- **Data Link Layer**
  - → NL↓
  - → PL↑
  - → Flow control
    - → Stop & wait
    - → Go Back N
    - → Selective Repeat
  - → Error Control
    - → CRC
    - → checksum
  - → Framing
  - → Physical Addressing. (MAC)
  - → Access control
    - → CSMA/CD/CA
    - → Aloha
    - → Token Ring

LLC
MAC

LLC → Logical Link Control

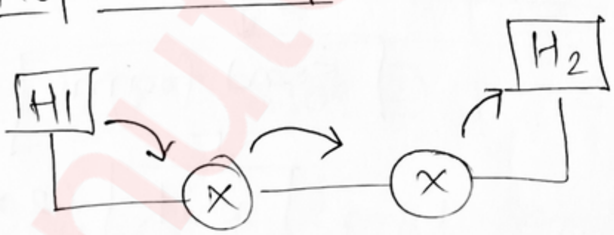
MAC → Media Access Control

Data

↓

Header	Payload	Trailer

- Hop-to-Hop (Node to node)



MAC

- Access Control
- Physical Addressing

LLC

- Flow control
- Error control

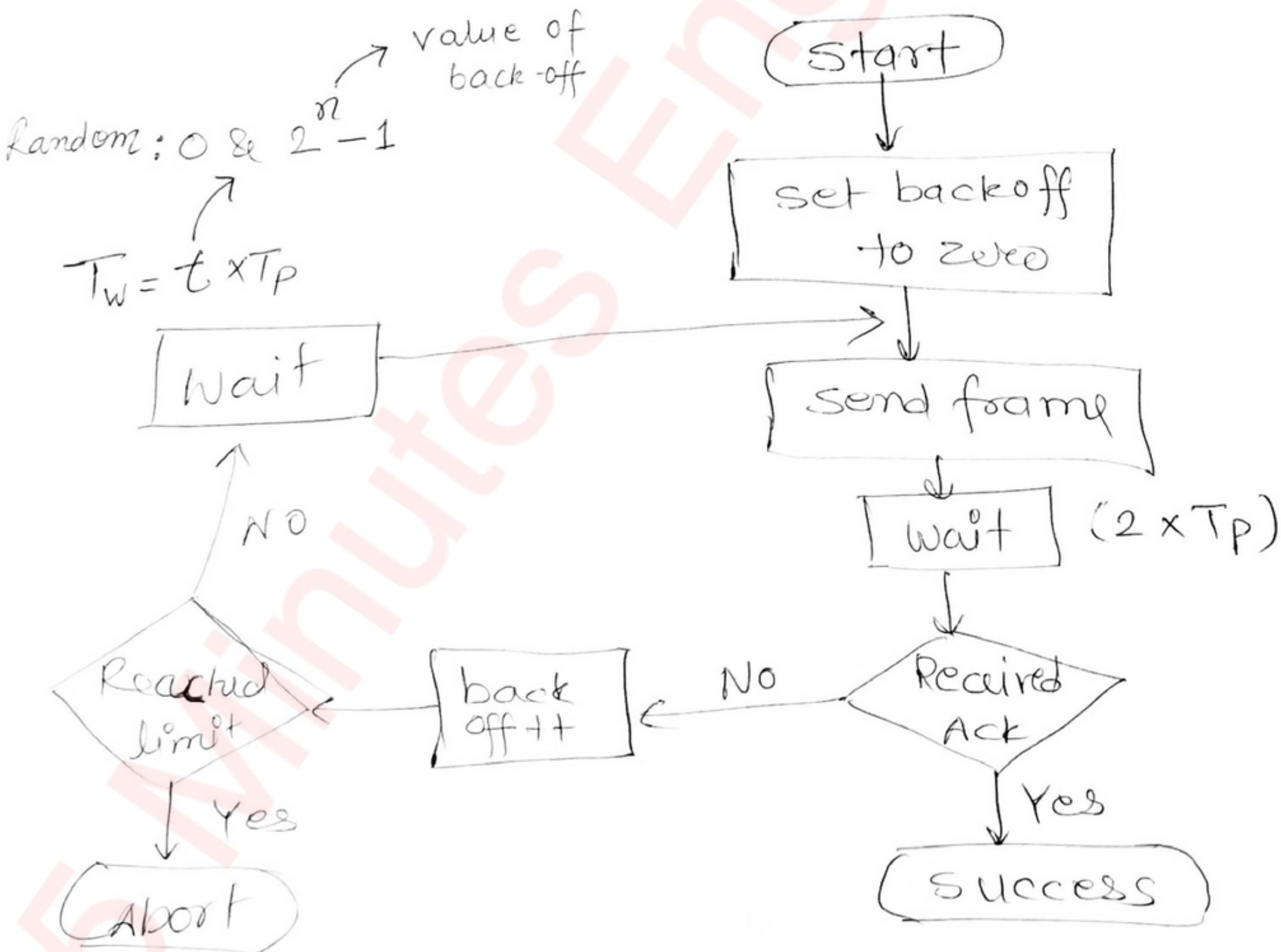
- Framing.

* Access Control

Random Access

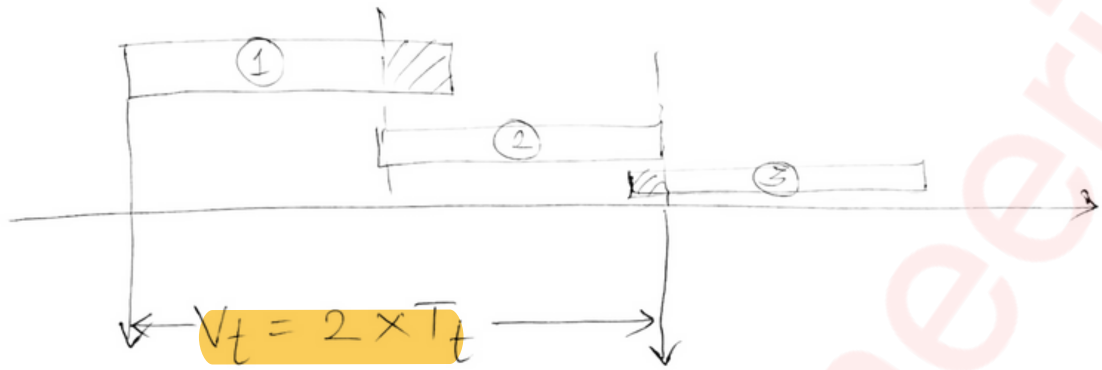
- ALOHA
  - Pure
  - Slotted
- CSMA
- CSMA/CD
- CSMA/CA

⇒ ALOHA



- Vulnerable Time

↳ Possibility of collision



$V_t = 2 \times T_t$

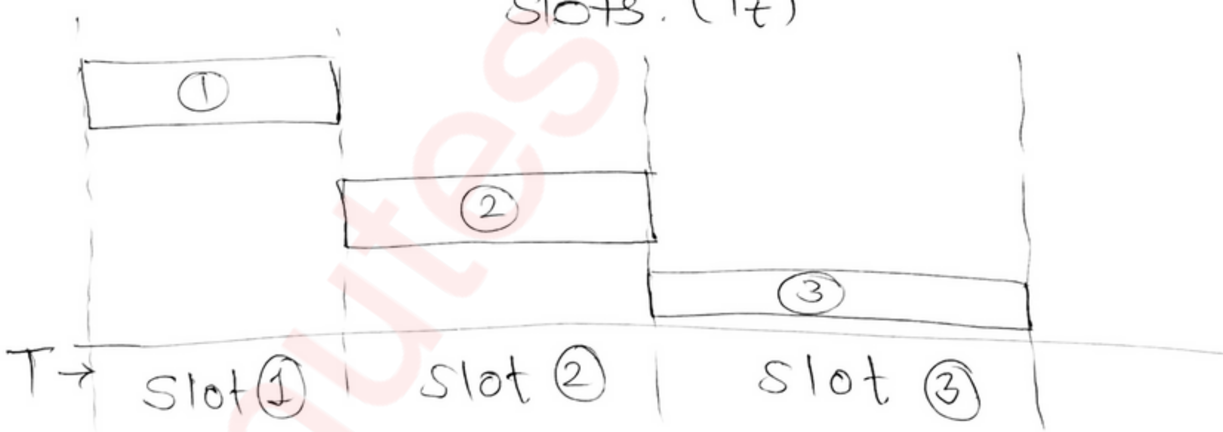
↑

Because of Randomness (18%) efficiency

"But"

↳ Slotted ALOHA

↳ Divide the time 'T' into slots. (T_t)

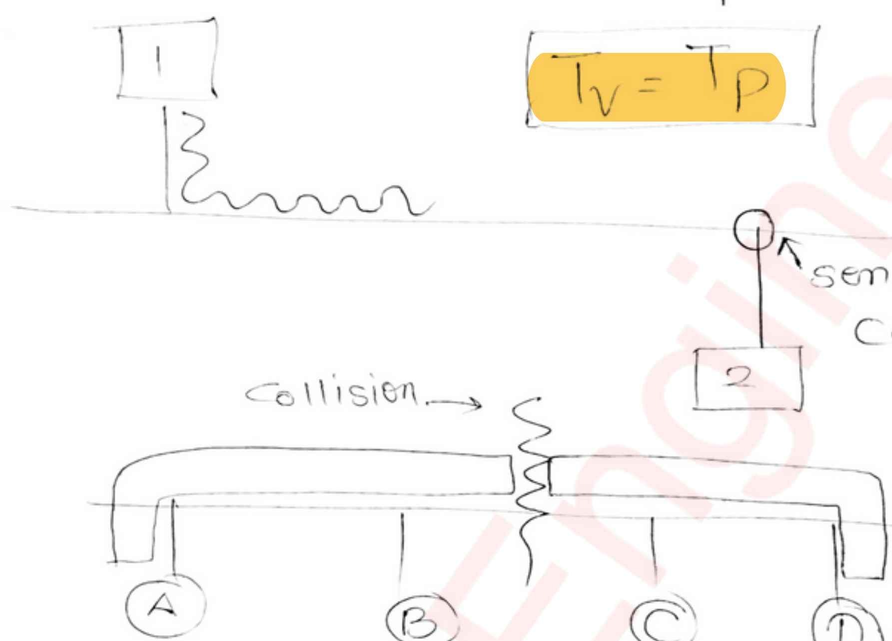


- Station can send only at beginning of slot. (37%) efficiency.

⇒ CSMA

- → Carrier Sense Multiple Access
- → Collision may happen due to "T_p" propagation delay.

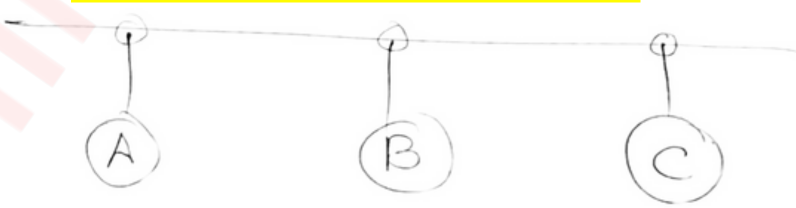
$\boxed{T_v = T_p}$



CD → collision detection

- Persistence Methods
  - → 1-persistent (continuosly sensing)
  - → Non-persistent (Random time wait then sense.
  - → P-persistent (Probability)

in P-persistent ,it continuously sense and if transmission is idle tb prob. ke According trsmission hoga



$P_1 > P_2 > P_3$

0.9   0.6   0.3

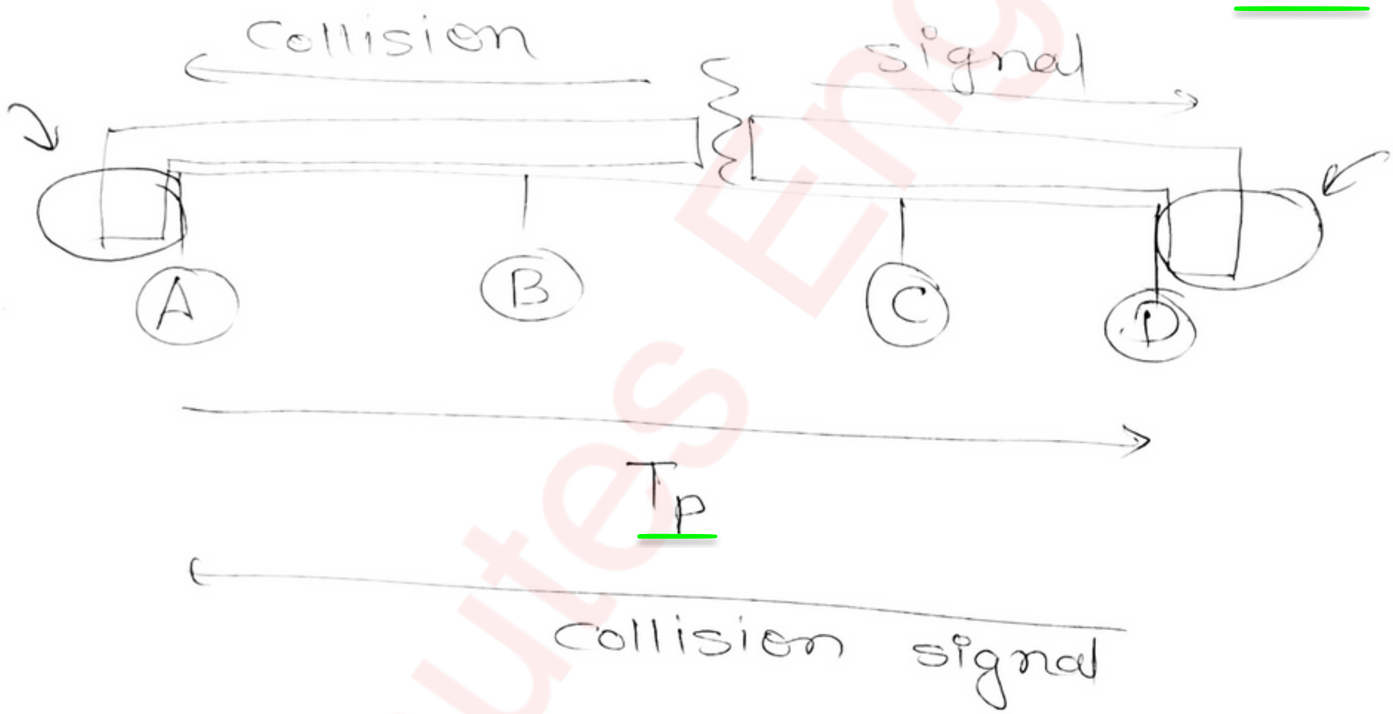
randomly allocated prob

CSMA/CD (wired)

$$T_t \geq 2 \times T_p$$

$$\frac{L}{B} \geq 2 \times \frac{D}{V}$$

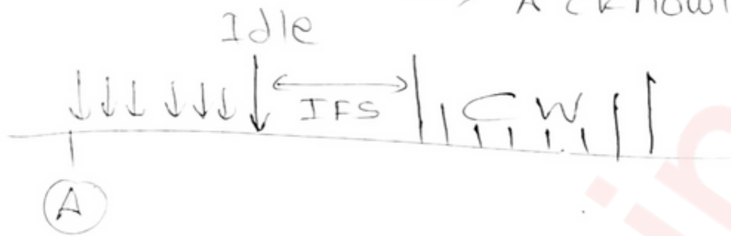
Imp.

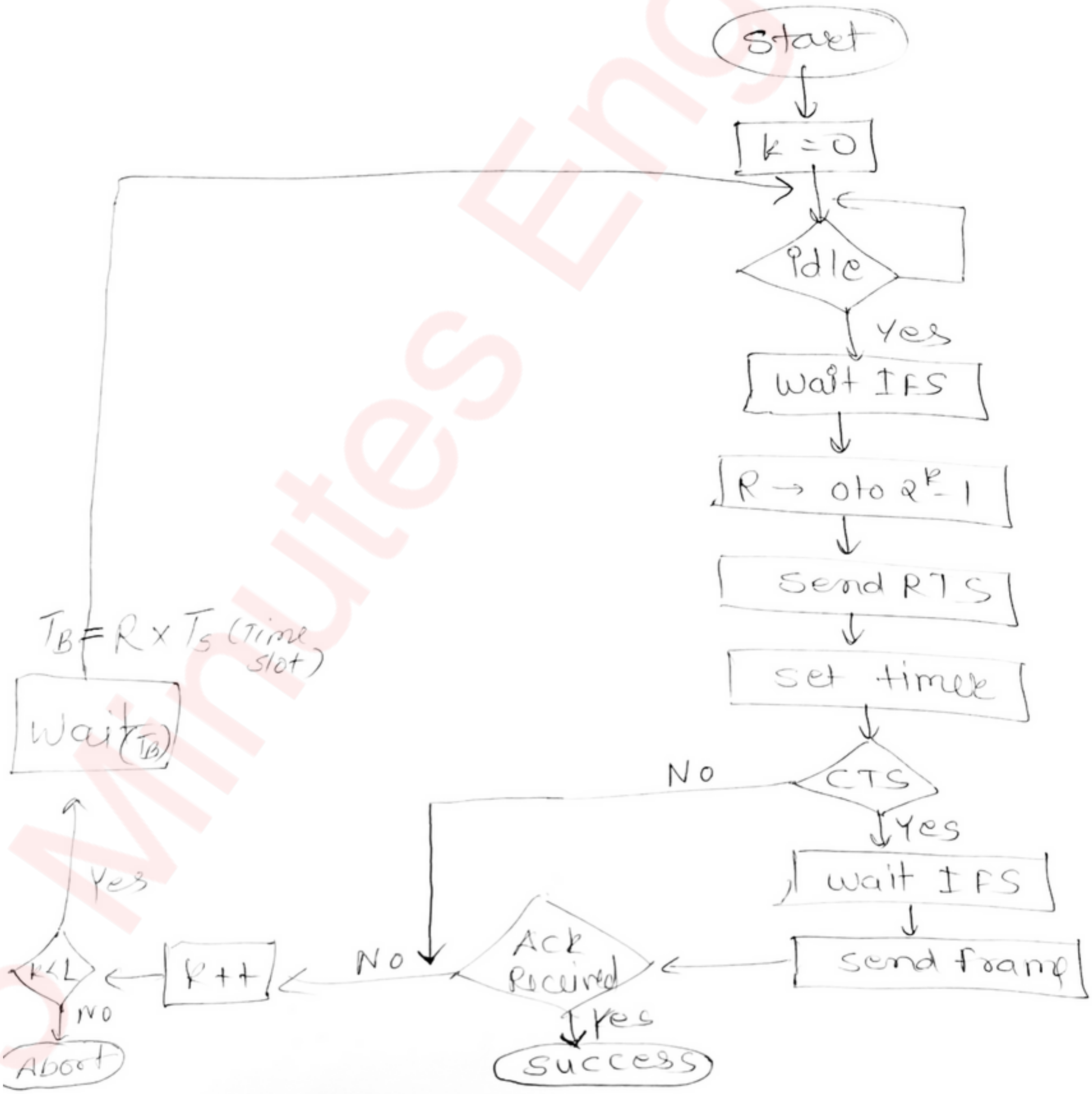


$$\boxed{L \geq 2 \times T_p \times B}$$

Length of packet.

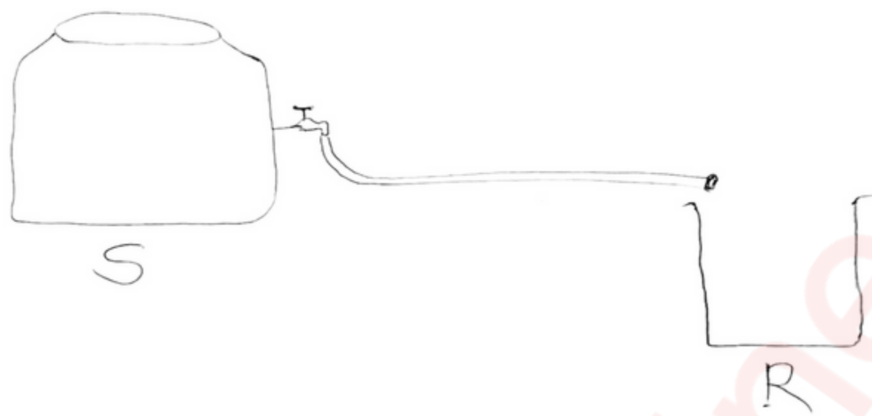
- CSMA/CA (Collision Avoidance) (wireless).
  - → Collision may occur.
  - → strategies
    - → Interframe space
    - → contention window
    - → Acknowledgement.





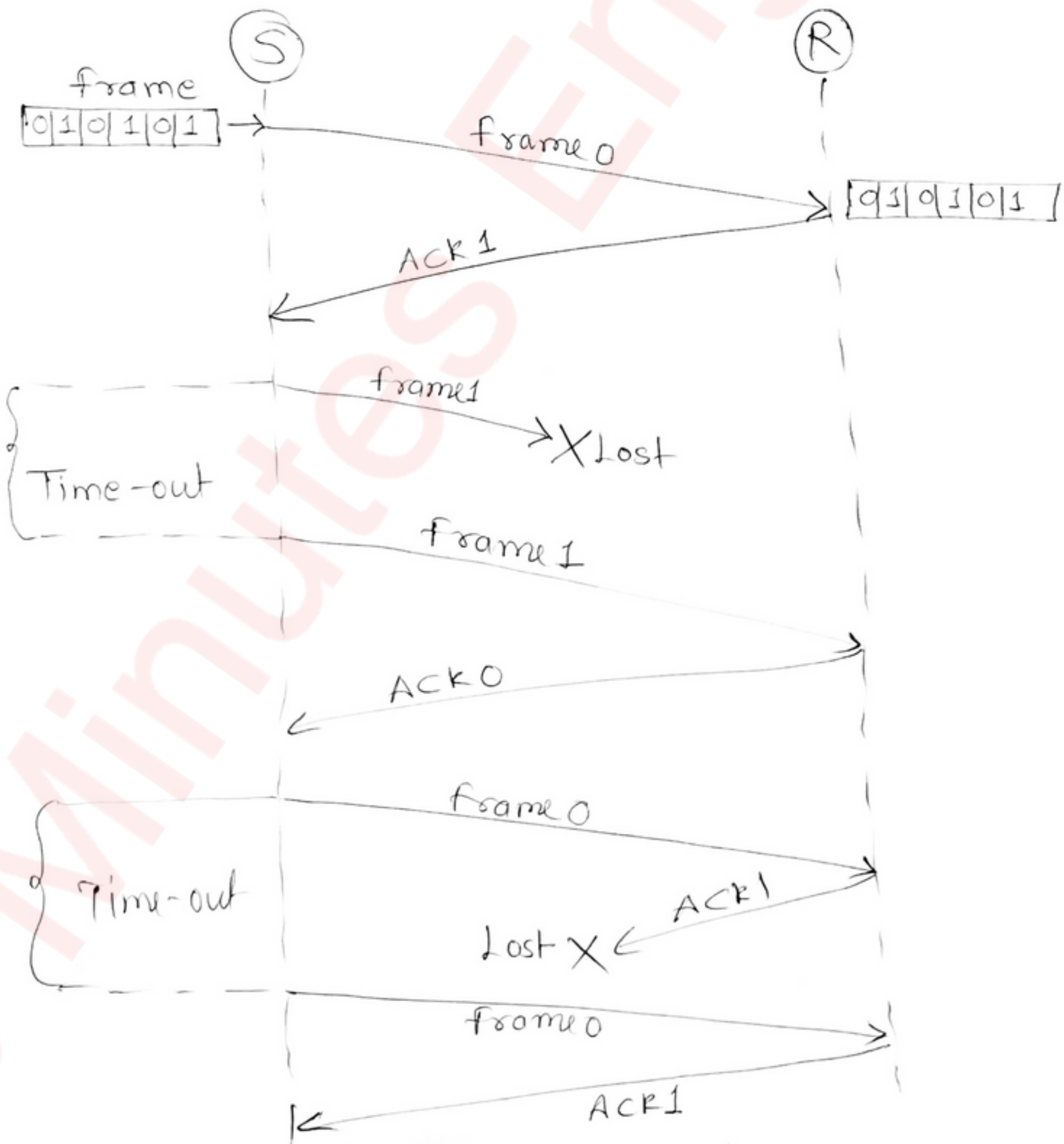
* Flow Control

↳ Data Overflow (x)



⇒ Sliding Window Protocol

① Stop & wait



Total time (1 packet) $= T_{t_{data}} + T_p + T_q + T_{pro} + T_{t_{ack}} + T_{p_{ack}}$

T_q (Queuing delay)
↳ 0 ↳ waiting in I/p or o/p queue of Router

T_{pro} (Processing delay)
↳ 0 ↳ Time for processing packet at destination end.

$TT = T_{t_{data}} + 2T_p + \underbrace{T_{t_{ack}}}_{\text{negligible}}$

$$\boxed{TT = T_{t_{data}} + 2T_p}$$

In piggy backing $T_{t_{data}} = T_{t_{ack}}$

$TT = 2T_{t_{data}} + 2T_p$

$\Rightarrow 2T_p \rightarrow$ RTT (Round trip time).

$$\text{Efficiency}(\eta) = \frac{\text{Useful time}}{\text{Total cycle time}} = \frac{T_t}{T_t + 2T_p} = \frac{1}{1 + \frac{2T_p}{T_t}} = \frac{1}{1+2a}$$

- Troughput : no. of bits we are actually able to send per second

$$S = \frac{L}{T_t + 2T_p} = \frac{(L/B) \times B}{T_t + 2T_p} = \frac{T_t}{T_t + 2T_p} \times B$$

$$= \frac{1}{1 + \frac{2T_p}{T_t}} \times B$$

$$S = \frac{1}{1 + 2a} \times B$$

$$\downarrow$$

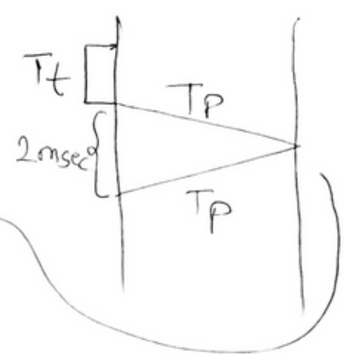
$$\boxed{S = \eta \times B}$$

Q

$T_t = 1\,msec$

$T_p = 1\,msec$

$$\eta = \frac{1}{1 + 2\left(\frac{1}{1}\right)} = \frac{1}{3}$$



$$RTT = 2T_p = 2 \times 1\,ms$$

$$= 2\,msec$$

- If $\eta \geq 0.5$ then

$$\frac{T_t}{T_t + 2T_p} \geq \frac{1}{2}$$

$\rightarrow T_t \geq 2T_p$

$$2T_t \geq T_t + 2T_p$$

$$\boxed{T_t \geq 2T_p}$$

$$\frac{L}{B} \geq 2 \times T_p$$

$$\boxed{L \geq 2 \times T_p \times B}$$

If $L = \uparrow$ then 50% 'η'

Q $B = 4\,Mbps$

$T_p = 1\,ms$

$L = ?$ for $\eta = 0.5$

$L \geq 2 \times T_p \times B$

$L \geq 2 \times 10^{-3} \times 4 \times 10^{6}$

$L \geq 2 \times 10^{3} \times 4$

$L \geq 8 \times 10^{3}$ bits

$S = \eta \times B = 0.5 \times 4 \times 10^{6}$

$$\boxed{S = 2 \times 10^{6} = 2\,Mbps}$$

- factor affecting 'η'.

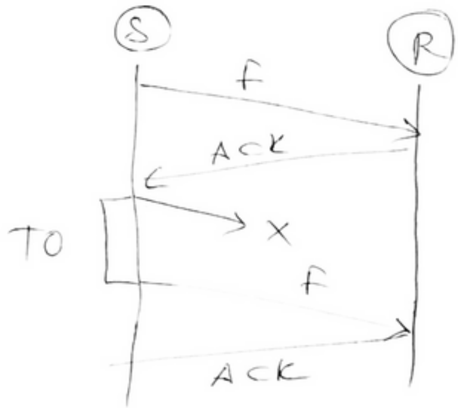
$$\eta = \frac{1}{1 + 2\left(\frac{T_p}{T_t}\right)} = \frac{1}{1 + 2\left(\frac{d}{v} \times \frac{B}{L}\right)}$$

If $d \uparrow$ $\quad \eta \downarrow$ $\quad$ v & B Constant as they are property of Link.

If $L \uparrow$ $\quad \eta \uparrow$

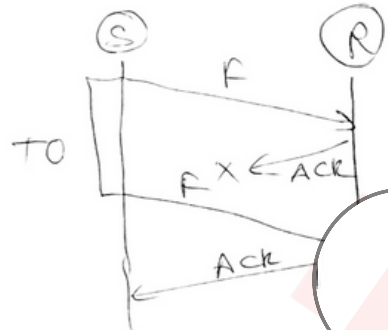
Problem in stop & wait

1) Data Packet lost



S&W + Time out = S&W ARQ (Automatic Repeat Request)

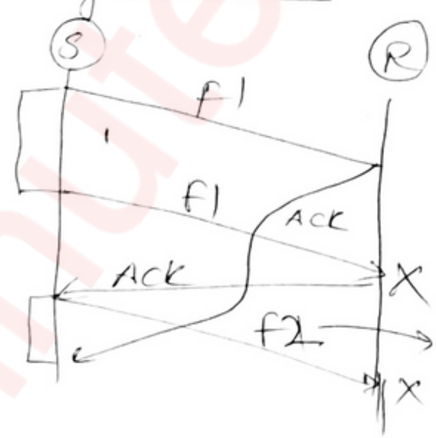
2) Ack lost.



Duplicate packet problem.

Sol^n: S&W + TO + seq. no. (sequence of data/frame)

3) Delayed Ack



missed packet

sol^n => sequence no. (ACK)

$\boxed{\text{S\&W + TO + Seq(Data) + Seq(Ack)}}$

(2) Go Back N (ARQ)

(1) WS: Sender window size (N)

GB10 → WS = 10 (N > 1)

If N = 1 then it's simply Stop & wait.

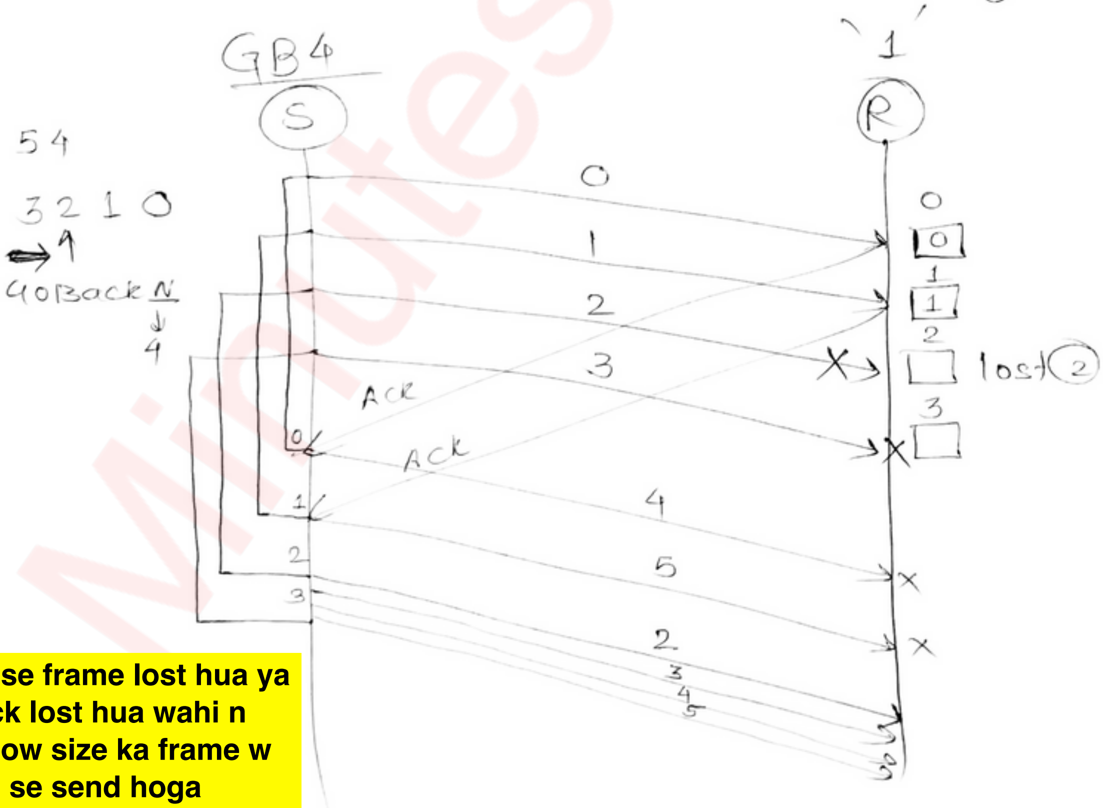
$$\eta = \frac{N}{1+2a} \qquad S\&W = \frac{1}{1+2a}$$

$$a = T_p / T_t$$

$$S = \eta \times B$$

$$S = \frac{NB}{(1+2a)}$$

(2) WR: Receiver window size is '1' always



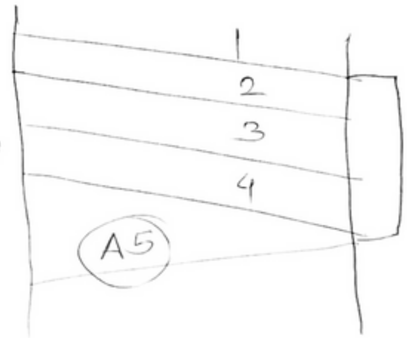
jaha se frame lost hua ya fir ack lost hua wahi n window size ka frame wapas se send hoga

- Acknowledgements types

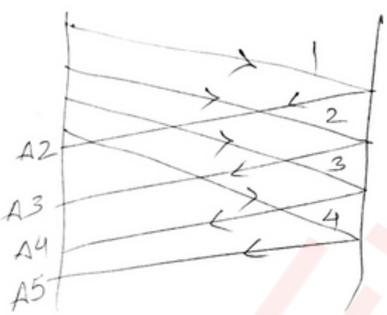
↳ Cumulative Ack

Adv : less Traffic

disadv: Reliability is less



→ Independent Ack



more { reliable, Traffic }

Timeout (TO) Timer > Ack Time [Not too long, nor too small]

→ TO expire

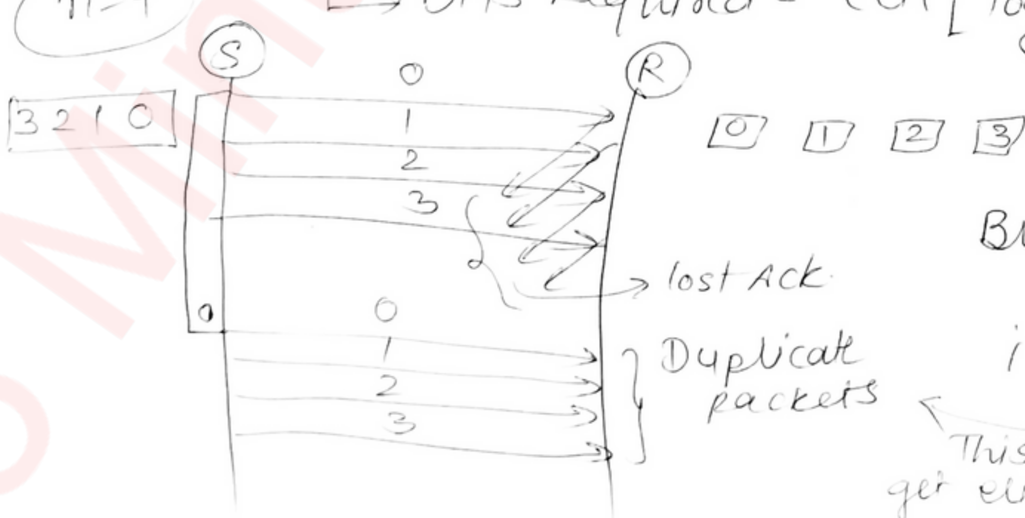
→ Independent Ack

⇒ Sequence Numbers (n)

→ $N+1$

→ Bits Required = ceil($\lceil \log_2(N+1) \rceil$)

$n=4$



But for $n=5$ i.e $N+1$

This problem get eliminated.

$\Rightarrow W_S$	W_R	seq. no. required
N	1	$(N+1)$

at least this much is required

Available sequence no. $\geq (W_S + W_R)$

$\Rightarrow$ Bits $= k$

then seq nos $= 2^k$

then $W_S = 2^k - 1$

$W_R = 1$

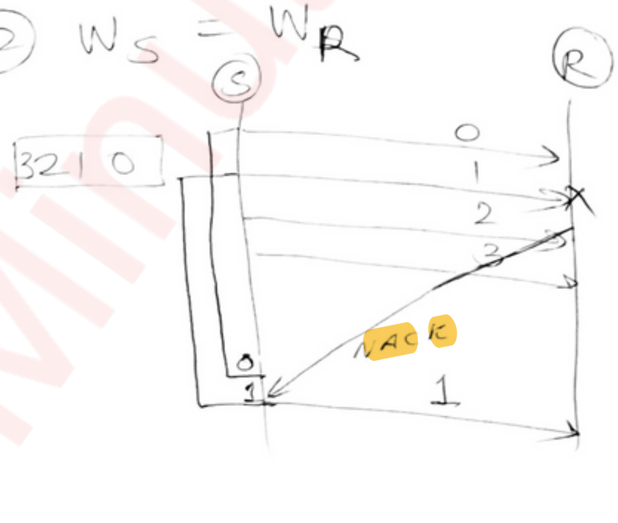
$$2^k \rightarrow 2^k - 1, \; 1$$

③ Selective Repeat

$$2^k \rightarrow \frac{2^k}{2} = 2^{k-1}, \; \frac{2^k}{2} = 2^{k-1}$$

① $W_S > 1$

② $W_S = W_R$



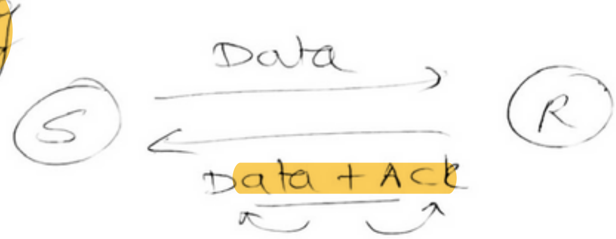
It will only Resend '0', & not the whole window as in GBN Approach.

SR

S&W (Re-transmission) ← SR → GBN (efficiency)

	S&W	GBN	SR
'η'	$1/1+2a$	$N/1+2a$	$N/1+2a$
Buffer	$1+1=2$	$(N+1)$	$(N+N)=2N$
Seq. nos	$1+1$	$(N+1)$	$(N+N)$
Re-transmission (If 1 Packet lost)	1	N	1
Ack	Independent	Cummulative	Independent
Implementation	Easy	medium/ moderate	Complex/ difficult

- Piggybacking



(3) Error Control

S → R

| 0 | 1 | 0 | 1 | 0 |

| 0 | 0 | 1 | 0 | 0 |

corrupted / modified / altered / changed / manipulated.

- 1 bit (single bit). [less common]
- Burst error. (2 or more bits) ✓ normal / common.

(1) Hamming Distance

↳ Counting the no. of dissimilar bits of given 2 nos.

eg:
$$
\begin{array}{r}
10101 \\
\text{XOR} \; 11010 \\
\hline
01111
\end{array}
$$

$\underbrace{0\,1\,1\,1\,1}_{} \rightarrow 4$ ✓

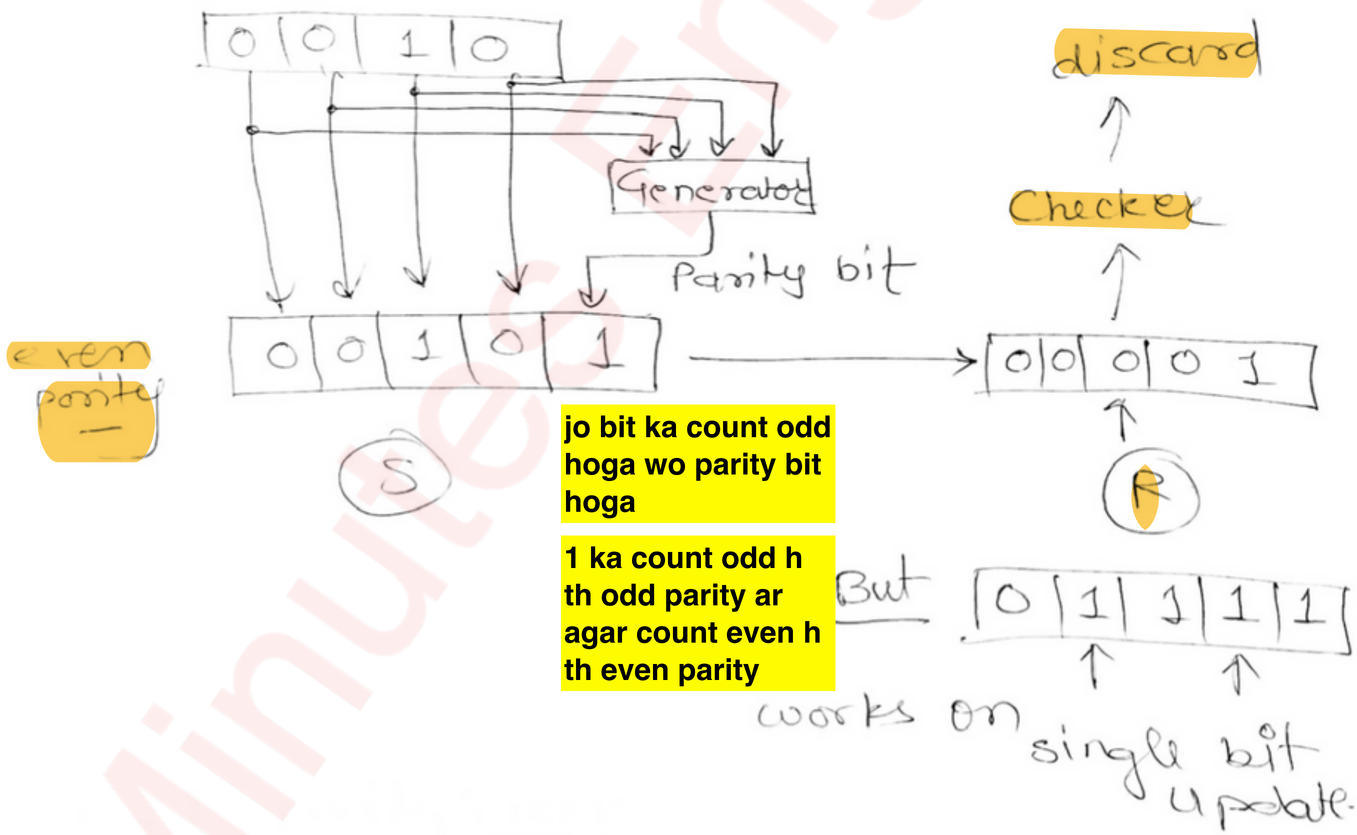
0	0	0
0	1	1
1	0	1
1	1	0

Detection of Error

- → simple Parity check
- → 2D Parity check
- → check sum
- → CRC

⇒ simple (single bit Parity).

- → odd
- → even.



jo bit ka count odd hoga wo parity bit hoga

1 ka count odd h th odd parity ar agar count even h th even parity

⇒ 2D Parity check

⇒ 1 0 1 , 0 1 0 , 1 1 1

1	0	1	0
0	1	0	1
1	1	1	1
0	0	0	

← Row parities (last column)

Column parities (last row)

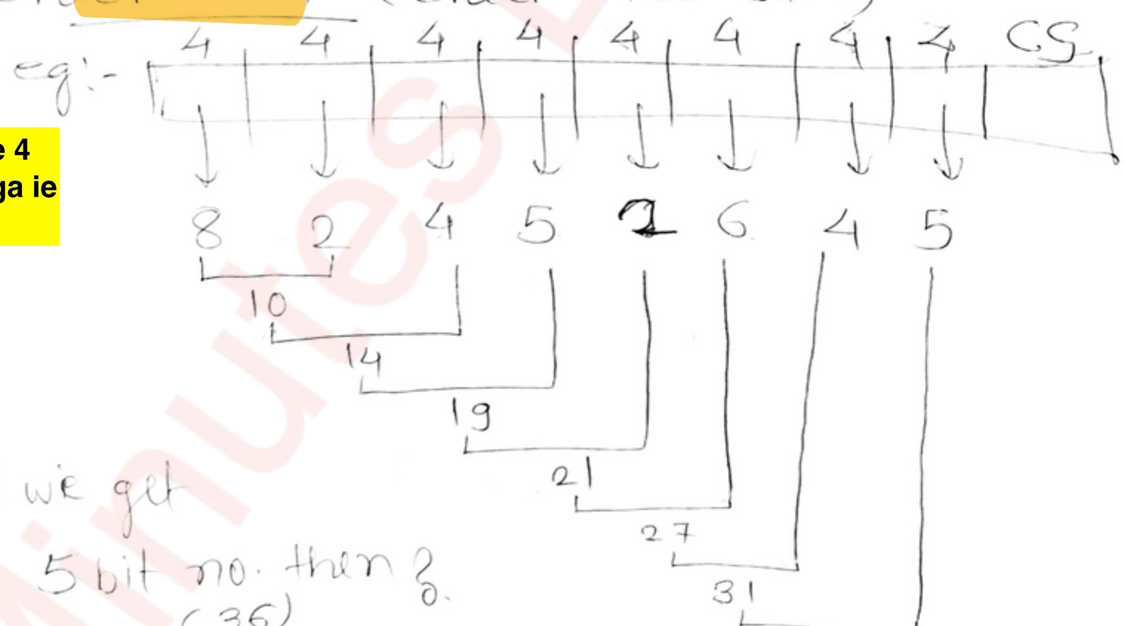
1/single bit error detect & correct.

Error detection till '3bits'

>3 bit error → nor detect, → neither correct.

- Checksum (check the sum)

eg:-



saree field mae 4 bit number hoga ie ex 8,2,4...

If we get 5 bit no. then ?.

(36)

↓

1 0 0 1 0 0

→ 10

0 1 1 0 (6)

$\boxed{1\ 0\ 0\ 1}$ (9) ← 1's complement

36 → 1's complement → −36

these 10 bit are extra ie th hm inne add kr dete h

(R) end : 36 + 9 = 45

1 0 1 1 0 1

$\quad$ + 1 0

---

1 1 1 1 (15) — 1's complement

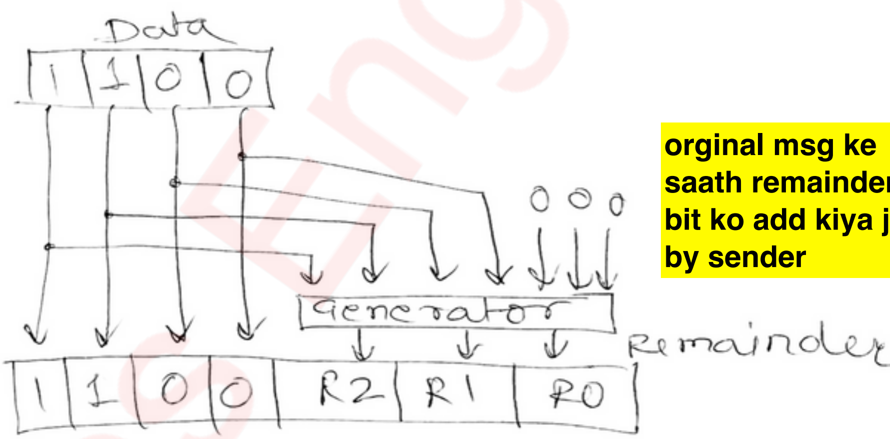
0 0 0 0

✓ valid / No error.

ie ki if all bit comes zero at the end th no error

=> CRC — Cyclic Redundancy Check.

eg: Data



orginal msg ke saath remainder bit ko add kiya jata by sender

Divisor : 1 0 1 1

$x^3 + x + 1$

↓ ↓ ↓ ↓

1 0 1 1 (x^2)

(4 − 1) no. of zeros

original data mae no. of divisor - 1 utne zero append kr dete h original data mae

divisor phle se hi decider hota h bw sender and receiver

```
1011) 1 1 0 0 0 0 0
XOR   1 0 1 1
      -------------
      0 1 1 1 0 0 0
        1 0 1 1
      -------------
        0 1 0 1 0 0
          1 0 1 1
      -------------
      0 0 0 0 1 0
              R2 R1 R0
```

=> 1 1 0 0 0 1 0

left to right jaenge ar jaise hi 1 dhkega waha tutrant divisor ko rhk denge ar xor opern krenge

jaise yaha 1 dusre bit pe tha 2 bit se divisor rhkha

why stop here ? kyu ki jaise hi 1 mila tb uss 1 ke right mae divisor jitne bits hi nhi h th xor nhi ho paega

At (R) side Checker

```
1011 ) 1100010
       1011
       -------
       0111010
        1011
       -------
        010110
         1011
       -------
         00000   <- all zero.
```

receiver pe bhi same hoga sab ar agar remainder zero hoga th no error

* Ethernet

- → Topology [BUS] 
- → Access control Method [CSMA/CD]
- → NO Ack
- → Encoding Technique (Manchester)
- → Data Rates: 10 Mbps — Normal
  100 Mbps — fast
  1 Gbps — Gigabits
- → Real Time Appl^n (X)
- → Interactive Appl^n (X)

} low performanc

Ethernet frame format

Preamble	SFD	DA	SA	Length	Data	CRC
7 byte	1 byte	6	6	2		4
PL Header		DL Header				Tail

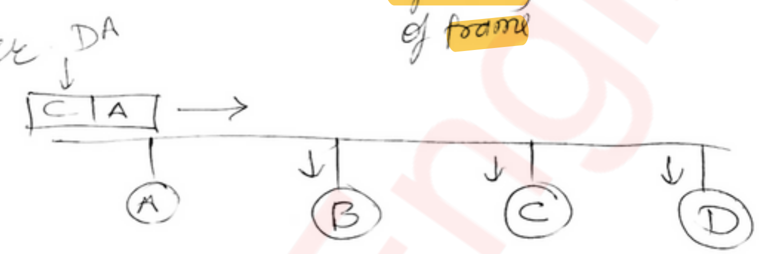
Preamble : 101010 - - 10

SFD : 10101011

(start of frame) delimiter

beginning of frame

MAC addr (DA, SA)



only valid Receive Reads it

	Min	Max
Data	64 - 18 = 46 B	1500 B
frame	64B	1518 B

* **MAC Address** :

NIC
↓
ROM (MAC addr Hard coded)

first 3 byte of mac address shows NIC manufacture

last 3 byte shows device ID

A1 : 2B : C4 : D2 : 89 : A5
A1 - 2B - C4 - D2 - 89 - A5

Format (: , -)

1B 1B 1B 1B 1B 1B = 6B = 48bi

mac address ke 1st byte ke LSB mae 0 hua th means ki wo unicast h

ex-A2 means 10 ..iske LSB mae 0 h

• Types:

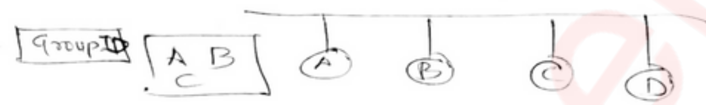
→ **Unicast** (one-to-one)

LS 1st byte → '0' A2 1010 0010

LSB

→ **Multicast** (one-to-many)

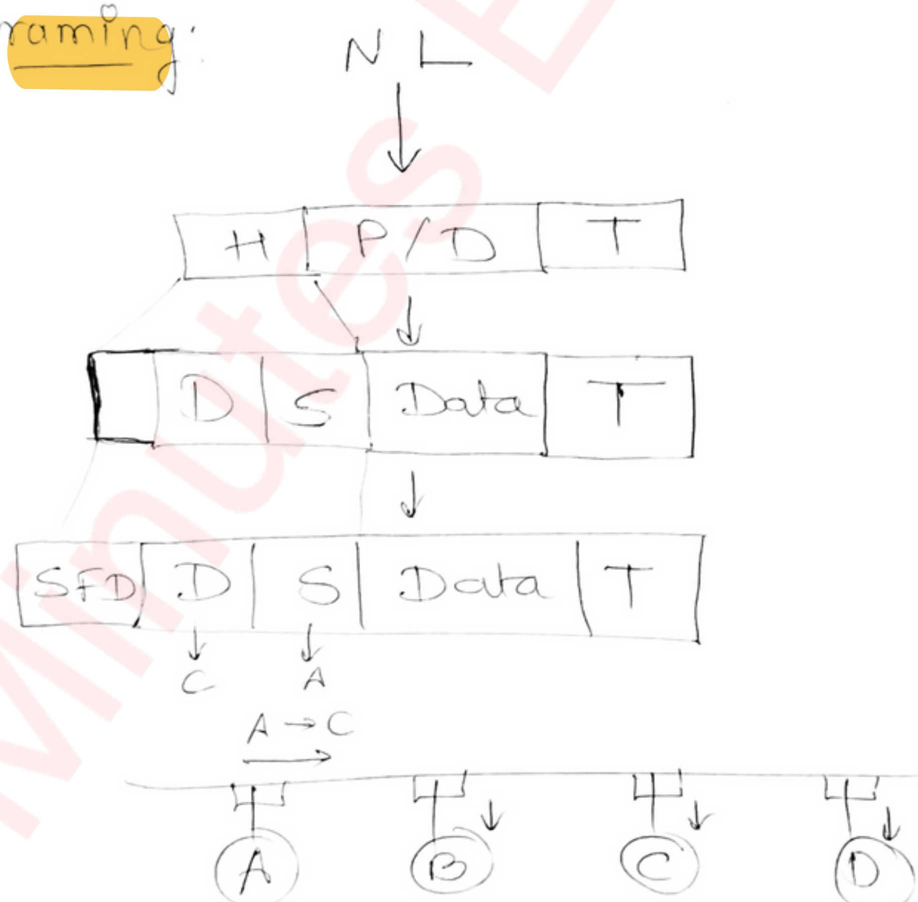
LSB 1 byte → '1'



→ **Broadcast** (one-to-all)

FF:FF:FF:FF:FF:FF

* **framing**:



reader ko pta chle ki frame kb khtm hoga th frame length ko introduce krna pdta h

frame length

- fixed (100 B)
  [20B Data + 80B padding]
- Variable (10B, 100B, 1000B)
  - End of frame
    - Length field (Ethernet)
    - (Token Ring) End Delimiter
      - character stuffing
      - Bit stuffing

if frame length fix kr diya let say 100 byte ..ar if data bas 20 byte ka h th 80 byte ka padding add hoga jiska actual mae koi sense nhi h

in var fraame length, let say ki last mae $ hua th th frame end h but if data mae hi $ hua th ..tb ek rule banate h ki data mae $ ke baad ek null character hoga jo indicate krega ki ye dollar data ka part h

H	$ \0	$

↓

H	$ \0 \0 \0 \0	$

same with null char in data hua tb jaise $ ke liye null tha waise hi null ke liye bhi ek null intro krenge

\0 → null character

10000

stuff the bit here.

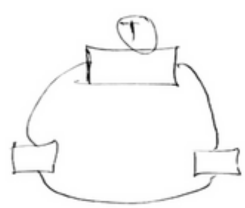
1 0 0 0 1 0
1 0 0 0 1 1
(Data)

ED = 10000

in bit stuff ,let sat ki 10000 hmne trailer le liya ar if data mae hi 10000 hua tb ek rule banate h ki every 3 consecutive zero ek 1 bit stuff krenge

* Token Ring

- → Topology [Ring]
- → Access control method [Token Passing]
- → Data flow : Unidirectional.
- → Ack - Piggybacking
- → Encoding : Differential Manchester
- → Data Rates : 4 Mbps, 16 Mbps



Token Ring frame format

SD	AC	FC	DA	SA	Data	CRC	ED	FS
1	1	1	6	6	(0 to max) "≥ 0"	4	1	1

Token:

SD	AC	ED

SD →

J	K	0	0	J	K	0	0

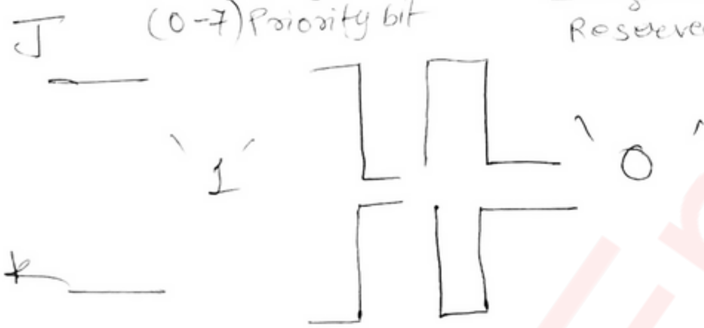
AC →

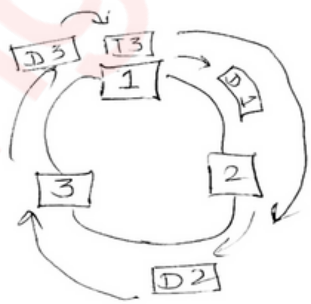
P	P	P	T	M	R	R	R

(0-7) Priority bit — Reserved.

T: Token (1) & T = 0 Not Token

M: Monitor bit





FC:

00 → data frame

11 → control frame

(AMP, Beckon

[Alive monitor Packet]

ED:

J	K	1	1	J	K	I	E

Info bit — Error bit.

FS:

A	C	0	0	A	C	0	0

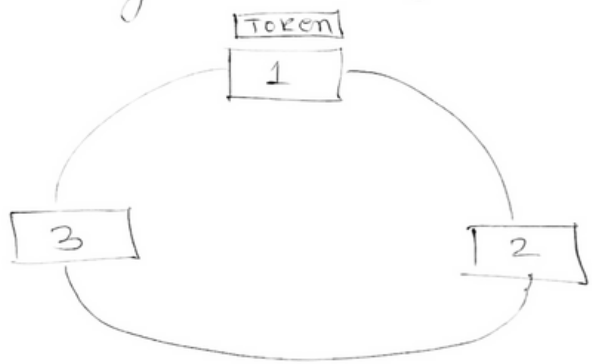
frame status — Availability (Destination Available or not) — copy

I = 1 [more data coming]

I = 0 [No more data.

Token Passing

→ Ring Topology

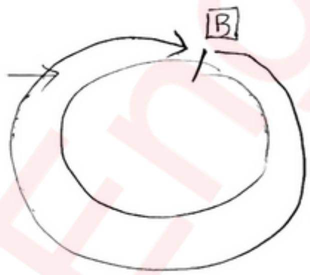


⇒ hold the token the transmit the data

⇒ unidirection.

⇒ NO collision

⇒ Ring Latency



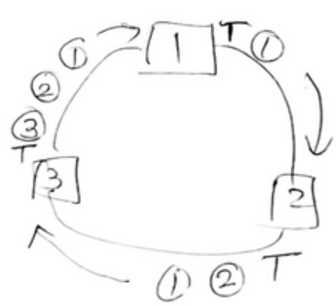
$$\Rightarrow \frac{d}{v} + N \times b$$

d → length; v → velocity; N → no. of station; b → Time taken by each station to hold the bit before Trasmitting.

⇒ LAN

⇒ Token Holding Time (THT) [default 10msec]

⇒ Delayed Token Reinsertion	Early Token Reinsertion
$T_t + RL$	T_t
Transmit the data on link, then it takes a Round trip of ring & return to station, then token is released.	NO Round trip
only one packet at a time in Ring.	More than 1 packet at a time in Ring

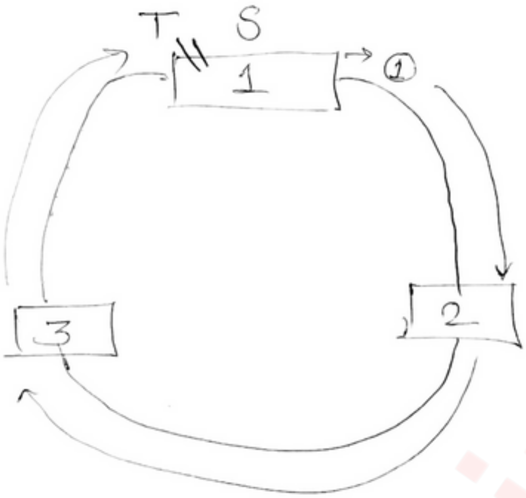


Token Ring Problems

(1) Source Related

as jis statation ka frame h wahi discard kr skta h but if source hi uska down ho tb th wo jhumta hi rhega

"Orphan" Packet as Source is down



"Stray" Packet gets too much corrupt"

So, station 1 doesn't Identify it & doesn't Remove it

- Now Monitor station solves it.

1st time M = 1

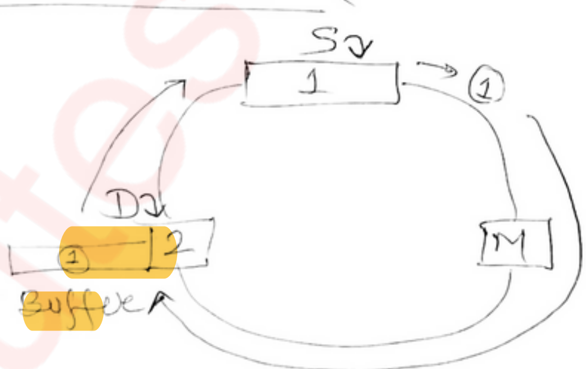
2nd time → Monitor discards the packet

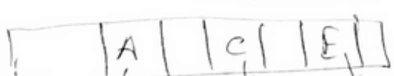
- Monitor station solves it "using "CRC"

"CRC mismatch" so packet is discarded.

(2) Destination Related

- Down
- Busy (Buffer full)
- Copied



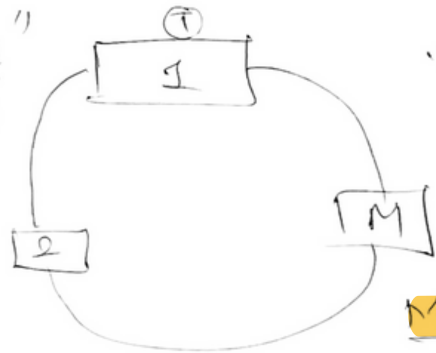


	available	copy	Error
Initially	0	0	0
Down	0	0	0
Busy	1	0	0
Error	1	0	1
Copied	1	1	0

③ Token Related

"Captured Token"
(Monopolisation)
[Injustice]

- Max THT
  ↳ 10 msec



"Token lost"

- Station ① holding Token ① gets down

Min TRT : RL

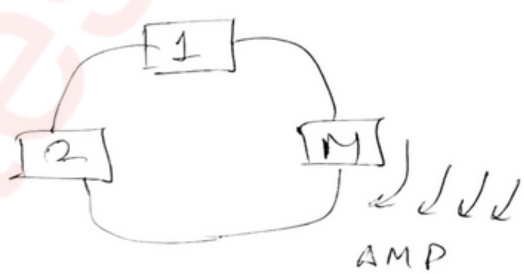
Max TRT : RL + THT × N

- Monitor regenerate Token after Max TRT

"Token corrupt"
(3 Byte Packet)
Monitor takes care of it
⇒ Its considered as Disturbance / Noise in Ring.

④ Monitor Related

"Monitor Down"
(Heart beat Signal)
↓
AMP
(Alive Monitor Packet)



Solⁿ: Polling (Make / elect a station as Monitor)

"Monitor Malfunction" (Checked).
Solⁿ: Human intervention.