CN (IT-3001)

Data Link Layer: MAC Protocol

Prof. Amit Jha

School of Electronics Engineering (SOEE)

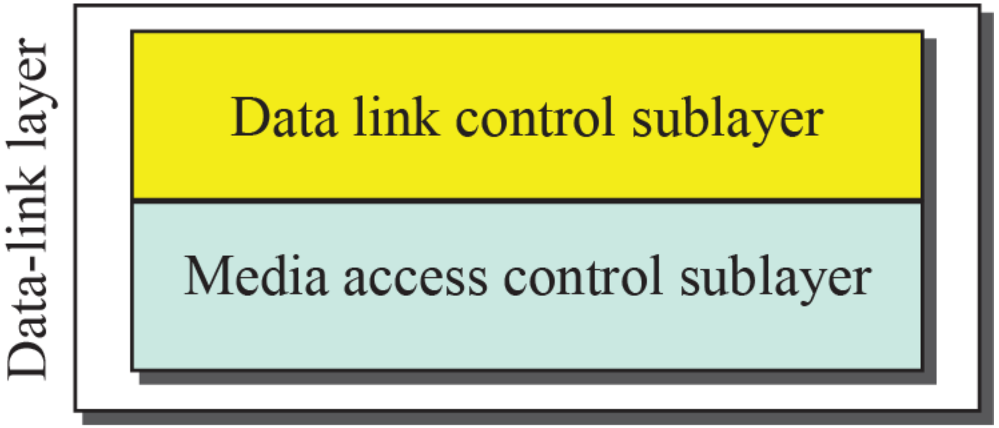
KIIT Deemed to be University

Objective

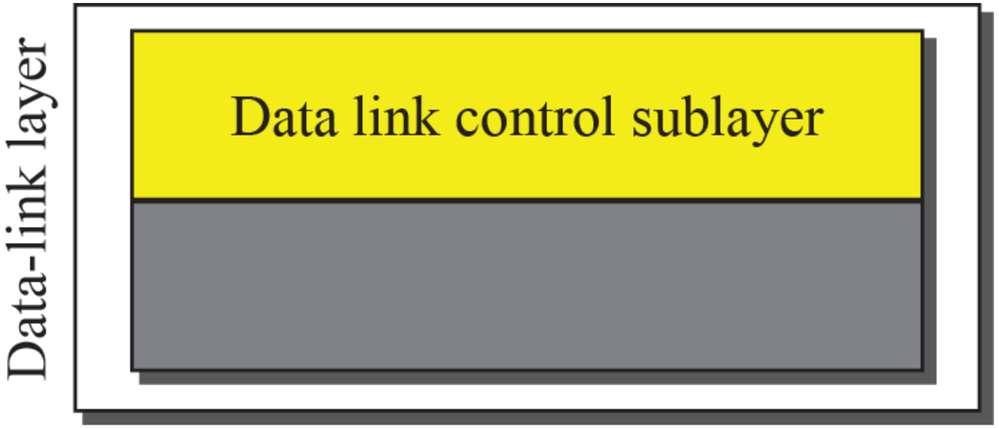
- Media Access/Multiple Access
  - Random Access
    - ALOHA
    - CSMA
    - CSMA/CD
    - CSMA/CA
- Controlled Access
  - Resevation
  - Polling
  - Token passing
- Cahnnelization
  - FDMA
  - TDMA
  - CDMA

Two Sublayers of the Data-Link-Layer

- The data link layer is divided into two sublayers as shown below.
    1. Data Link Control (DLC) sublayer
    2. Media Access Control (MAC) Sublayer



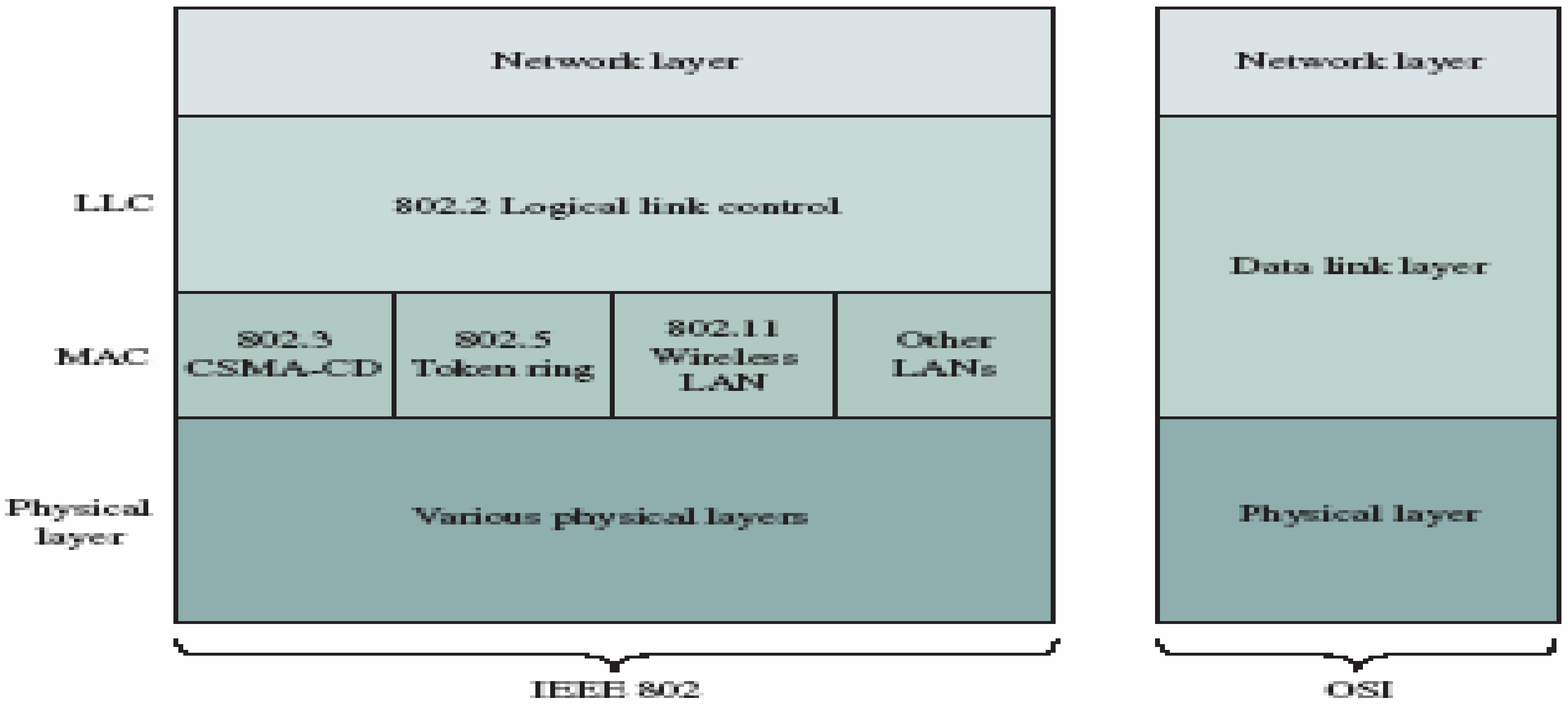
a. Data-link layer of a broadcast link



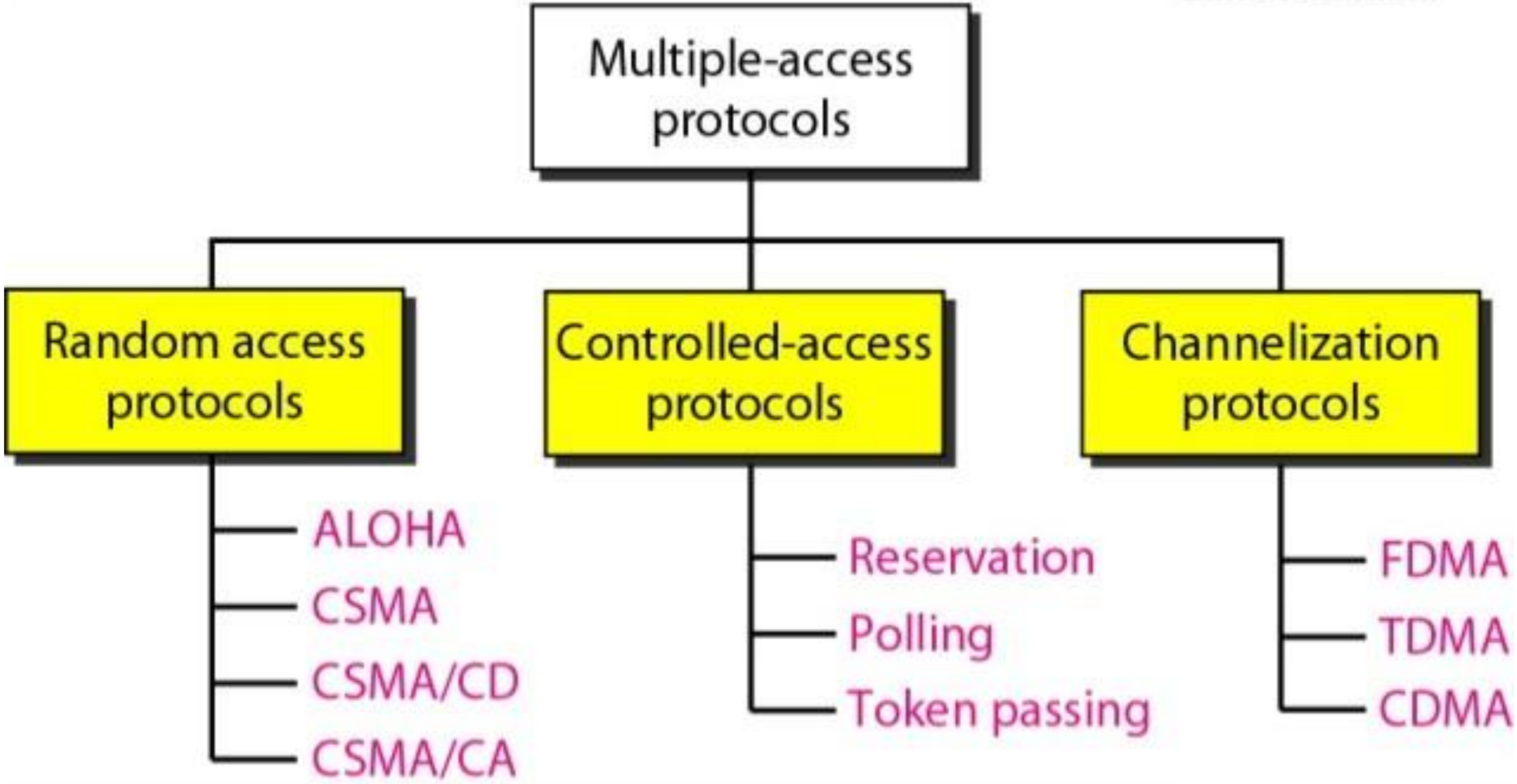
b. Data-link layer of a point-to-point link

- The upper sublayer that is responsible for flow and error control is called the ***logical link control*** (LLC) layer.
- The lower sublayer that is mostly responsible for multiple access resolution is called the ***media access control*** (MAC) layer.
- **Why do we need multiple-access protocol?**

Ans: In a broadcast or multipoint, nodes use a common link. To use this common link efficiently, we need a multiple-access protocol to coordinate access to the link.


Network layer
LLC
802.2 Logical link control
MAC
802.3
CSMA-CD
802.5
Token ring
802.11
Wireless
LAN
Other
LANs
Physical
layer
Various physical layers
IEEE 802
Network layer
Data link layer
Physical layer
OSI

Types of Multiple-Access Protocol/ MAC Protocol

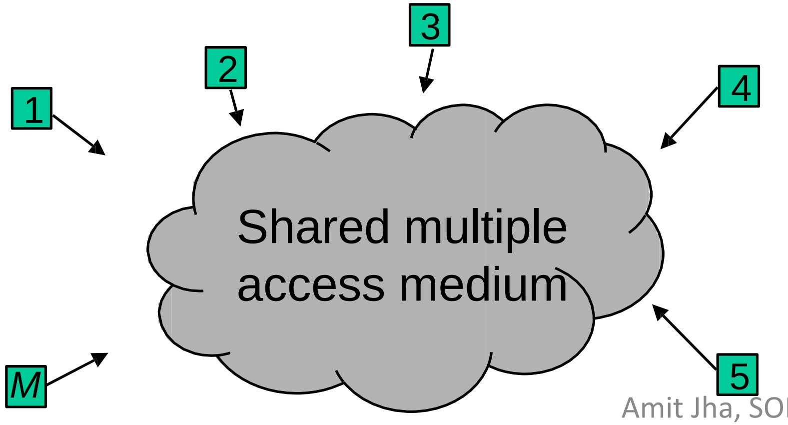


Random Access Protocol

- Why the name *random access*?
  - There is no scheduled time for a station to transmit.
  - Transmission is random among the stations.
  - No station is superior to another station and none is assigned the controlled over another.
- In a random access method, each station has the right to the medium without being controlled by any other station. However, if more than one station tries to send, there is an access conflict-collision-and the frames will be either destroyed or modified.

- To avoid access conflict or to resolve it when it happens, each station follows a procedure that answers the following questions:

  - When can the station access the medium?
  - What can the station do if the medium is busy?
  - How can the station determine the success or failure of the transmission?
  - What can the station do if there is an access conflict?



ALOHA: Pure ALOHA

- Based upon the simplest solution: **just do it**
  - A station transmits whenever it has data to transmit.
  - If more than one frames are transmitted, they interfere with each other (collide) and are lost.
  - If ACK not received within timeout, then a station picks **random back-off time** (to avoid repeated collision).
  - Station retransmits frame after back-off time denoted as T_B
- **Note:** A collision involves two or more stations. If all these stations try to resend their frames after the time-out, the frames will collide again.
- After a maximum number of retransmission attempts K_{max} a station must give up and try later.

Four stations transmitting 2 frames each.

Out of all the frames, only two frames survive: frame 1.1 and frame 3.2

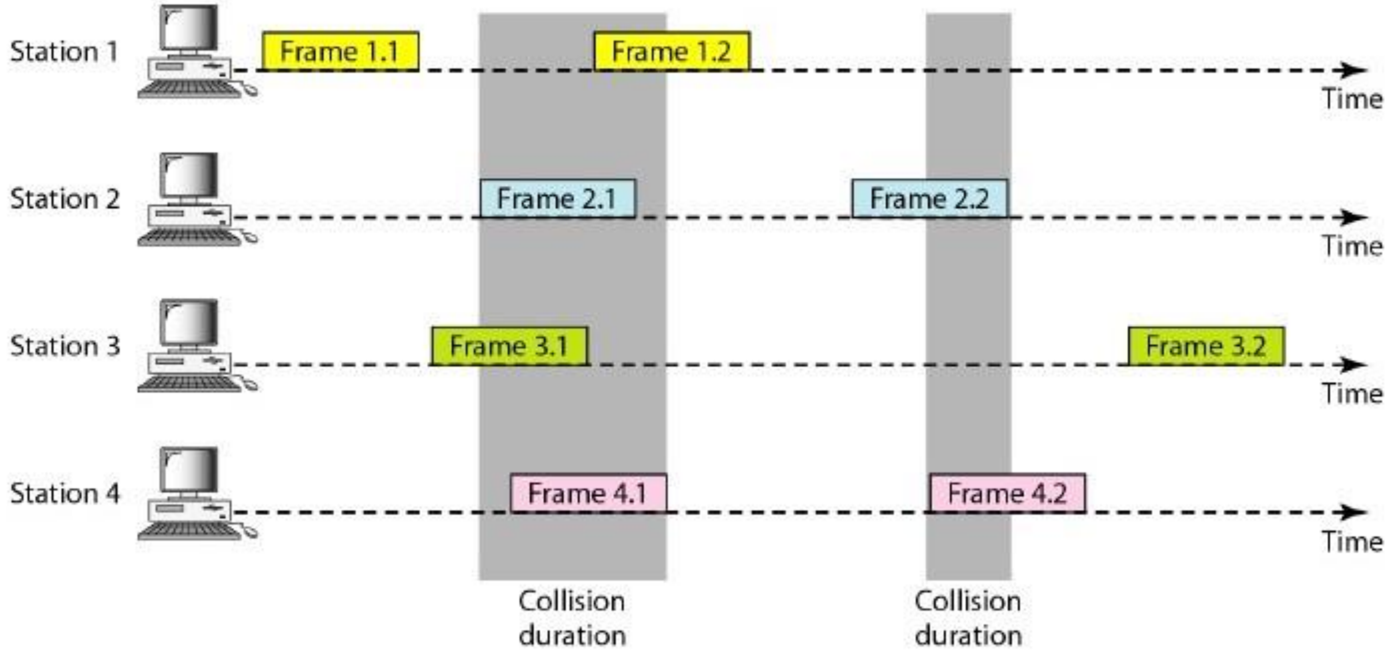
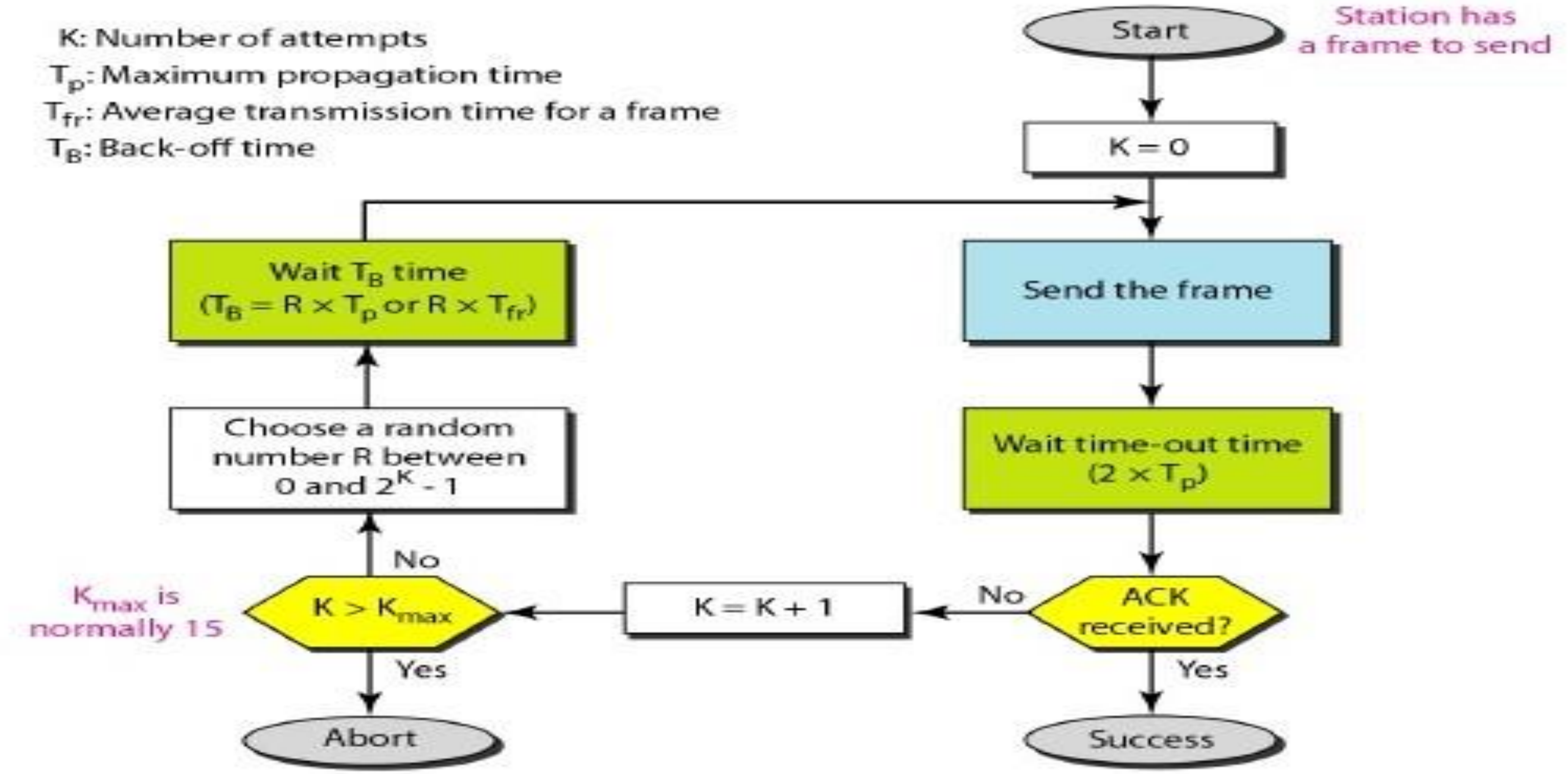


Fig. Example of frame collisions in pure ALOHA

Procedure for pure ALOHA protocol



Note: R is a random number chosen from the range 0 to $2^k - 1$, and value of the random number increases after each collision.

Example 1: The stations on a wireless ALOHA network are a maximum of 600 km apart. If we assume that signals propagate at $3 \times 10^8\, m/s$, we find T_P = (600 x 10^3) / (3 x 10^8) = 2 *ms*. Now we can find the value of T_B for different values of *K*.

a) *For K=1, the range of R is {0, 1}. The station needs to generate a random number with value 0 or 1. So, T_B is either 0 or 2ms, based on outcome of the random variable.*
b) *For K=2, the range of R is {0, 1, 2, 3}. So, T_B can be 0, 2, 4 or 6ms, based on outcome of the random variable.*
c) *For K=3, the range of R is {0, 1, 2, 3,…, 7}. So, T_B is can be 0, 2, 4, 6, 8, 10, 12, or 14ms, based on outcome of the random variable.*
d) *So on…………*
e) *We need to mention that if k >10, it is normally set to 10.*

Vulnerable time: It is the time duration , in which there is a possibility of collision. **Vulnerable time in pure ALOHA = $2 \times T_{fr}$**

$T_{fr} = frame\ transmission\ time$

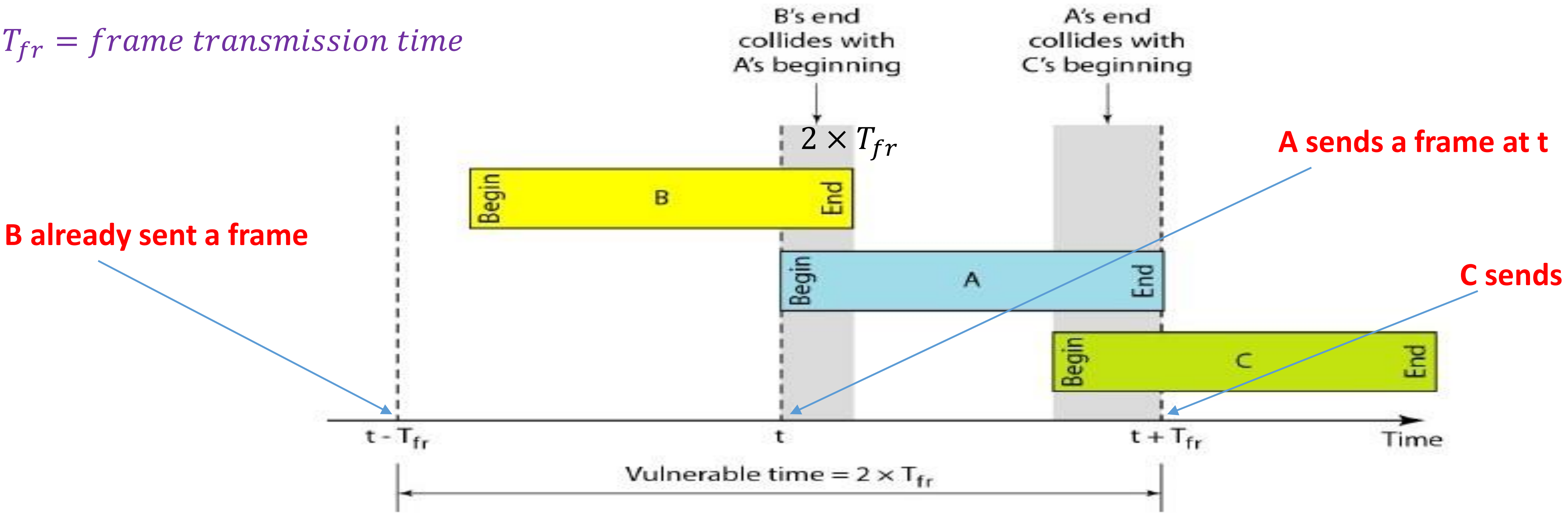


Fig: Vulnerable time for pure ALOHA

Example 2: A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the requirement to make this frame collision-free?

Sol:

Average frame transmission time T_{fr} *is 200 bits/200 kbps or 1 ms. The vulnerable time is 2 x1 ms =2 ms.*

This means no station should send later than 1 ms before this station starts transmission and no station should start sending during the one 1-ms period that this station is sending.

Pure ALOHA Model

- Definitions and assumptions
  - T_{fr} frame transmission time (assume constant)
  - S: throughput (average # successful frame transmissions per T_{fr} seconds)
  - G: load (average # transmission attempts per T_{fr} sec.)
  - $P_{success}$: probability a frame transmission is successful

Note: Any transmission that begins during vulnerable period leads to collision. Success if and only if no arrivals during 2 T_{fr} seconds.

Throughput is given by,

$$\boxed{S = GP_{success}}$$

Abramson's assumption for calculation of $P_{Success}$

- *What is probability of no arrivals in vulnerable period?*

- **Abramson's assumption:** Effect of back-off algorithm is that frame arrivals are equally likely to occur at any time interval.

- G is avg. # arrivals per T_{fr} seconds
- Divide T_{fr} into n intervals of duration $\Delta = T_{fr}/n$
- p = probability of arrival in Δ interval, then

$G = n\,p$ since there are n intervals in T_{fr} seconds

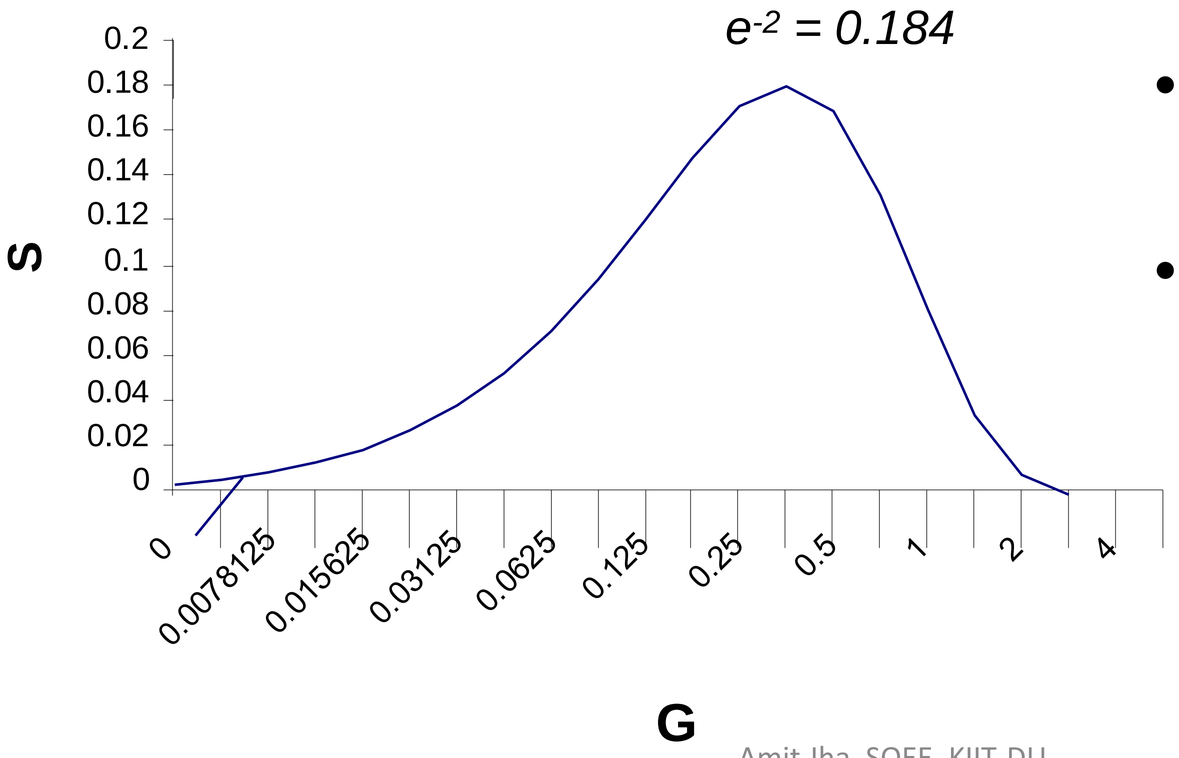
$$P_{success} = P[0 \text{ arrivals in } 2T_{fr} \text{ seconds}] =$$

$$= P[0 \text{ arrivals in 2n intervals}]$$ …………Abramson's assumption:

$$= (1-p)^{2n} = \left(1 - \frac{G}{n}\right)^{2n} \rightarrow \boldsymbol{e}^{-2G} \quad \text{as } n \rightarrow \infty$$

Throughput of ALOHA

$$S = GP_{success} = Ge^{-2G}$$



- Collisions are means for coordinating access
- Max throughput is $\rho_{max} = 1/2e$ *(18.4%)*
- Bimodal behavior:
  Small G, S≈G
  Large G, S↓0

Use basic maths

Example 3: A pure ALOHA network transmits 200-bit frames on a shared channel of 200 kbps. What is the throughput if the system (all stations together) produces

a. 1000 frames per second

b. 500 frames per second

c. 250 frames per second

Sol: $Here,\ T_{fr}$ *is 200 bits/200 kbps or 1 ms.*

a. If the system creates 1000 frames per second, this is 1 frame per millisecond. The load is 1. In this case S = $G \times e^{-2G}$ or S =0.135 (13.5 percent). This means that the throughput is 1000 X 0.135 =135 frames. Only 135 frames out of 1000 will probably survive.

b. If the system creates 500 frames per second, this is (1/2) frame per millisecond. The load is *(1/2)*. In this case S = $G \times e^{-2G}$ or S = 0.184 (18.4 percent). This means that the throughput is 500 x 0.184 = 92 and that only 92 frames out of 500 will probably survive. Note that this is the maximum throughput case, percentagewise.

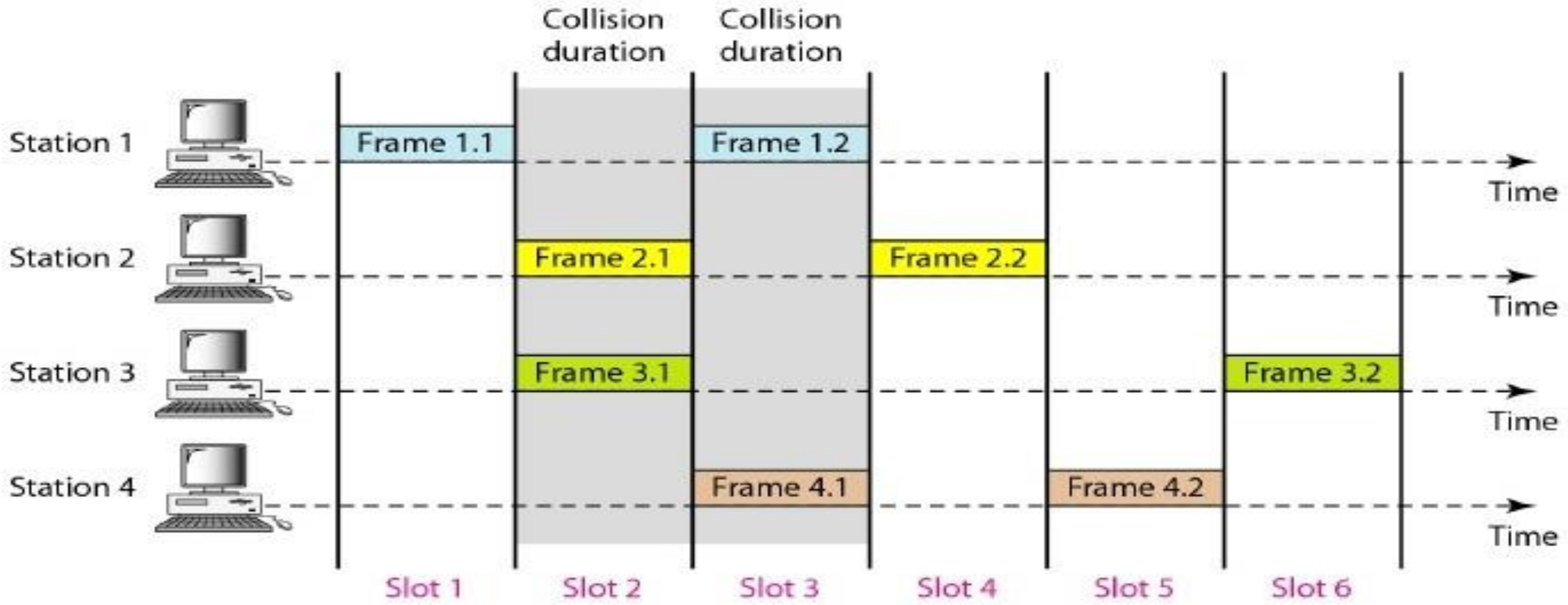
c. If the system creates 250 frames per second, this is (1/4) frame per millisecond. The load is (1/4). In this case S = $G \times e^{-2G}$ or S =0.152 (15.2 percent). This means that the throughput is 250 x 0.152 = 38. Only 38 frames out of 250 will probably survive.

Slotted ALOHA

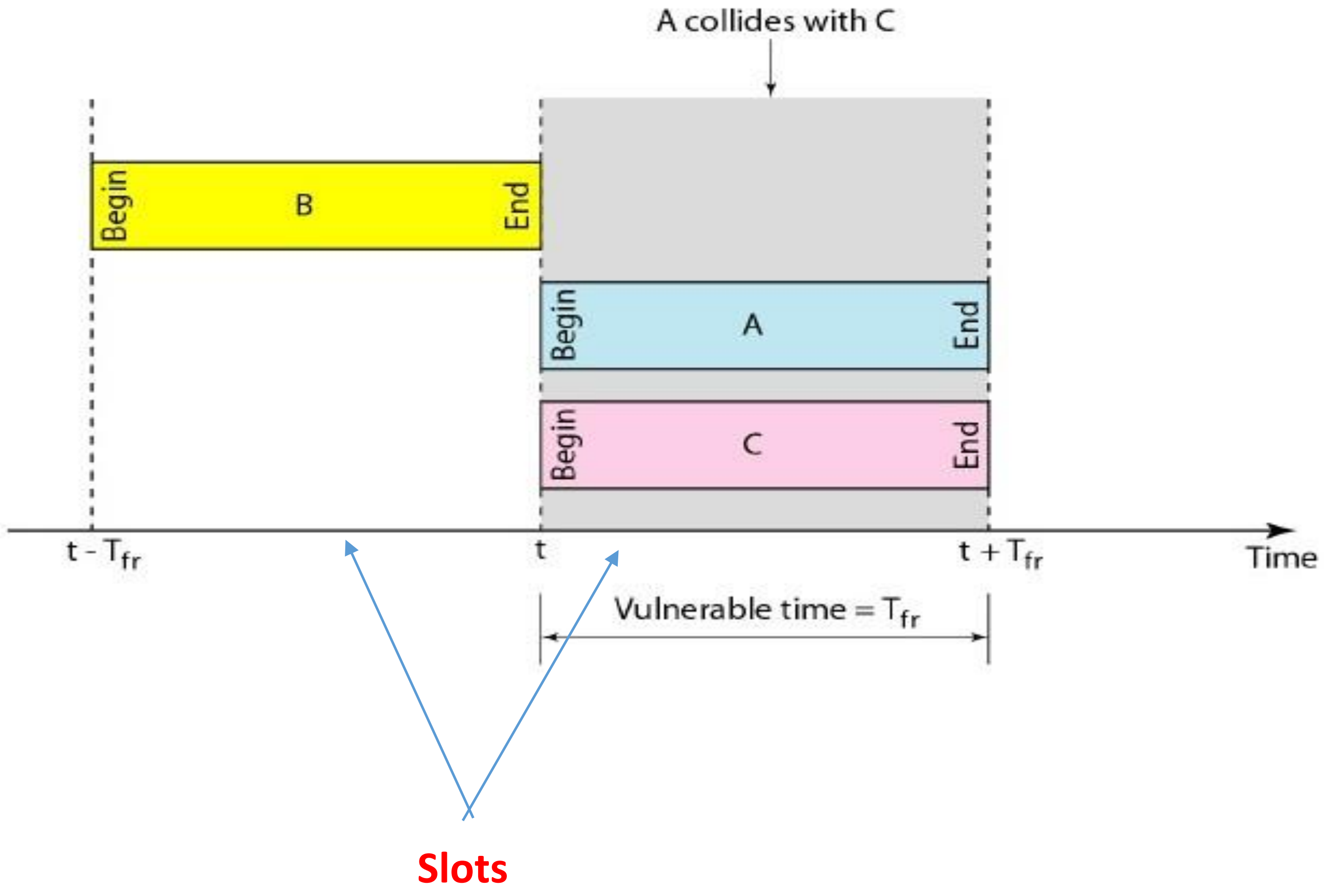
Time is slotted in T_{fr} seconds slots Stations synchronized to frame times

Stations transmit frames in first slot after frame arrival

Backoff intervals are in multiples of slots



Vulnerable time for slotted aloha



Throughput of Slotted ALOHA

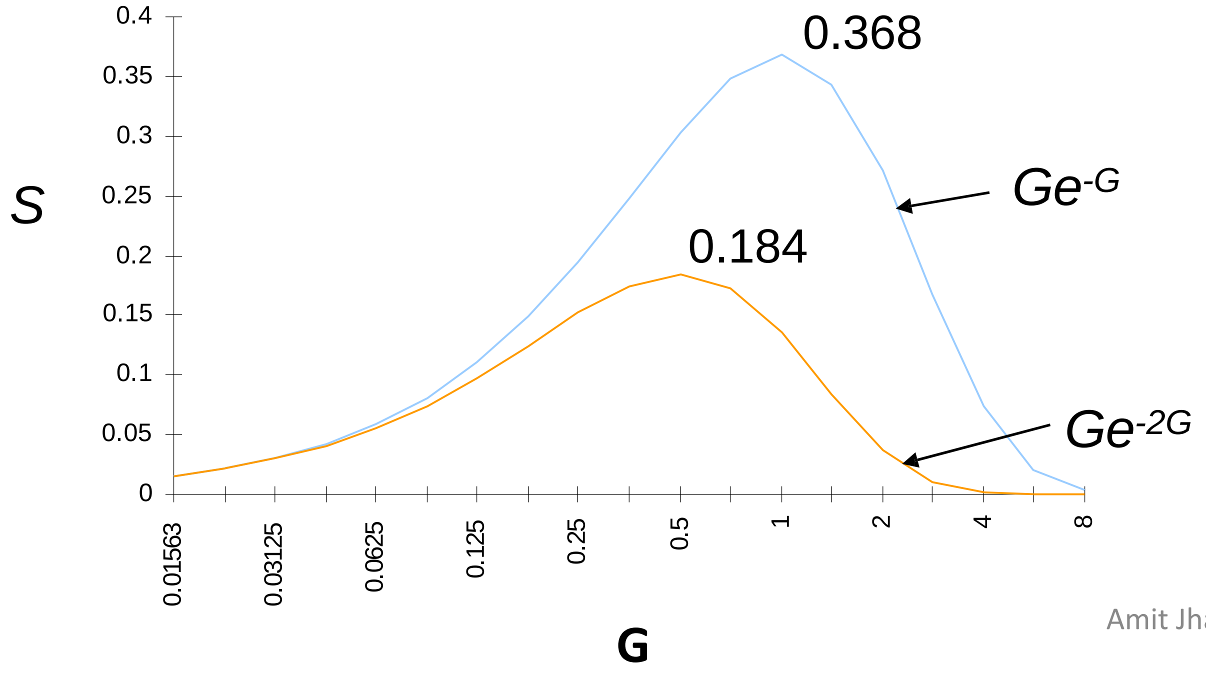
$$P_{success} = P[0 \text{ arrivals in } T_{fr} \text{ seconds}]$$

$$= P[0 \text{ arrivals in n intervals}] \quad \ldots$$ **Abramson's assumption**

$$= (1-P)^n = \left(1 - \frac{G}{n}\right)^n$$

$$\rightarrow \boldsymbol{e^{-G}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{as n} \rightarrow \infty$$

$$\boxed{\therefore S = G P_{Success} = G e^{-G}}$$



Limitations of ALOHA

The throughput for pure ALOHA is S =G x *e-2G*.
The maximum throughput S_{max} = 0.184 when G =(1/2).

The throughput for slotted ALOHA is *S* = G x *e*-G.
The maximum throughput S_{max} = 0.368 when G =1.

Homework:1) Repeat Example 3 for slotted ALOHA, and observe the conclusion.
2) Derive the formulae for the maximum throughput for Pure and Slotted ALOHA.

Carrier Sense Multiple Access (CSMA)

- **Principle:** CSMA is based on the principle "sense **before** transmit" or "listen **before** talk.“

- CSMA can reduce the possibility of collision, but it cannot eliminate it.

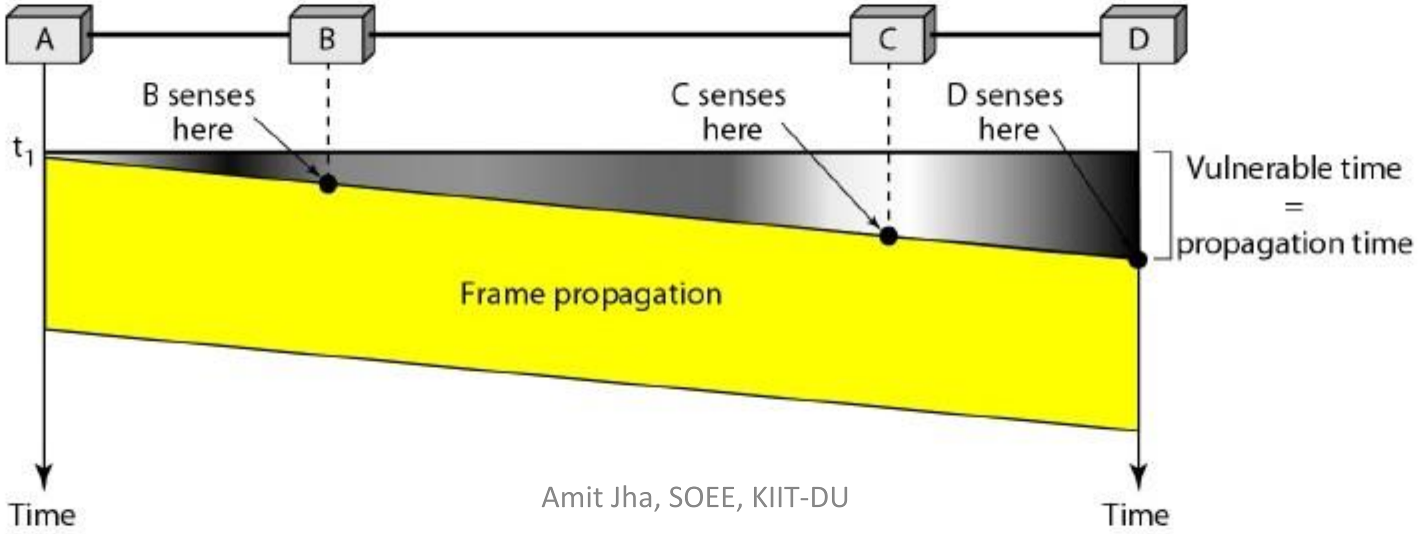
- **Why collision exists even after sensing?** The possibility of collision still exists because of propagation delay; when a station sends a frame, it still takes time (although very short) for the first bit to reach every station and for every station to sense it.

- In other words, a station may sense the medium and find it idle, only because the first bit sent by another station has not yet been received.

Note: $\boldsymbol{T_{fr}\ is\ generally\ greater\ than\ T_p.}$

Vulnerable Time for CSMA

- The vulnerable time for CSMA is the propagation time T_P . This is the time needed for a signal to propagate from one end of the medium to the other.
- In other words, it is the time taken by a bit to reach to the last station from first station.



Persistence Methods

Not continuously sensing

- What should a station do if the channel is busy?
- Three methods have been developed for this:
  1. The non-persistent method
  2. The 1-persistent method
  3. The p-persistent method

- **Non-persistent method (least greedy):** a station that has a frame to send senses the line. If the line is idle, it sends immediately. If the line is not idle, it waits a random amount of time and then senses the line again.

- The non-persistent approach reduces the chance of collision because it is unlikely that two or more stations will wait the same amount of time and retry to send simultaneously.
- However, this method reduces the efficiency of the network because the medium remains idle when there may be stations with frames to send.

- **1-persistent method:** Simplest method. Any station sends frame with probability 1 as soon as it finds channel idle. Thus, it has highest probability of collisions.

Note: Persistent means *continuous*

- **P-persistent method:** It combines the advantages of the other two strategies. It reduces the chance of **collision** and **improves efficiency**.

- In this, a channel continuously senses the channel, this improves efficiency.

- In this, after the station finds the line idle it follows these steps:

  1. With probability *p,* the station sends its frame.

  2. With probability *q* = 1 - *p,* the station waits for the beginning of the next time slot and **checks the line again.**

    a. If the line is idle, it goes to step 1.

    b. If the line is busy, it acts as though a collision has occurred and uses the back-off procedure.

Persistence methods

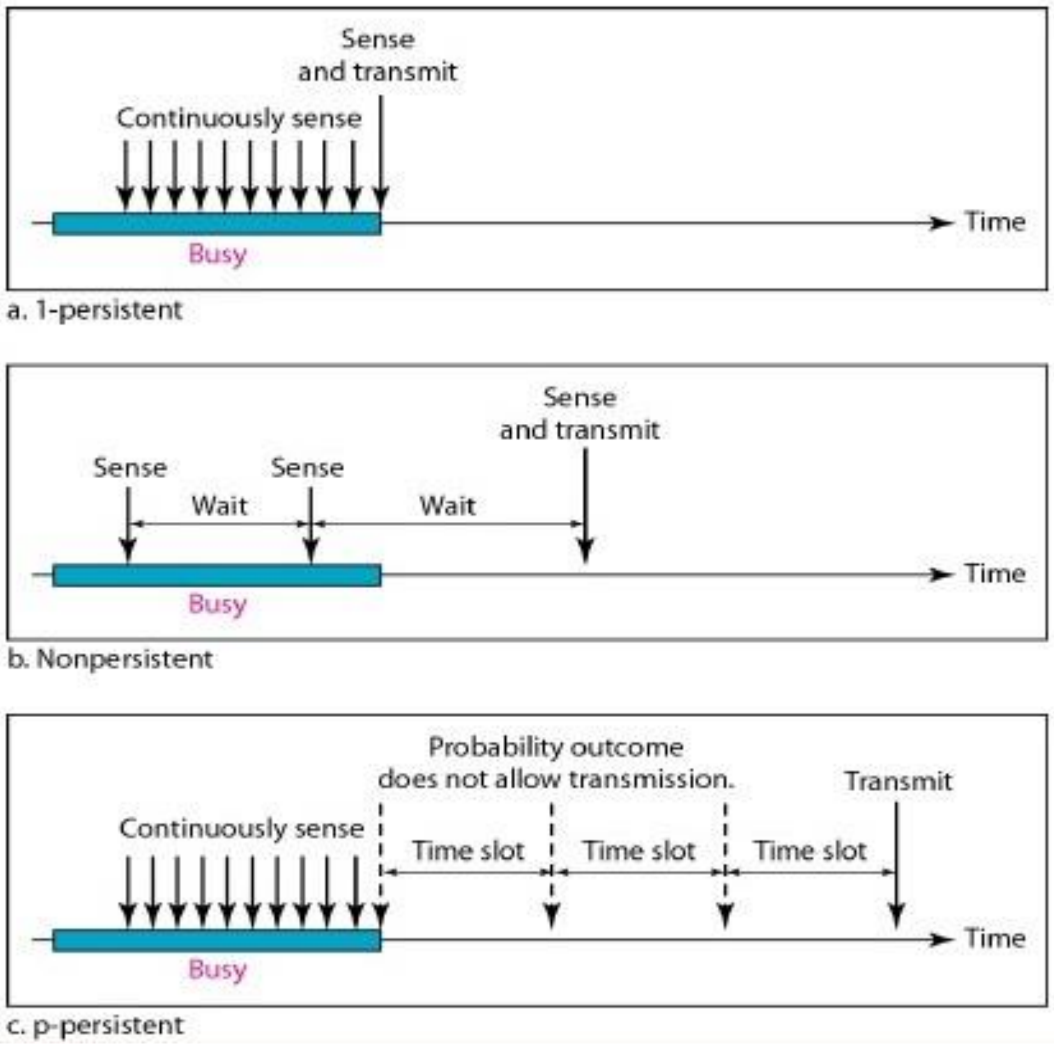


Fig: Behaviour of three persistence methods

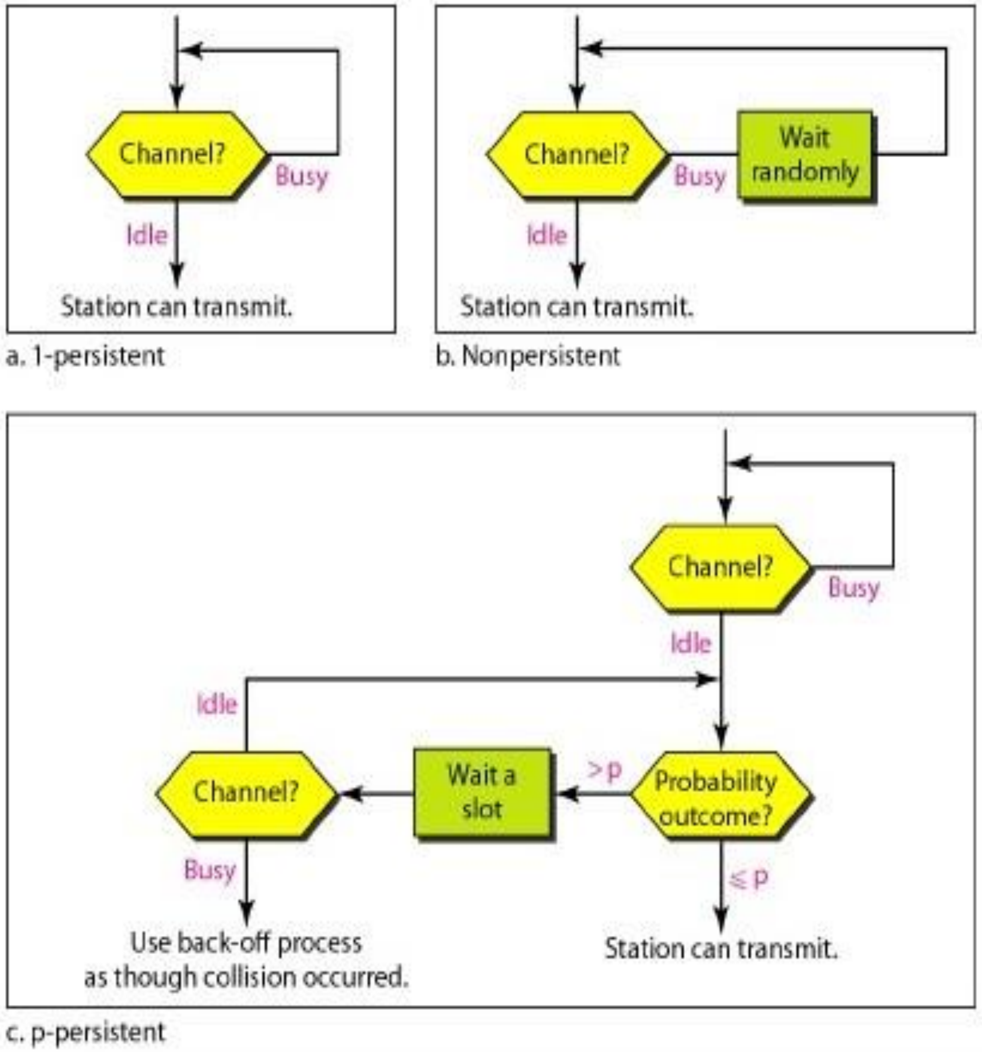
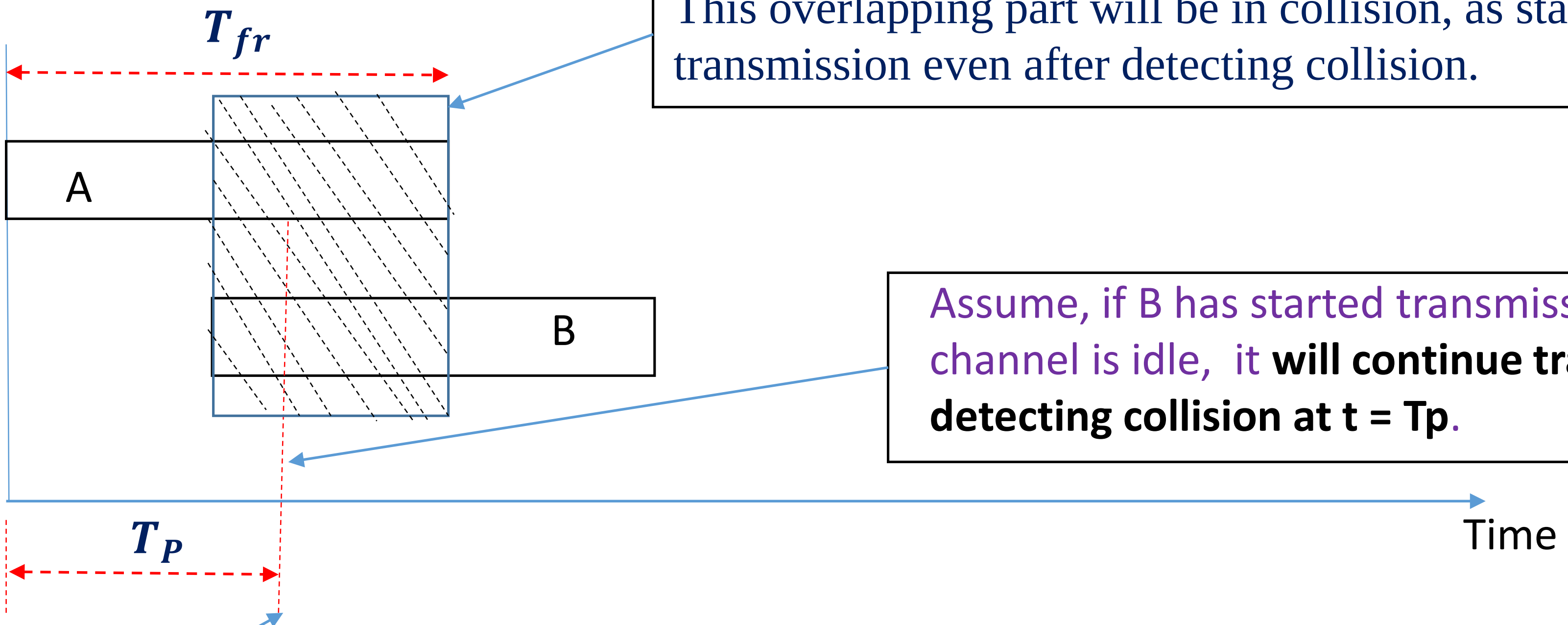


Fig: Flow diagram of three persistence methods

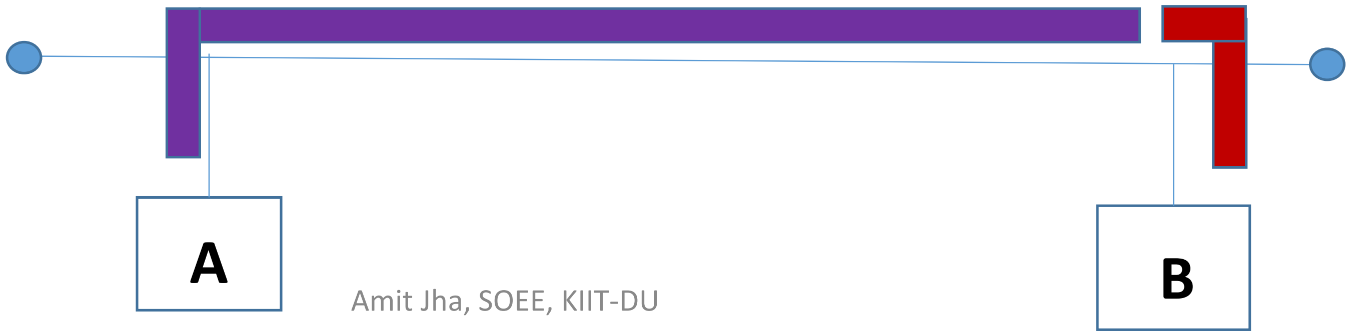
Limitations of CSMA



This overlapping part will be in collision, as station B does not stop transmission even after detecting collision.

Assume, if B has started transmission before t = Tp, where channel is idle, it **will continue transmission even after detecting collision at t = Tp**.

At t = Tp, B comes to know about collision



Limitations of CSMA

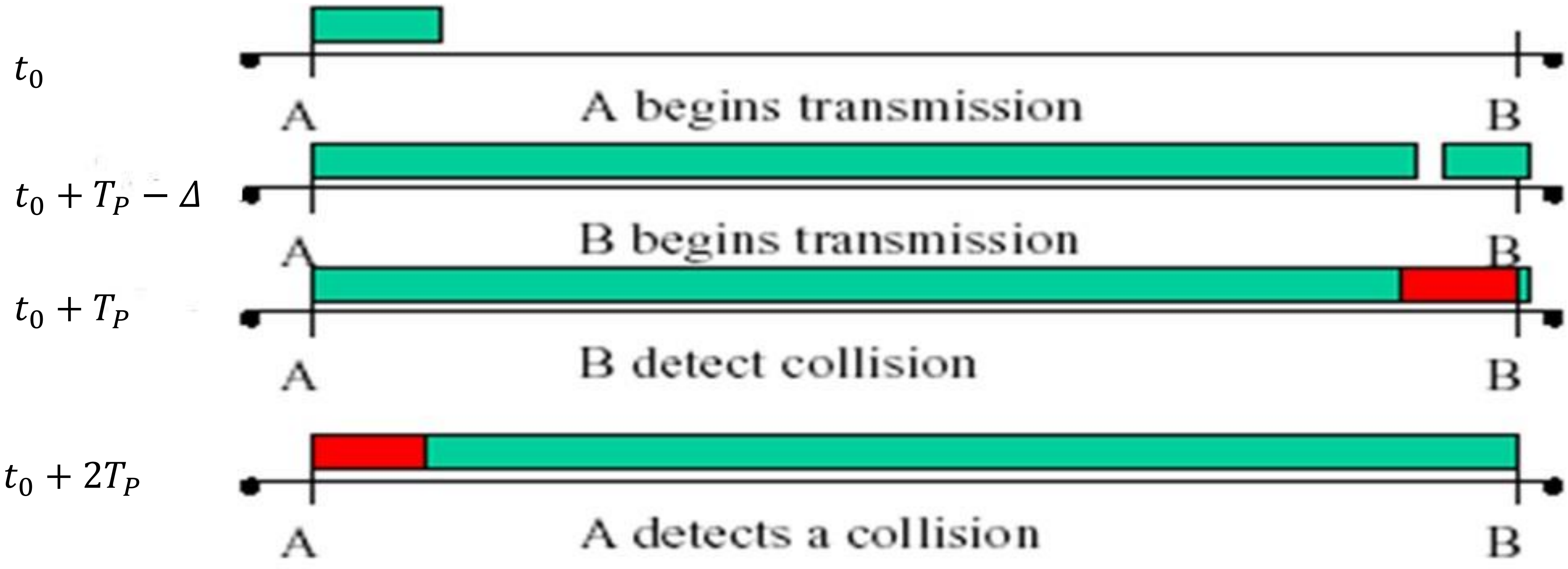
- A station can not sense a channel busy even when another station has already started sending .
- This is because of the propagation delay. Although, the propagation delay is very small, but still it exists there.
- Whenever a station detects that the collision has occurred, it does not stop transmission.

Carrier Sense Multiple Access with Collision Detection (CSMA/CD)

- In this method, a station **listens while transmitting (LWT)** to see if the transmission was successful.
- Possible cases when channel is idle:
  1. Packet is transmitted in case of non-persistent or 1-persistent
  2. For p-persistent, the packet is sent with probability p or delayed by end-to-end propagation delay ($\boldsymbol{T_P}$) with probability (1-p).
- If channel is busy, possible cases:
  1. For non-persistent, the packet is **backed off** and the algorithm is repeated.
  2. For 1-persistent, the station **differs** the transmission until the channel is sensed idle, and then immediately transmits when channel becomes idle.
  3. For p-persistent, the station **differs** until the channel is idle, then follow the channel idle procedure (as used in p-persistent CSMA case).

Question: **How long does it take to detect a collision?**

Ans: In the ***worst case***, **twice the maximum propagation delay of the medium, i.e.,** $2T_p$



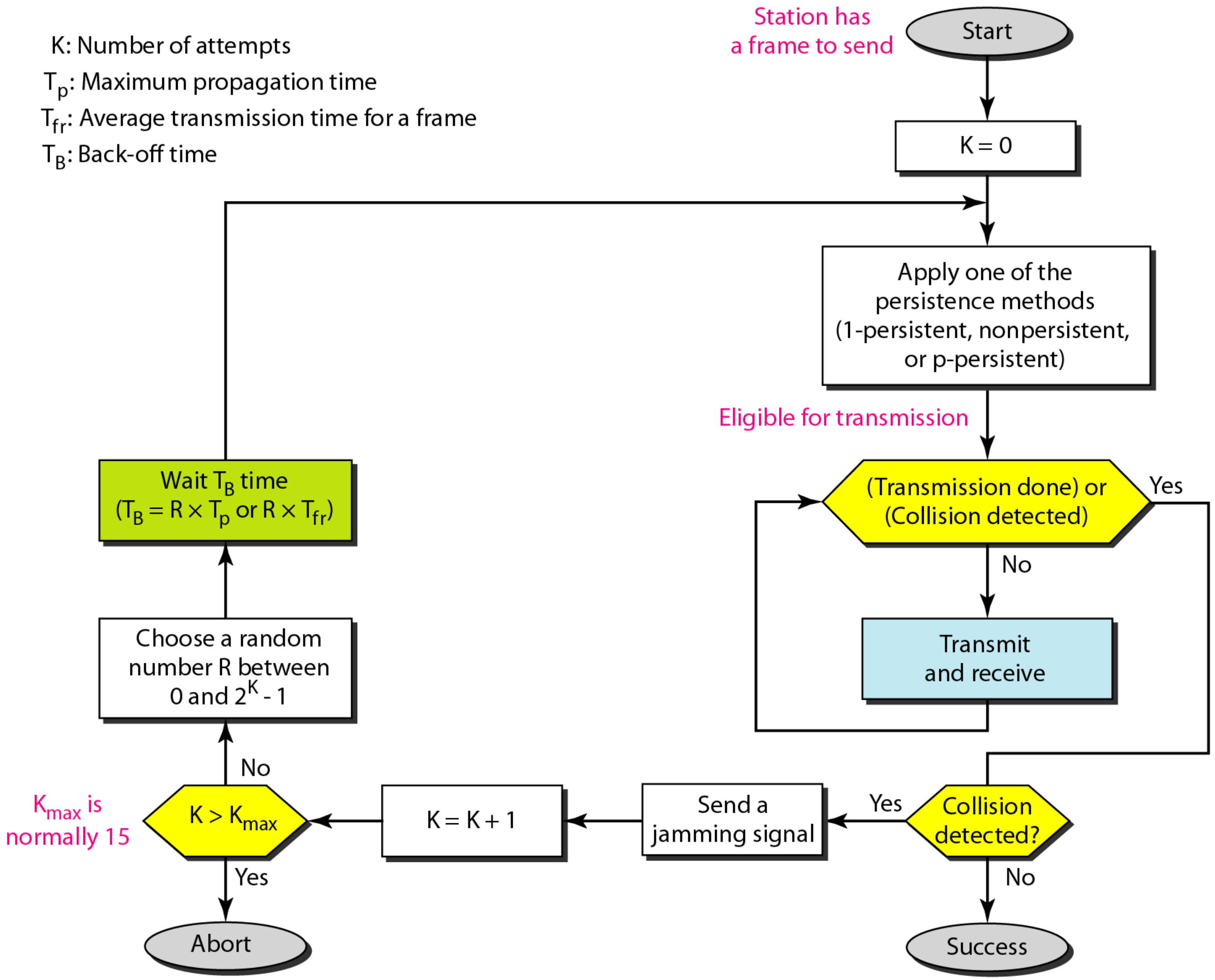
Restrictions in CSMA/CD

- Frame/Packet **transmission time** should be **at least** as long as the time needed to detect a collision + time needed to send a jamming signal (i.e., 2 * maximum propagation delay + *jam sequence* transmission time).
- Otherwise, CSMA/CD does not have an advantage over CSMA

$$\boxed{\therefore T_{fr} \geq 2T_P + jam\ sequence\ \text{transmission time}}$$

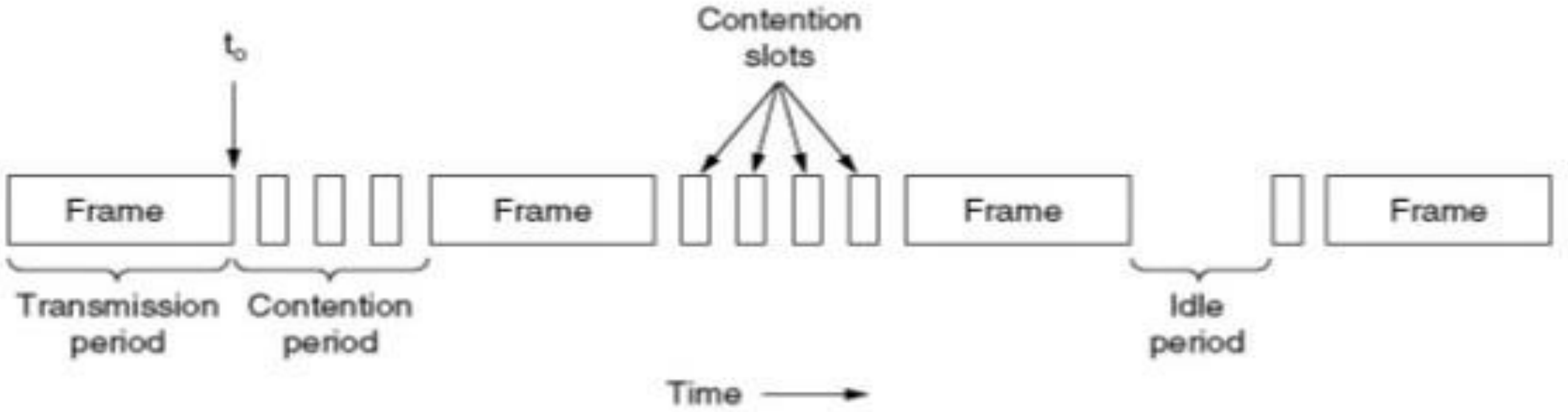
Note: The station which detects collision, sends a jamming signal to all other stations to inform that a collision has detected. So, please stop transmission.

Flow diagram for the CSMA/CD



The three periods in CSMA/CD

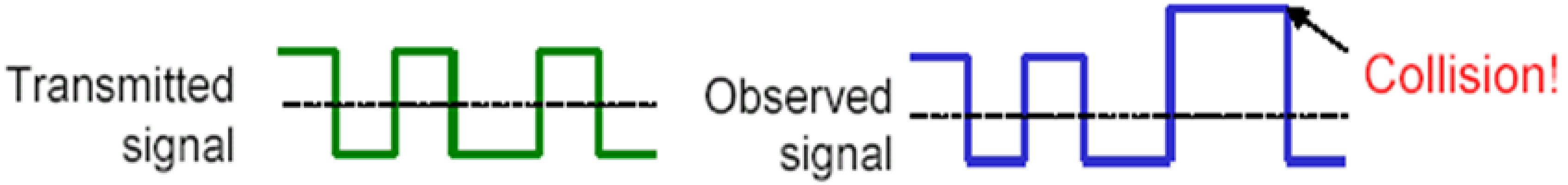
- The following three periods exists in CSMA/CD:
  1. **Contention period:** During this period, each station continuously senses (content) the channel to send a packet.
  2. **Transmission period:** During this, a station has found channel idle and sent a packet over it.
  3. **Idle:** No packet during this period; possible in case of light traffic channel.



Q.) Collision detection is not possible/difficult in a wireless environment, why?

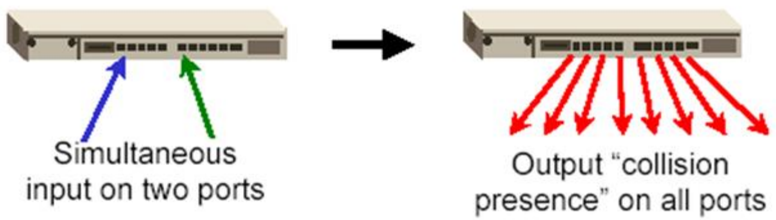
Q.) Collision detection is not possible/difficult in a wireless environment, why?

Ans: *When there is a collision, the station receives two signals: its own signal and a signal transmitted by the second station. To distinguish between, these two signals, they must differ by a significant amount of energy.*
In wired network, the received signal has almost same energy as sent signal. This is because, either the length of cable is short or repeaters are used. It means, in collision, the detected energy is almost double as shown below.

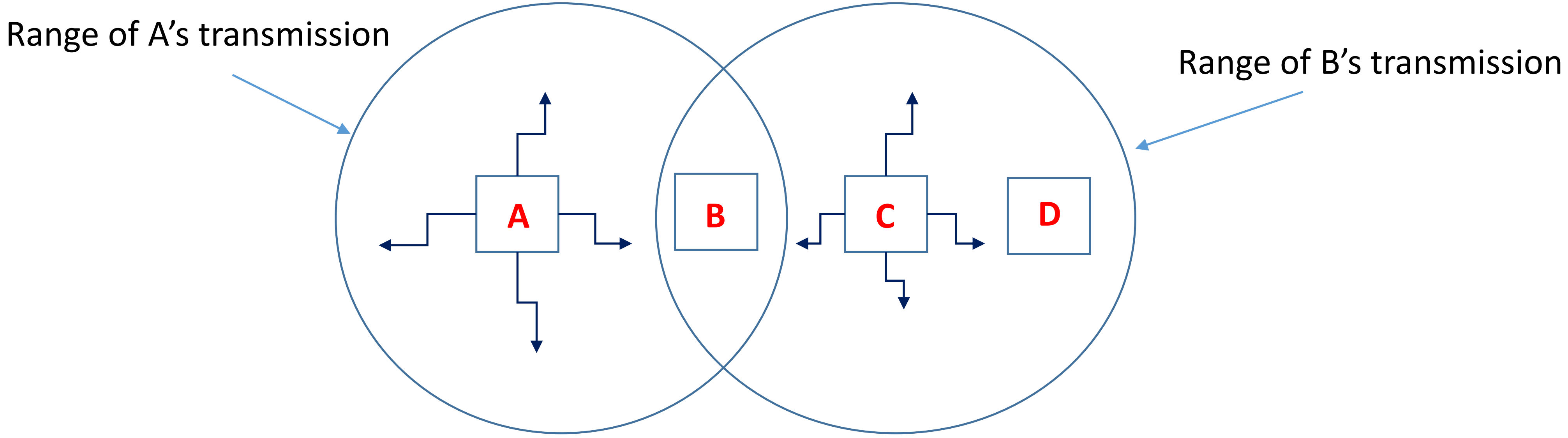


However, in a wireless network, much of sent energy is lost in transmission. The received signal has very little energy. Therefore, a collision may add only 5 to 10 % additional energy. This is not useful for collision detection.

*Not only this but also there exists the **hidden station** and **exposed station** problem in wireless environment.*
***Note:** In case of hub, if input occurs simultaneously on two ports, it indicates a collision. In this case Hub sends a collision presence signal on all ports.*

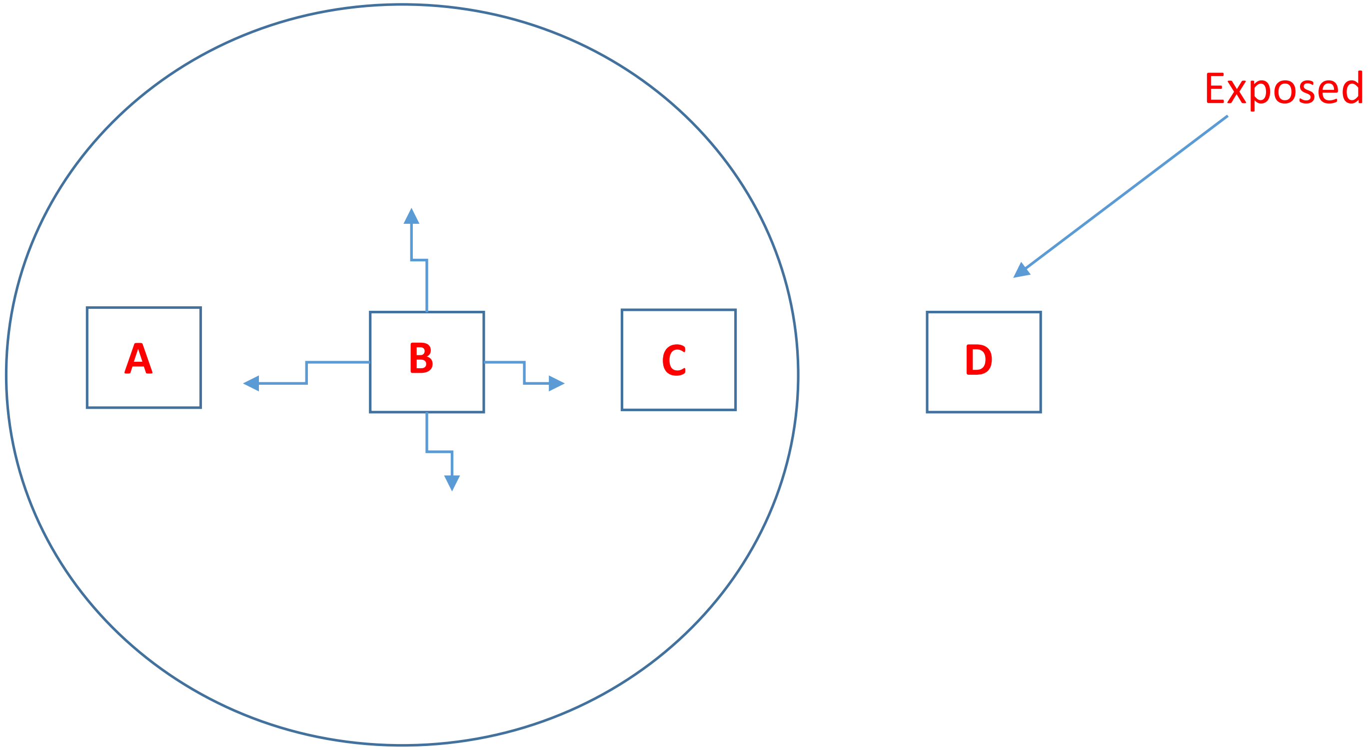


The Hidden Station Problem



- Both the stations A and C, tries to communicate with B simultaneously.
- Both the signals will reach to B and **collision will occur at B**.
- **But A and C will not be able to detect** this collision because **A does not come in the range of C and vice-versa**.

The Exposed Station Problem



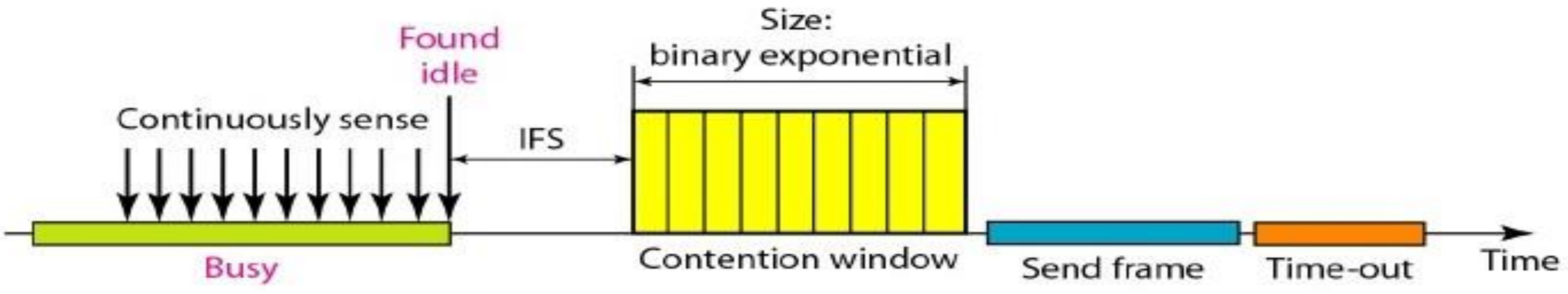
- Station B wants to communicate with A, which is also listened by C.
- Thus**, C assumes** that the medium is not free and thus **it can not communicate with D.**
- But in practice, C can communicate with D.

CSMA/CA→ Its not in your syllabus.

- Developed because collision detection is not possible in wireless system.
- In this case, collisions are avoided through the use of CSMA/CA's three strategies:
  1. The inter-frame space
  2. The contention window
  3. Acknowledgement

- **Interframe space:** When an idle channel is found, the station does not send immediately. It waits for a period of time called ***Interframe space*** or **IFS.**

- **Contention window:** It is the amount of time divided into slots. A station which is ready to send chooses a random number of slots as its wait time.
- **Acknowledgement:** Even with all these precautions, there still may be a collision resulting in destroyed data, or corrupted data.



CSMA: Key-points

- In CSMA/CD Collisions are detected.
- In CSMA/CA collisions are avoided.
- CSMA/CD is used in wired LAN, Ethernet LAN (802.3).
- CSMA/CA is used in wireless LAN, 802.11 standard.
- Collisions are not completely eliminated in CSMA/CA. However, it is reduced as compared to CSMA/CD.
- Collision detection is not possible in wireless LAN because of:
  - ➢ Reduction in the strength of the received signal to a greater extent
  - ➢ Hidden station problem
  - ➢ Exposed station problem

Refer→

- Chapter 5, Computer Networks- B.A. Forouzan, et al.