Mod 2. The Link Layer:

Links, Access Networks & LANs

2.1

Multiple Access Protocols

- Random Access Protocols
  - ALOHA
  - CSMA
  - CSMA/CD
  - CSMA/CA
- Controlled Access Protocols
  - Reservation
  - Polling
  - Token Passing
- Channelization Protocols
  - FDMA
  - TDMA
  - CDMA

Random Access Protocols

ALOHA

- **Pure ALOHA:**

→ ALOHA was invented in University of Hawaii in 1970's

→ It was originally developed for wireless LANs but it can be used in any shared medium.

→ Each channel sends equal size frames (Assumption)

→ Whenever a station has a data to send, it can send it on the channel (no limited rule). Hence, chances of collision is high

→ Sender acknowledges if data is received.

→ Data will wait for acknowledgement from receiver. This waiting time is known as Time-out & equal to maximum possible round trip delay.

$$\boxed{T_0 = 2 \cdot T_p}$$

where, T_0 → Time-out
T_p → Propagation time.

→ After Time-out, station will again send data, but if it immediately sends data then collision will occur & Time-out will also be same. Hence, no station can effectively send data

Now, concluding.

1. Station must not send frame immediately after Time-out
2. Number of attempts must be fixed for each Station (15).

→ Because, station must not send ~~time~~ frame immediately, after time-out. So, we must wait for amount of time called back-off time.

$$T_B = R \times T_{slot}$$

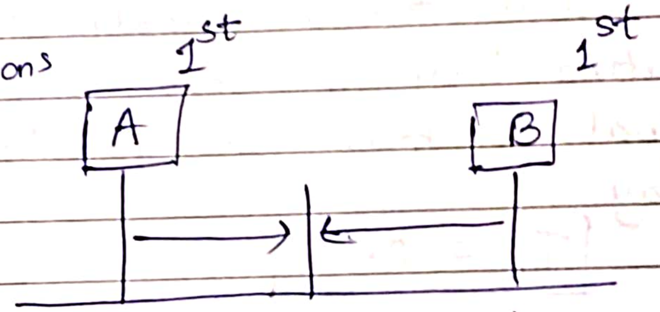
$R \rightarrow$ Random no. btw 0 & 2^{n-1}
where, $n \rightarrow$ no. of collisions

$T_{slot} \rightarrow T_p \,/\, T.T \,/\, R.T.T\,(2 \times T_p)$.

→ Binary exponential back-off time algorithm.

↓

2-stations



0 & 2^{1-1}	0 & 2^{1-1}
0 or 1	0 or 1

A ms	A	B	ms	
0×2 = 0	0	0	0×2 = 0	Collision
0×2 = 0	0	1	1×2 = 2	A wins 1st Back
1×2 = 2	1	0	0×2 = 0	B " " . . . .
1×2 = 2	1	1	1×2 = 2	Collision

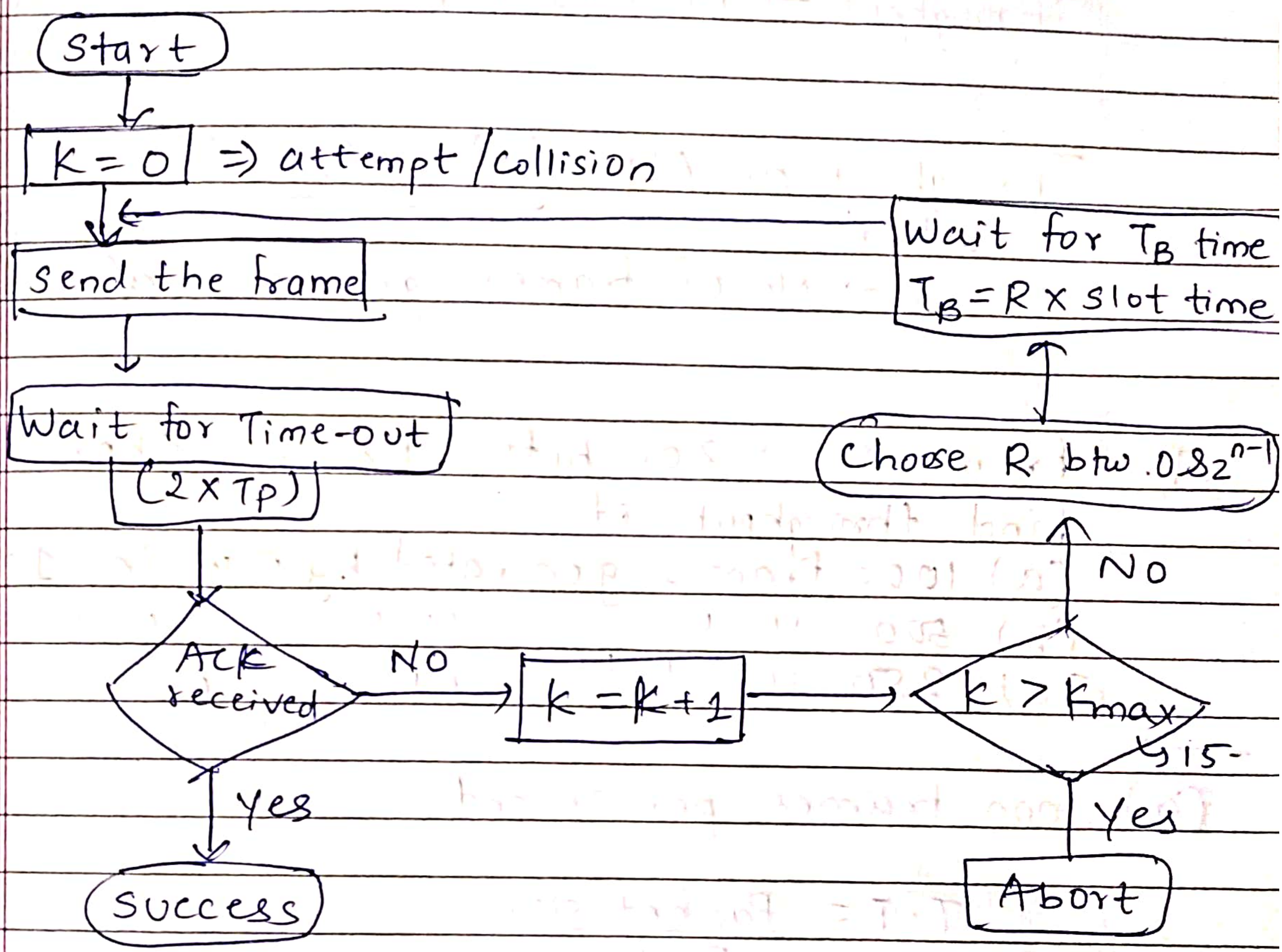
$P(C) = \frac{2}{4} = \frac{1}{2}$

$\boxed{P(C) = 0.5}$

$P(A) = \frac{1}{4}$

$P(B) = \frac{1}{4}$

- Algorithm of ALOHA



- **Throughput of Pure ALOHA :**

Throughput → How fast we can send data...

Throughput of ALOHA (S) = $G \times e^{-2G}$

where,

G → No. of frames generated by n/w in 1 T.T

Q. Frame size = 200 bits, BW = 200 kbps.
Find throughput if
(a) 1000 frames generated by n/w in 1 sec
(b) 500 " " " " " " "
(c) 250 " " " " " " "

→

(a) 1000 frames per second

$$T.T = \frac{\text{Packet size}}{\text{Bandwidth}}$$

$$= \frac{200}{200 \times 1000}$$

$$\boxed{T.T = 1\ ms}$$

G, ??

1 sec — 1000

1 ms — G_1

$G_1 = 1000 \times 1\ ms$

$$\boxed{G_1 = 1}$$

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Now,

$$S_1 = G_1 e^{-2G_1}$$

$$= 1 \times e^{-2}$$

$$= \frac{1}{e^2}$$

$$S_1 = 0.135335$$

$$\% S_1 = 13.5\%$$

(b) 500 frames per second

$$T \cdot T = 1ms$$

G_2 ??

$$\begin{array}{ccc} 1\ sec & \to & 500 \\ 1ms & & G_2 \end{array}$$

$$G_2 = 500 \times 1ms$$

$$G_2 = 0.5$$

$$S_2 = 0.5 e^{-2(0.5)}$$

$$= 0.18394$$

$$\boxed{\% S_2 = 18.39\%}$$

(c) G_3 ??

$$\begin{array}{ccc} 1\ sec & & 250 \\ 1ms & & G_3 \end{array}$$

$$G_3 = 250 \times 1ms$$

$$G_3 = 0.25$$

$$S_3 = 0.25 e^{-2(0.25)} = 0.151633$$

$$\boxed{\% S_3 = 15.16\%}$$

☆ Slotted ALOHA

- → In slotted ALOHA n/w, time is divided into slots for each T.T.
- → Unlike ALOHA, here station can't send data immediately rather it has to wait for beginning of next time slot.
- → Collision can take place if for eg. 3 stations have data to send at 2.1, 3 & 3.5 s then all will send data at 4 sec as per following eg. of slots.

0 sec | 2 sec | 4 sec | 5 sec |

- → Vulnerable time for ALOHA = T.T.

Throughput

$$S = G \times e^{-G}$$

Q. Packet size = 200 bits, BW = 200 Kbps
Throughput?
(a) 1000 packets in 1 sec

→

$T.T = 1\ ms$

$G = 1$

$S = 1 \times e^{-1}$

$= \frac{1}{e}$

$S = 0.3678$

$\boxed{\% S = 36.78\%}$ ← Maximum

Max. Throughput
1. Pure ALOHA = ~~18.4~~% 18.4%
2. Slotted ALOHA = 36.78%

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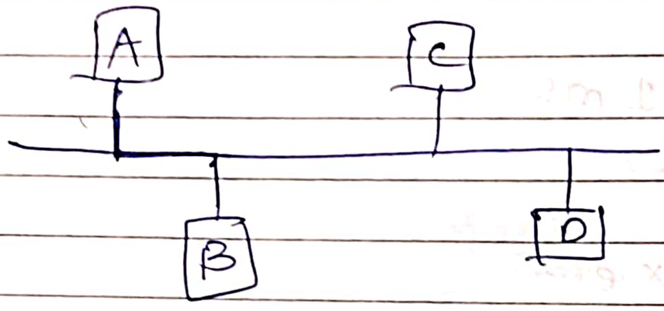
☆ CSMA

→ CSMA stands for "Carrier Sense Multiple Access".
→ Developed to minimize the collision chance.
→ CSMA is based on principle of "listen before talk" or "Sense before transmit".



→ When A & B are communicating then C & D can't communicate because C will sense the channel as busy.
→ Still there are chances of collision here because of propagation delay.
→ When station sends a frame it still takes small amount of time for the 1st bit to reach every station, so, other station will sense channel idle & transmit which would lead to collision.
→ Vulnerable time = Propagation time.

$$\boxed{\begin{aligned} V_{T_A} &= 2 \times T.T \\ V_{T_{SA}} &= T.T \\ V_{T_{CSMA}} &= T_P \end{aligned}}$$

capacity of channel = BW × T_{p}
(BW delay product)

- Persistance method in CSMA :

what should station do if channel is busy or idle ?

3 - methods of persistance:

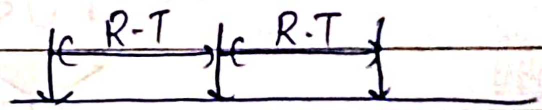
1. 1 - persistance:

→ Station keeps on checking the Channel, & as soon as it finds the channel idle it immediately sends the frame.

→ Probability of Collision is high

→ If Bandwidth delay product is high, then Chances of collision are high.

→ Ethernet LAN uses 1-persistance method



2. Non-persistance:

~~→ If a channel~~

→ If a station finds a channel busy, it waits for random time then check again, Still busy it will wait for random time & check again, if the channel is idle it immediately sends frame

→ This method reduces the efficiency of the n/w. ∵ medium may remain idle when there are many stations want to send data

→ Channel utilization is more than 1-persistance

→ Chances of collision are less than 1-persistance.

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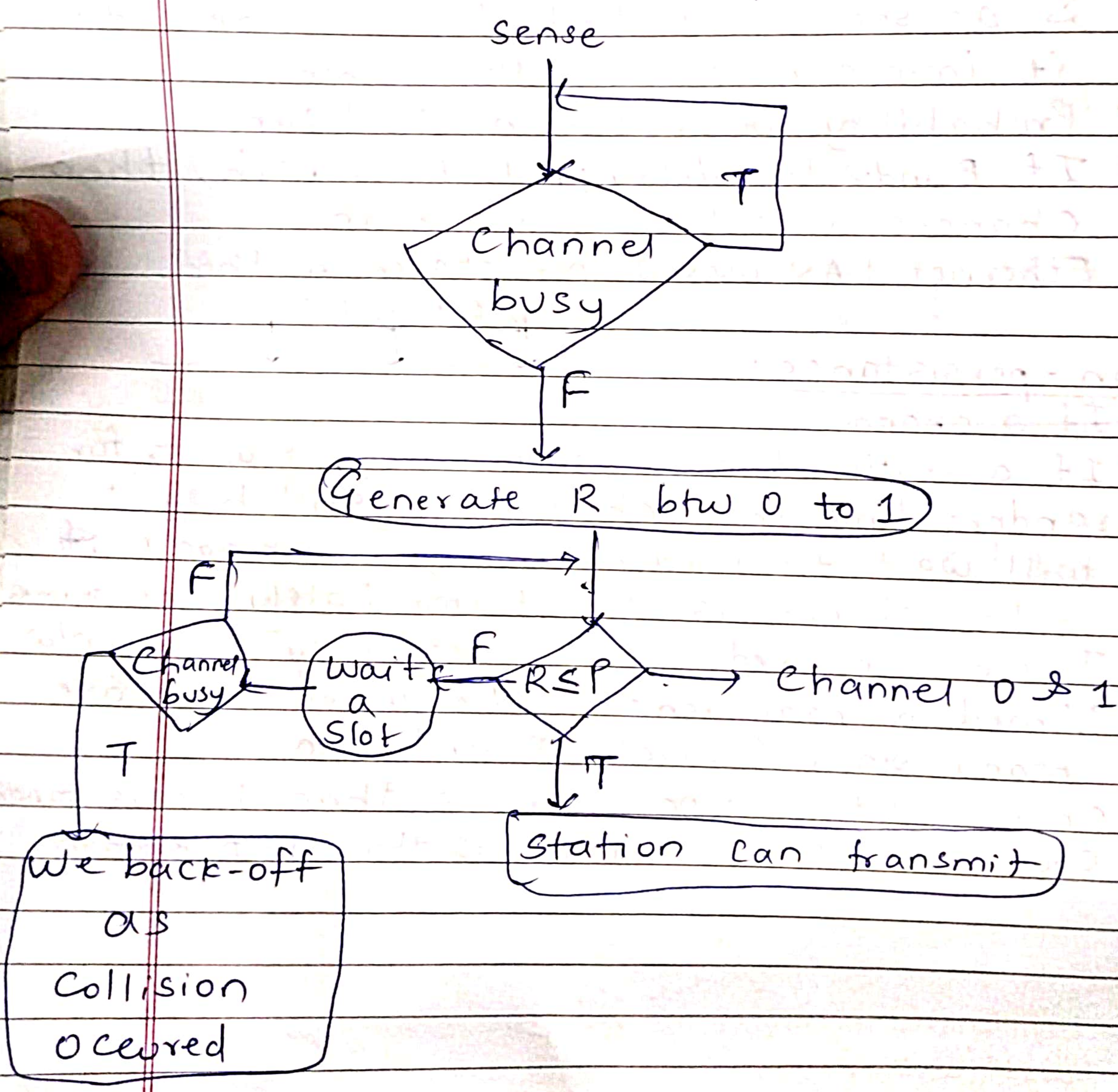
3. P-persistance :

→ This method is used if channel has time slots with slot duration equal to or greater than max. propagation time

→ It uses advantages of 1-persistance & non-persistance method.

→ Hence, reduced chances of collision & increased efficiency.



works in wired networks only

↓

☆ CSMA / CD (Extension of CSMA)

→ CD ⇒ Collision Detection
→ CSMA doesn't specify procedure following a collision.
→ Better way to save time & BW is to detect the collision & immediately stop transmission.
→ In CSMA/CD, station doesn't check for collision after transmission, it simultaneously checks for collision.
→ That means sender needs two different ports
i.e 1 for sending data.
1 for deting collision.
→ If collision is detected then sender immediately stop sending frame & sends the Jam signal

3 obvious observations--

① No acknowledgement
- There is no need of acknowledgement because if collision is not detected then frame is definatively received by receiver.
- ~~NOTE: This layer is not~~

② No copy:
- station doesn't maintain a copy of frame at MAC layer since station is sending data & simultaneously sensing collision.
- & if collision detected, it doesn't know whose data collided.

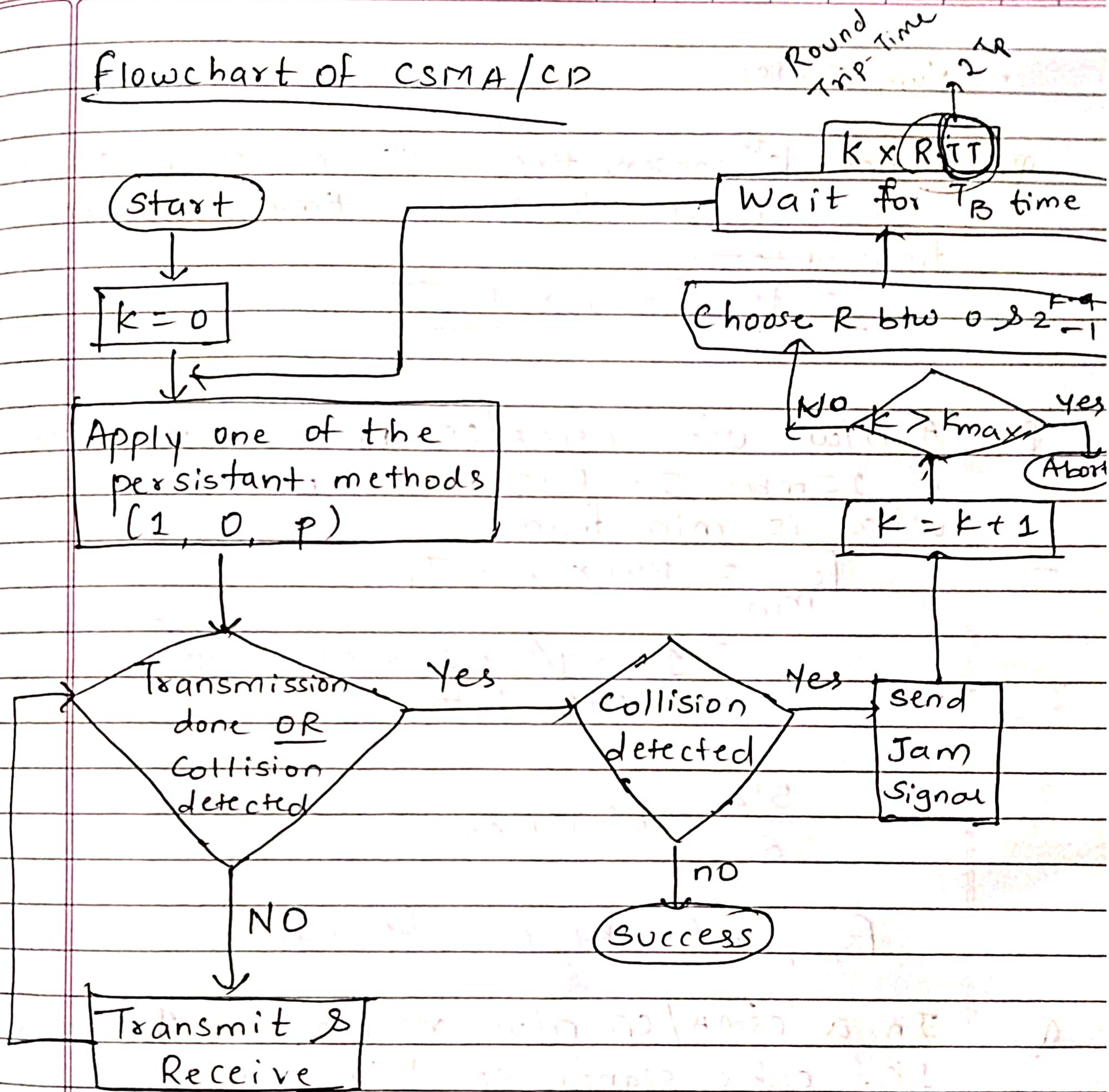
③ Min. frame duration must be $2T_p$

- first bit from sender takes T_p time to reach the receiver & the effect of collision takes another T_p time.
- Hence, requirement is that sender must be transmitting the frame after $2T_p$ time.
- Hence, we need ~~to~~ minimum frame size.
- This frame size depends on BW & propagation time.

$$\text{min. } F_s = BW \times (F.D)_{min}$$

$$\boxed{F_{S_{min}} = BW \times 2T_p}$$

Flowchart of CSMA/CD



- Numericals:

Q. After k^{th} conservative collision, each collective station waits for random time choosen from ~~entered~~

$(0 \text{ to } 2^k - 1) \times R.TT$

Q. A n/w uses CSMA/CD protocol with BW of 10 mbps. If RTT is 5.12 μsec then what is min. frame size?

→ $Fs_{min} = BW \times 2 \times Tp$

$= 10 \times 10^6 \times 2 \times 51.2 \times 10^{-6}$

$= 512$ bits.

$\frac{512}{8} = 64$ bytes

$Fs_{min} = 64$ bytes (padding)

Q. In a CSMA/CD n/w running at 1 Gbps over 1 km cable, signal speed in cable is 200000 km/sec. What is minimum Fs?

→ WKT, $S = \frac{D}{T}$

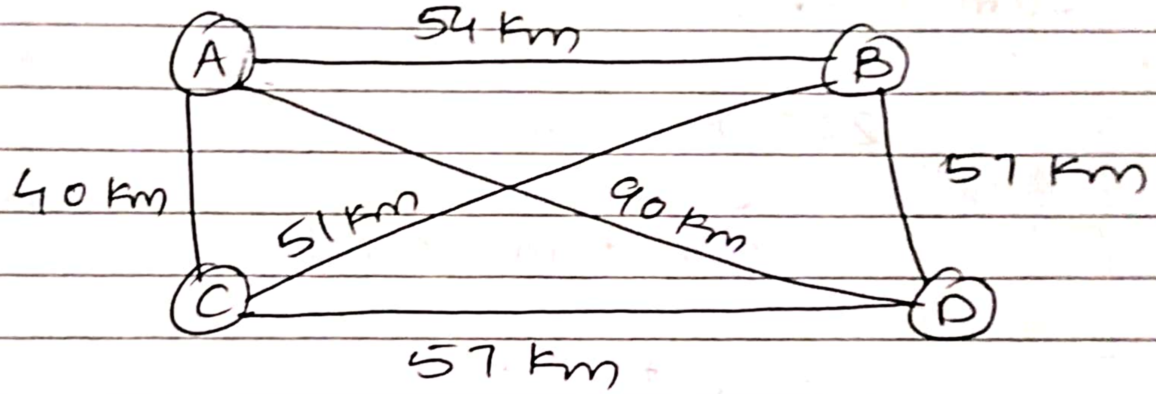
$200000 = \frac{1}{Tp}$

$Tp = 0.5 \times 10^{-5}$

$\boxed{Tp = 5 \mu s}$

$$f_{s_{min}} = 10^9 \times 2 \times 5 \times 10^{-6}$$
$$= 10 \times 10^9 \times 10^{-6}$$
$$= 10^{9+1-6}$$
$$= 10^4 \text{ bits}$$

Q. A n/w consists of 4 hosts as shown



Assume the n/w as CSMA/CD & signal travels with a speed of 3×10^5 km/sec. If sender sends at 1 Mbps, what would be max. packet size?

→

$$f_{s_{min}} = BW \times 2T_p$$

$T_p = \dfrac{\text{Distance}}{\text{speed}}$ → (most wide (large))

$$T_p = \frac{\cancel{90}\ 30}{\cancel{3} \times 10^5}$$
$$= 30 \times 10^{-5}$$
$$\boxed{T_p = 3\mu s}$$

$$f_{s_{min}} = \cancel{10^6} \times 2 \times 3 \times \cancel{10^{-6}}$$
$$= 6 \text{ bits}$$

Q. Suppose nodes A and B are on the same 10 mbps Ethernet segment & propagation time delay b/w 2 nodes is 225 bit times. Assume A & B send frames at $t = 0$, the frame collides them at what time &, they finish transmitting a jam signal. Assume 48-bit Jam signal.

→

225 bit times.

↓

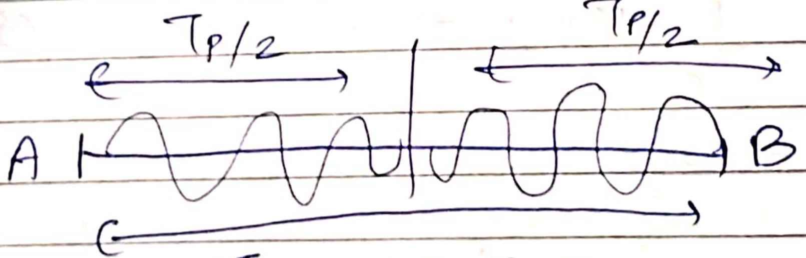
225 bit @ 10 mbps.

10^7 bits → 1 sec

$1 \rightarrow \frac{1}{10^7}$

$225 \rightarrow \frac{225}{10^7}$

$\frac{22.5}{10^6} \Rightarrow 22.5\,\mu s. = T_p$



$T_p = 22.5\,\mu s$

Assuming collision occured in middle

~~They finish sending jam signal at Tp.~~

Collision occurs at $\frac{T_p}{2}$

10^7 bits   1 sec

1    $\frac{1}{10^7}$

48    $\frac{48}{10^7}$

$$\boxed{T_{js} = 4.8\,\mu s}$$

Collision returns at T_p

Sending jamming signal in $= T_p + T_{js}$
$= 22.5 + 4.8$
$= 27.3\,\mu s$ //

1 sec 10^7 bits

$27.3\,\mu s$ x

$x = 27.3 \times 10^{-6} \times 10^7$

$x = 273$ bit times.

They finish transmitting a jamming signal at 273 bit times.

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Q. 2
(A) CSMA / CD n/w

$BW = 100$ mbps
$T_p = 51.2 \mu s$
$F_{s_m} = ?$

$F_{s_{min}} = BW \times 2 \times T_p$
$= 100 \times \cancel{10^6} \times 2 \times 51.2 \times \cancel{10^{-6}}$
$= 2 \times 5120$
$= 10240$ bits.

In bytes,
$\frac{10240}{8} = 1280$

Min. frame size $= 1280$ bytes

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☆ CSMA/CA

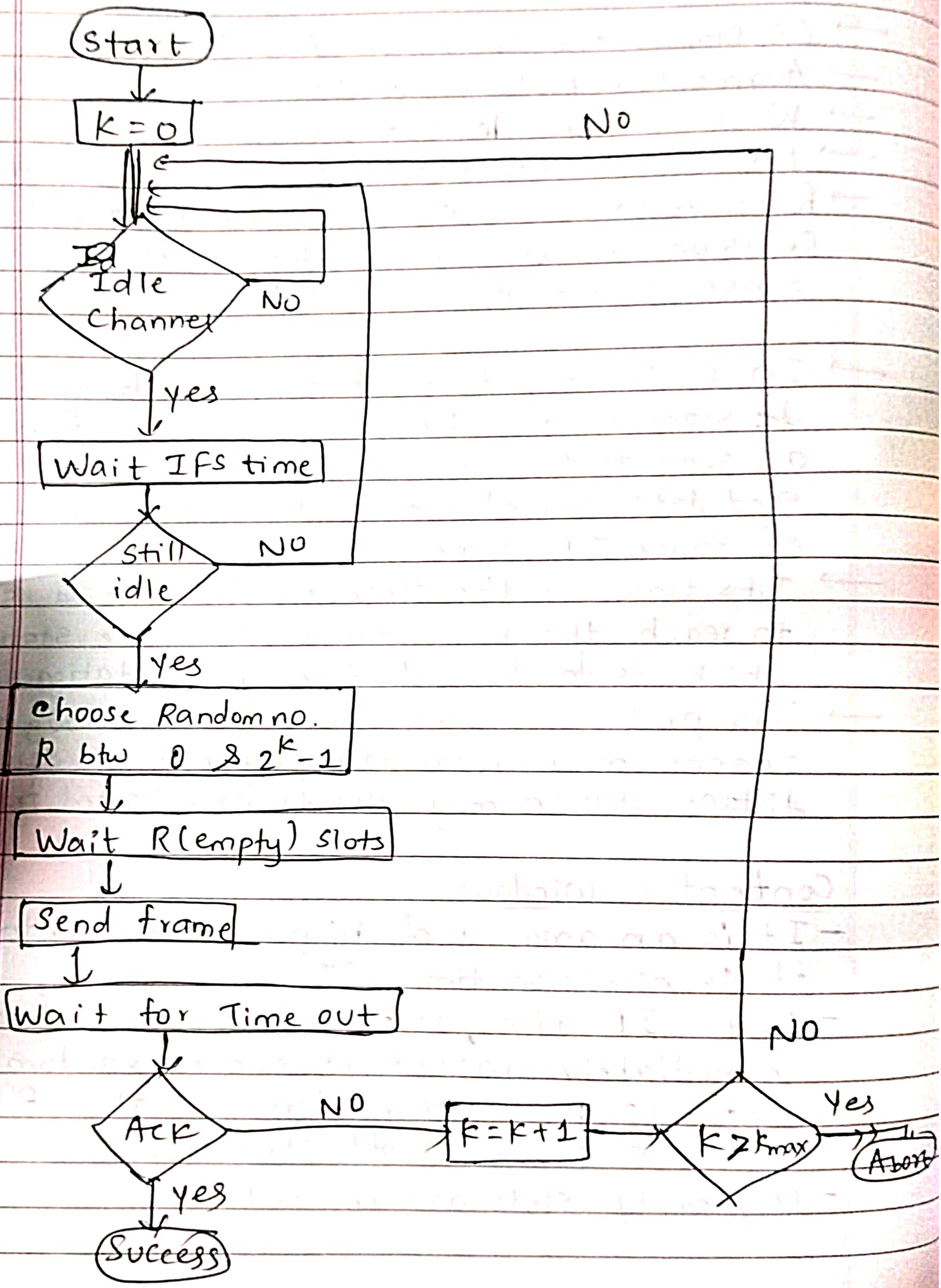
- → CA Stands for Collision Avoidance.
- → Augmented protocol of CSMA
- → Works in wireless networks only.
- → for wired networks, CSMA/CD works fine
- → for wireless networks, we need to avoid Collision as we cannot detect the collision since attenuation is high.

- → In CSMA/CA, if a channel is busy the ~~de~~ station will keep on sensing it but as soon as the channel is idle it will not send data immediately, it waits for a period of time IFS time.
- → IFS time is the time needed for a signal to reach the given station from the station which is far behind the given station.
- → This protocol assumes that even though the channel may appear idle, when it is sensed, a distant station may already have started transmission.

Contention window:

- It is an amount of time divided into slots of transmission time (TT).
- After IFS time, station doesn't send frame immediately rather it choses random no. of slots as its waiting time & this R is chosen as per back off strategy.
- Only empty slots are counted.

Flowchart of CSMA/CA

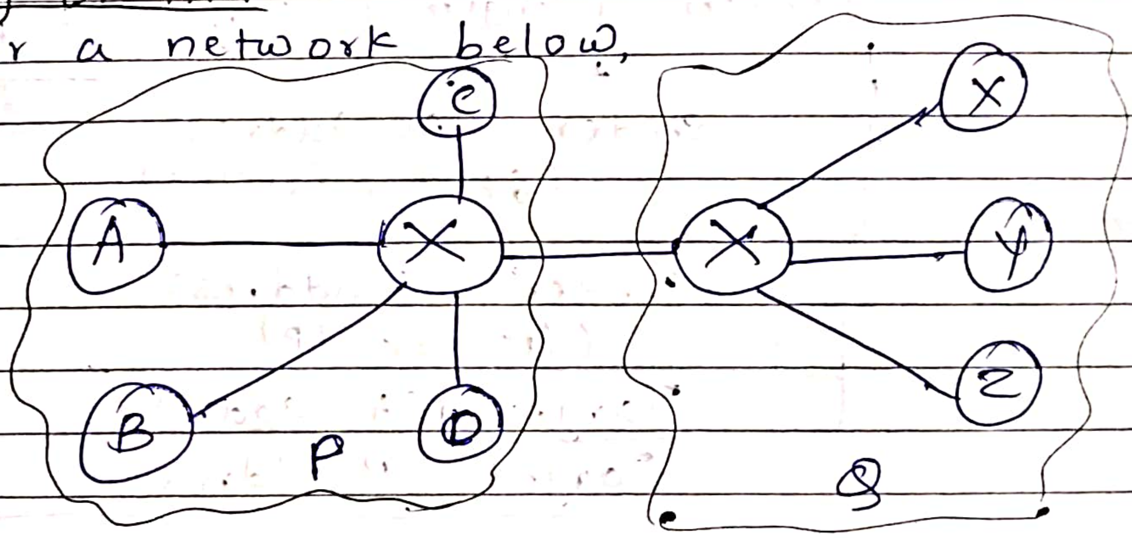


Address Resolution Protocol

- The Address Resolution Protocol (ARP) is a crucial communication protocol used to map a network layer address (such as IP address) to a link layer address (such as MAC address).
- This mapping is essential for devices to communicate within a local network.
- ARP operates at the ~~Data Link Layer (DLL)~~ Network layer of the OSI model and is primarily used in IPv4 networks.

Working of ARP:

Consider a network below,



ARP

1) ~~ARP request~~

- When a device (let's say host A) needs to send a packet to another device (Host B) on the same local network P and knows Host B's IP address & not its MAC address.

So,

Host A broadcasts an ARP request packet.

1.) ARP request packet:

It contains:

→ Sender's IP & MAC address.

→ Target IP address (whose MAC is reqd).

This packet is broadcasted to all devices in the network (MAC: ff:ff:ff:ff:ff:ff

Here is the ARP packet format: (32 bit).

<table>
<tr><td colspan="2">16 bits</td><td>16 bits</td></tr>
<tr><td colspan="2">Hardware Type</td><td>Protocol Type</td></tr>
<tr><td>Hardware Length</td><td>Protocol length</td><td>Operations
Req-2, Rep-2</td></tr>
<tr><td colspan="3">Sender MAC Address
(6B for Ethernet)</td></tr>
<tr><td colspan="3">Sender IP address
(4B for IP)</td></tr>
<tr><td colspan="3">Target MAC address</td></tr>
<tr><td colspan="3">Target IP address</td></tr>
</table>

2.) ARP reply

- The device with the matching IP address (Host B) responds with an ARP reply.
- This ARP reply is unicast directly back to the requester (Host A) and includes:

→ Host B's IP add.

→ Host B's MAC add.

3) Caching:

- Upon receiving the ARP reply, Host A stores the IP-to-MAC mapping in its ARP cache (a table in memory) to avoid sending ARP request for same address repeatedly.
- ARP cache entries have a timeout and may be refreshed or removed periodically.

4.) Packet Transmission:

- After obtaining, the MAC address, Host A can now encapsulate the IP packet within an Ethernet frame and send it directly to host B.

NOTE:

- If the target device is outside the local network, ARP resolves the MAC address of the default gateway/router instead.
- ARP is limited to local subnet.

☆ Reverse Address Resolution Protocol (RARP):

- Reverse ARP is a network protocol a client machine uses in a local area network to request its IP address (IPv4) from the gateway router's ARP table.
- The network administrator creates a table in the gateway router, which maps the MAC address to the corresponding IP address.

ARP	RARP
A protocol used to map an IP address to a physical (MAC) address.	A protocol used to map a physical (MAC) address to IP address
Client broadcasts its IP address and requests a MAC address, and server responds with the corresponding MAC address.	Client broadcasts its MAC address & requests an IP address and the server responds with corresponding IP address
1 for request 2 for reply	3 for request 4 for reply

2.4

★ High Level Data Link Protocol (HDLC)

- The HDLC is developed by ISO.
- HDLC is a bit-oriented data link protocol, and it is designed to satisfy many of data Control requirements.
- HDLC protocol has three stations defined
  1. Primary station.
  2. Secondary station
  3. Combined station.

Bit-oriented protocol

- Modes of operation.

① Normal Response Mode (NRM):
→ This mode is suitable for point-to-point as well as point-to multipoint configurations.
→ Primary station is the ruler here, it controls the data flow.

② Asynchronous Response Mode (ARM):
→ This mode is used for communication between primary and secondary stations

③ Asynchronous Balanced Mode (ABM): → station can act both ways
→ This mode is applicable to point-to-point communication between combined stations.
→ Frame structure in HDLC

0111 1110					0111 1110
Flag field	Address	Control	Information	FCS	Flag field
8-bits	8-bits	8-16 bits		16 bits	

Info Transfer Frame

FCS: Frame ~~control~~ check sequence — for error detection

Supervisory frame

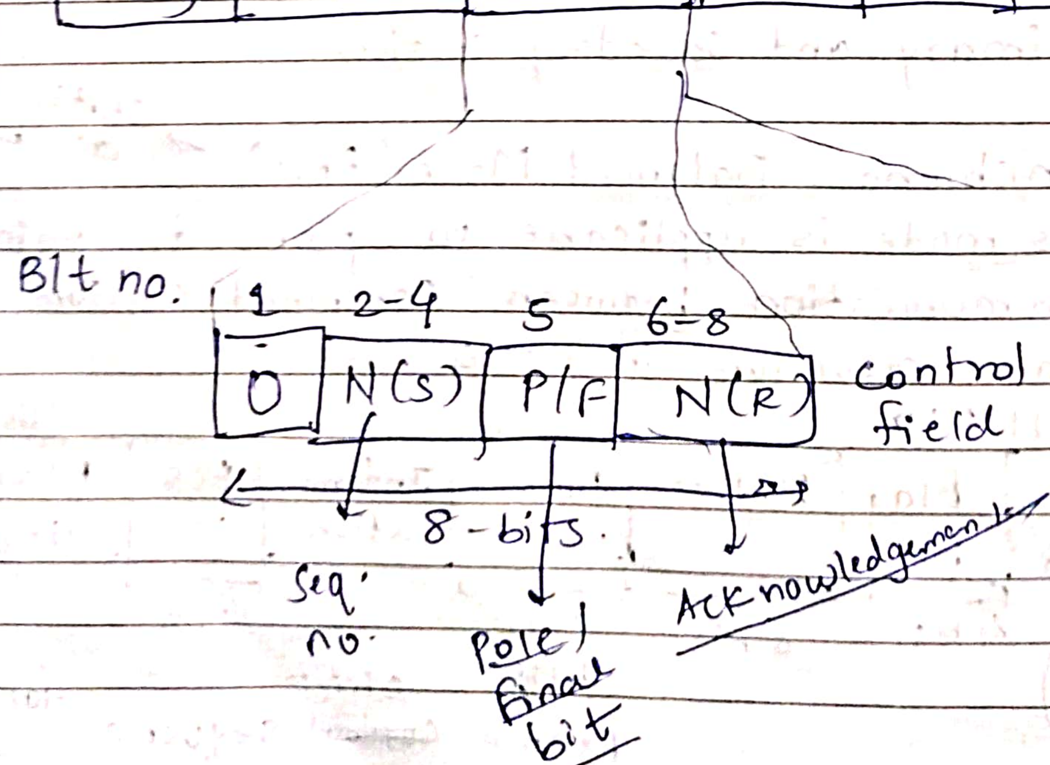
Flag	Address	Control	FCS	Flag

1. Flag shows start & end of frame.
2. Address contains address of secondary station where data is to be transmitted
3. Control field shows acknowledgment, frame no., sequence no, etc all management.
4. Frame Check sequence

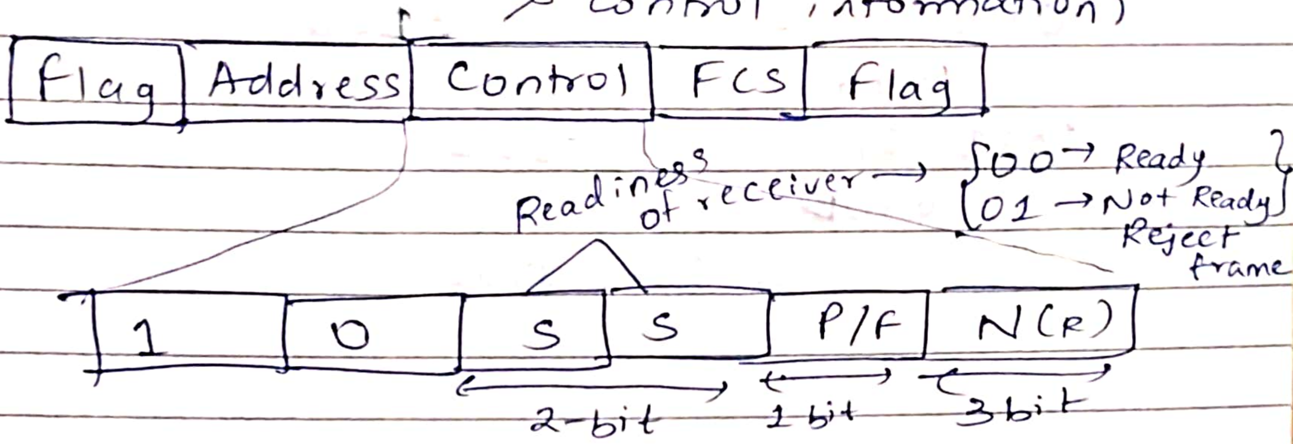
☆ Three frames in HDLC
I-frame, S-frame, U-frame
Information, Supervisory, Unnumbered

1. The I-frame (Used to transport user data & control information).

Flag	Address	Control	Info	FCS	Flag

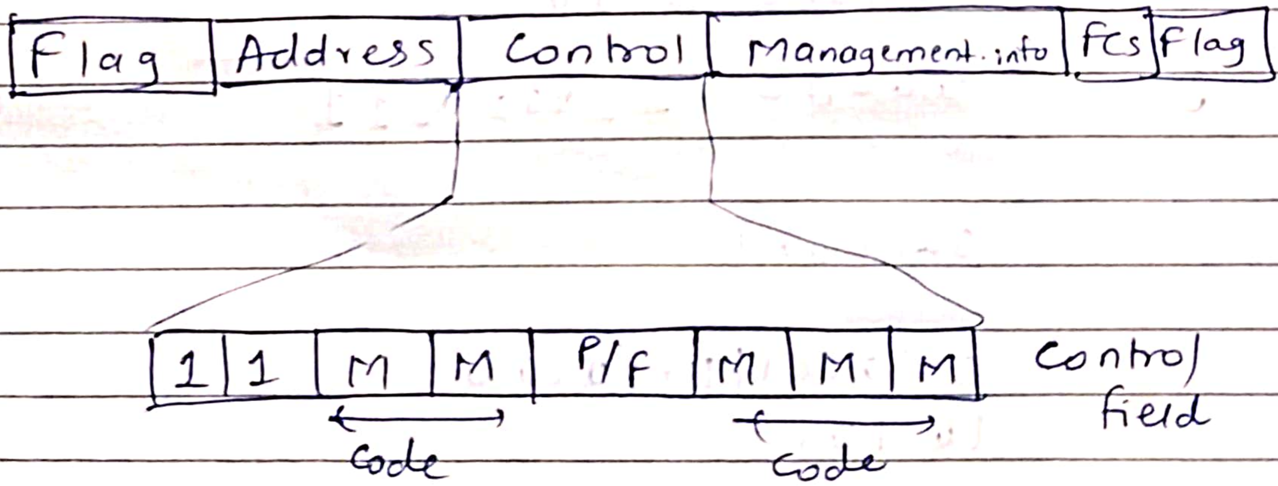


② The s-frame (Used to transport user data & control information)



SS = 00 → (RR) - Receive ready.
SS = 01 → (Rej) - Reject frames
SS = 10 → (RNR) - Receive not ready
SS = 11 → (selective) - Repeat frame

③ The U-frame: (system management).



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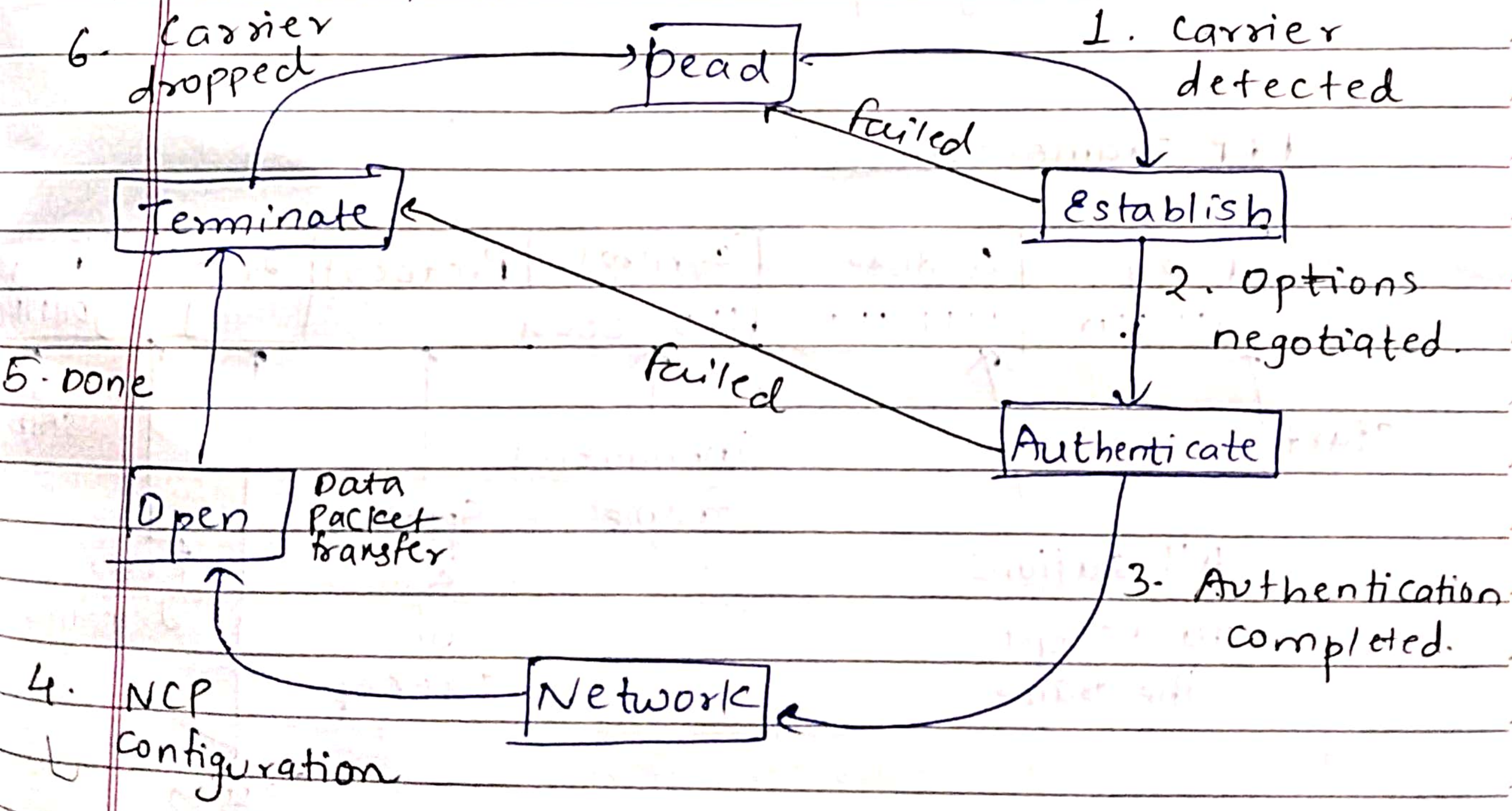
☆ Point to Point Protocol (PPP):

- PPP is a byte oriented protocol used for point to point access.
- Defines the format of the frame that has to be exchanged between two devices.
- Design to support multiple network protocols simultaneously.
- It can transfer packets that are produced by different network layer protocols.
- PPP defines how to devices can authenticate each other.



Example of PPP

Home PC to Internet service Provider (ISP):

1. PC calls router via modem
2. PC & router exchange LCP (Link Control Protocol) packets to negotiate PPP parameters
3. check on identities.
4. Packets exchanged to configure network layer.
5. Data transfer, send/receive IP packets.
6. NCP (Network control Protocol) tear down the network layer connection, LCP used to shut down link.
7. Modem hangs up.

PPP frame format: