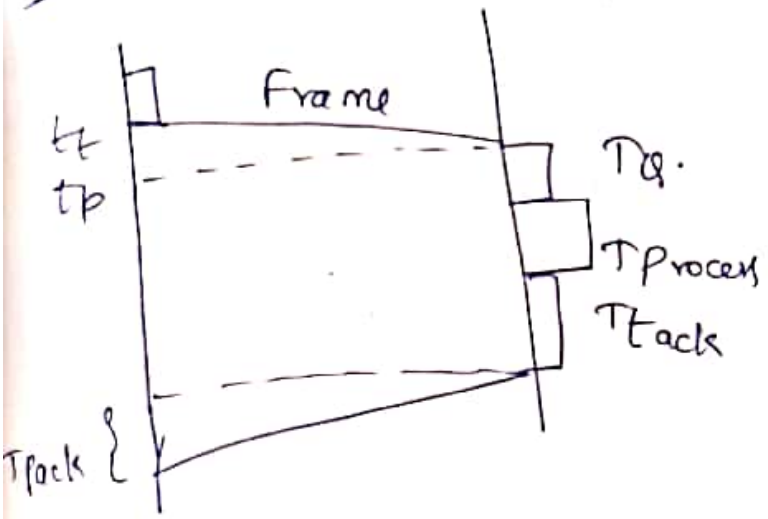
(~~an Ack with Ack no of frames~~)

an Ack with Ack number 6,

Ack no:6 indicates pack no 4, 5 are received correctly & expected pkt no 6 ~~from~~ Sender.

Sequence number & acknowledge number must be greater than & Equal to Sf and less than Sn.

S&W ARQ (Stop & Wait)



$$\eta = \frac{T_t}{T_t + 2T_p}$$

Ex. $L = 10$ bits.

$$T_t = \frac{L}{B}.$$

$$T_p = \frac{d}{V}.$$

Transmission delay :- time taken to ~~come out the~~ last bit of data to go to other end ?

$$T_{total} = T_t + T_p + \cancel{T_q} + \cancel{T_p} + T_{tack} + T_{pack}$$

$$= T_t + T_p + \cancel{T_{tack}} + T_{pack}$$

$$T_T = T_t + 2 \times T_p$$

$$\eta = \frac{\text{useful time}}{\text{Total time}} \rightarrow \text{time required to transmit frame}$$

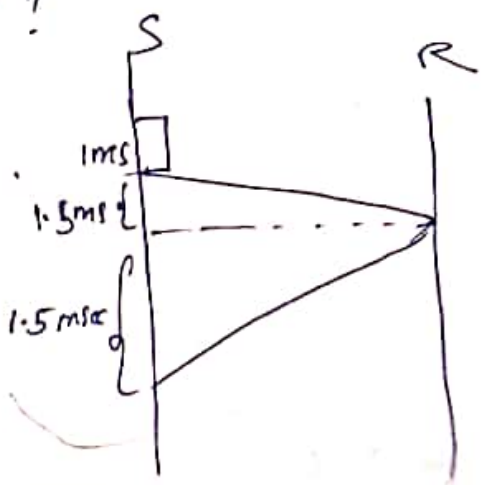
$$= \frac{T_t}{T_t + 2T_p} = \frac{1}{1 + 2\left(\frac{T_p}{T_t}\right)}$$

$$\boxed{a = \frac{T_p}{T_t}} = \frac{1}{1+2a}.$$

Ex

$T_t = 1$msec, $T_p = 1.5$msec $\eta = ?$

Sol $\eta = \frac{1}{1 + \frac{2(1.5)}{1}} = \frac{1}{1+3} = 1/4.$

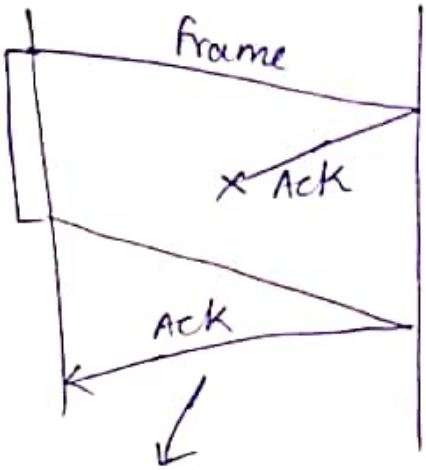


$$\eta = \frac{1}{1 + 2\frac{T_p}{T_t}} = \frac{1}{1 + 2\left(\frac{d}{v}\right)\frac{B}{L}}$$ d & L Varies.

→ To ↑ efficiency we go for (pipeling).

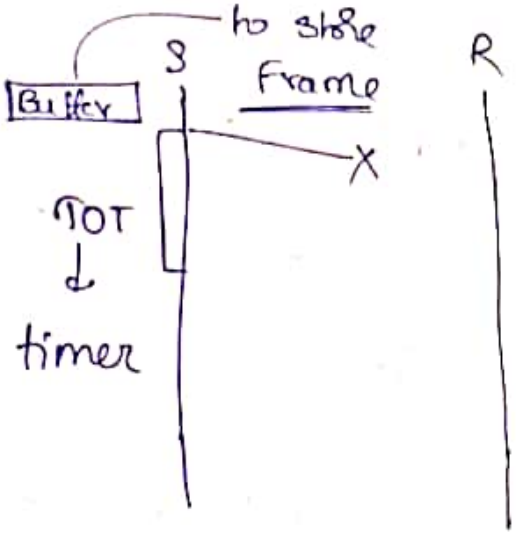
Noiseless mean ① no duplication
② no frame loss
③ no error.

Dead lock :- when sender doesnot retransmit & receiver will not send ack occurs in noisy channel.

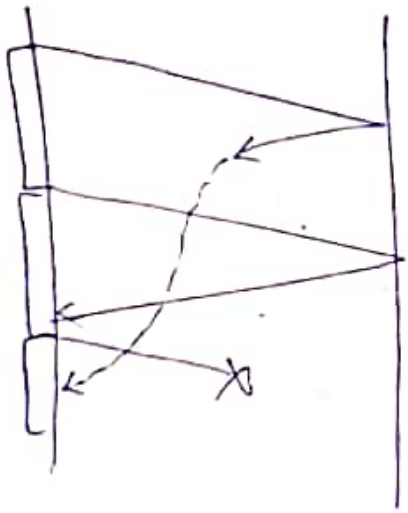


here data is sent twice & received twice

duplication



missing data



to overcome this give sequence number in both frame & acknowledgement.

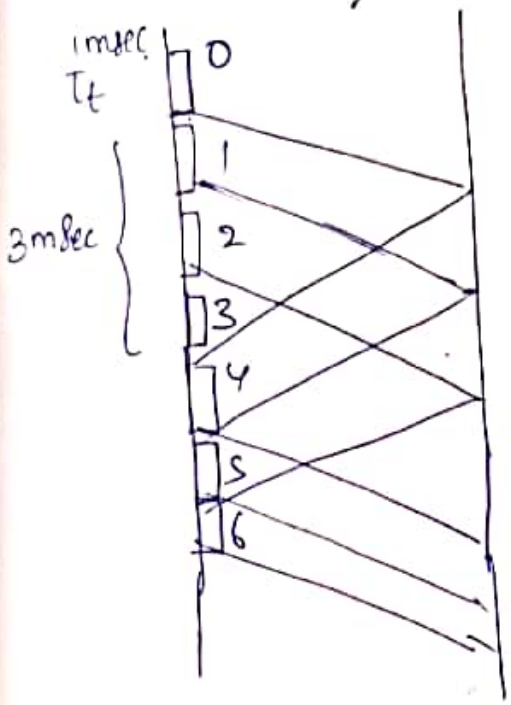
data is missing in receiver

Automatic Repeat Request (ARQ).

pipelining :-

Sliding Window Protocol:

let $T_t = 1$ m&c , $T_p = 1.5$ m&c



By instead of wasting 3 m&c to send next pkt we can send pkts in that time so that by the time we send 4th pck we will get 1st ack.

after every ack the window will slide & takes next outgoing pck.

$$\eta = \frac{4}{1+\frac{2(1.5)}{1}} = \frac{4}{4} = 100\%$$

GBN :-

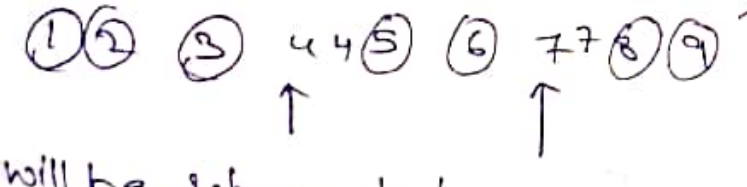
i) Sender Window Size = $W_S = N$ (GBN) . always ($W_S > 1$)

ii) receiver —u— $= W_R = 1$ (Can only accept 1 frame at a time)

Retransmission

from last transmitted frame to Go back N then retransmit all the frames from there

→



4 will be retransmitted ..

total ?

among 10 pkts every 4th pkt frame is lost so what are total no. of transmitted pckts not retransmitted

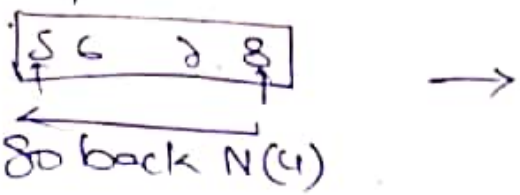
$500 + 500(0.2) + 100(0.2) + 50(0.4) \leftarrow - - -$

want to transmit 500 pckt with error 20%. for every 100 pckt 20 pkts are lost

$\rightarrow n\left(\frac{1}{1-p}\right) = 500\left(\frac{1}{1-0.2}\right) = \frac{500}{0.8} = 625.$

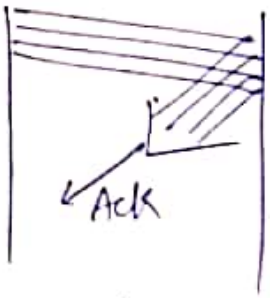
* 1 2 3 4 5 6 ~~7 8 9~~ 10

for 5th pckt loss (GBG) ?



Acknowledgment

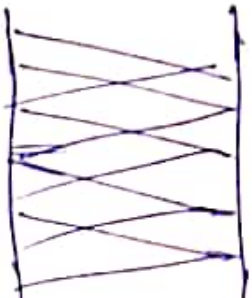
Cummulative



Adv = less traffic

dis - unreliable (for 1 lost we send all)

Independent



Adv : reliable.

dis : more

→ Sender window size = N

receiver window size = 1

min no. of Seq numbers = N+1

no. of bits = $\lceil \log_2^{N+1} \rceil$ → (upper ceiling). means we go for higher number

GBN 100.

$$\left\lceil \log_2^{101} \right\rceil = 6.65 = 7$$

Suppose

→ Sequence number = N

then sender window size = N-1

receiver —11— = 1

$$\text{no of bits} = \log_2^N$$

Suppose

→ bit = k

$Seq = 2^k$ $\quad W_S = 2^k - 1$ $\quad W_R = 1$

Sum

$V = 2.1 \times 10^8$ m/sec $\quad T_t = L/B$

$d =$ $\quad T_P = d/V.$

$L =$

$B =$

Throughput = $\eta \times B.W$

(or)

Effective B.W (or) B.W utilisation

for $\eta = 50\%$ B.W = 4Mbps Throughput = 2Mbps

Ex:-

$T_t = 1$ msec, $T_P = 49.5$ msec BW = 4Mbps $\eta = ?$

Throughput = ?

$$\eta = \frac{N}{1 + 2\frac{T_P}{T_t}} = \frac{N}{1+99} = \frac{N}{100} = 1\% = \frac{50}{100}$$

$= 0.5 = 50\%$

Selective Repeate (SR)

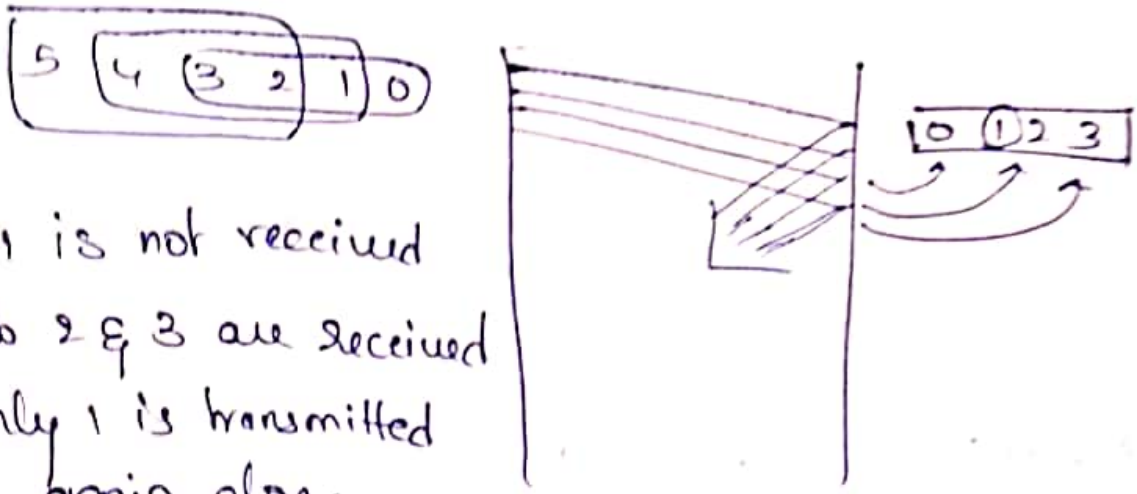
1) $W_S > 1$

$W_S = 2$, $T_t = 1\text{msec}$, $T_p = 1.5\text{msec}$ $\eta = ?$

$$\eta = \frac{2}{1+2\left(\frac{1.5}{1}\right)} = \frac{2}{4} = \frac{1}{2} = 0.5$$

2) $W_R = W_S$.

Search



1 is not received
& 2 & 3 are received
only 1 is transmitted
again alone.

again another efficient way is in the time of time out if we get -ve acknowledgement from receiver then within timeout the retransmission of that particular frame is transmitted Seperately

-ve Ack will tells you which frame to send

NACK1 → means 1. Frame is Corrupted

Ack 1 → -ve ———— received

send 2.

sender has to transmit 10 pkt every 4 packets getting lost.

$\frac{500}{0.7}$ = 714 total no of Transmission.
└ 30% error prob.

	Stop & wait	GBN	SR
efficiency	$\frac{1}{1+2a}$	$\frac{N}{1+2a}$	$\frac{N}{1+2a}$
Buffer	1+1	N+1	N+N
retransmission (1 packet lost)	1	N	1
Sequence number req	1+1	N+1	N+N.
BW	low	high	moderate.
Implementation	Simple	moderate	complex

error ↓	error ↑
outorder (not there)	all er'dd du
BW ↑	s.w.d
CPU ↑ (efficiency)	CPU ↑
└ GBN	└ SR

node — node → GBN
higher layer — SR.