Data Link Layer

Objectives

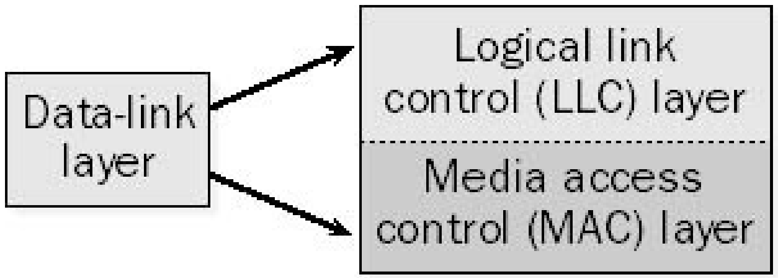
- **Specific responsibilities of the data link layer include –**

1. ***framing,***
2. ***addressing,***
3. ***flow control,***
4. ***error control, and***
5. ***Media access control.***

Data Link Layer

- Two sublayers:

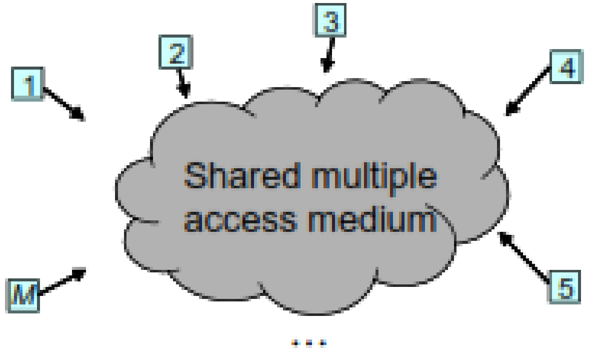
1. **LLC (Logical Link Control)** sublayer
2. **MAC** (**Medium Access Control**) sublayer



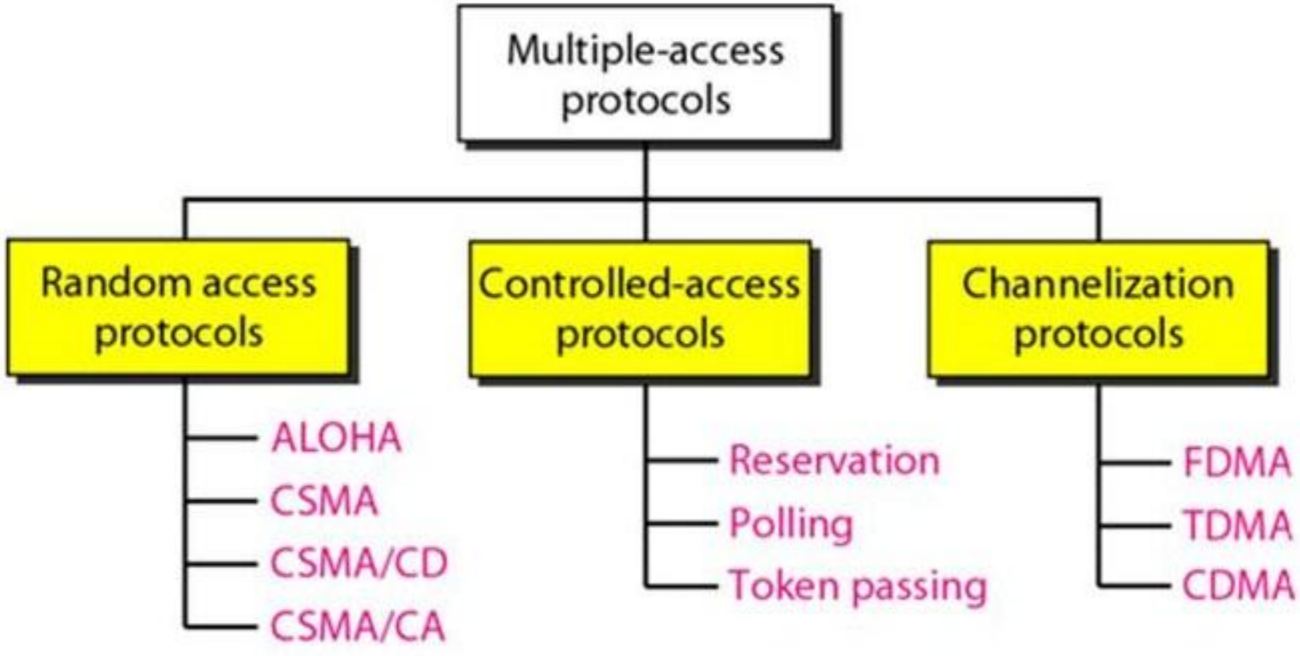
- The upper sublayer that is responsible for flow and error control is called the logical link control (LLC) layer;
- The lower sublayer that is mostly responsible for multipleaccess resolution is called the media access control (MAC) layer. When nodes or stations are connected and use a common link, called a multipoint or broadcast link, we need a multiple-access protocol to coordinate access to the link.

multiple access networks

- multiple access networks – multiple sending & receiving stations share the same transmission medium
- **Advantages:**
- low cost infrastructure
- all stations attached to the medium hear
- transmission from any other station ⇒ routing not necessary
- **Disadvantages:**
- access of multiple sending and receiving nodes to the shared medium must be coordinated
- stations should not be transmitting simultaneously or interrupting each other
- stations should not be able to 'monopolize' the transmission/shared medium
- • examples: LAN, cellular and satellite networks



Multiple Access Communications



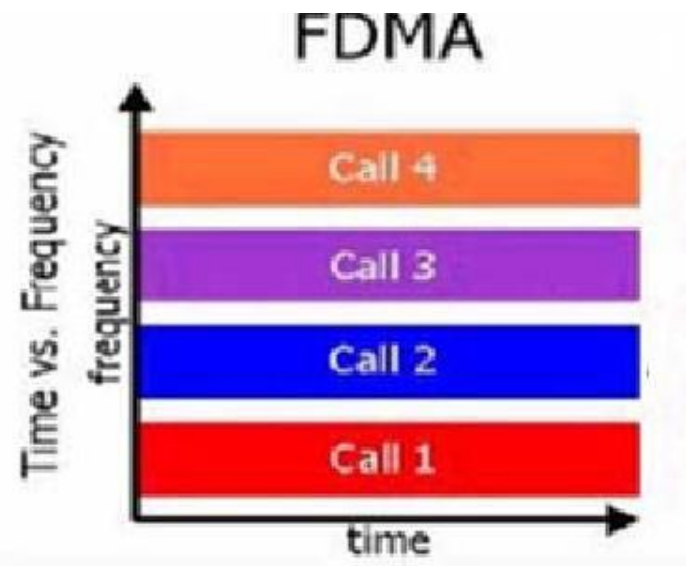
Channelization Protocol

- Channelization is a multiple access method in which the available bandwidth of a link is shared in ***time***, ***frequency*** or ***code*** between different stations.
- There are three basic channelization protocols:

1. **Frequency Division Multiple Access (FDMA)**
2. **Time Division Multiple Access (TDMA)**
3. **Code Division Multiple Access (CDMA)**

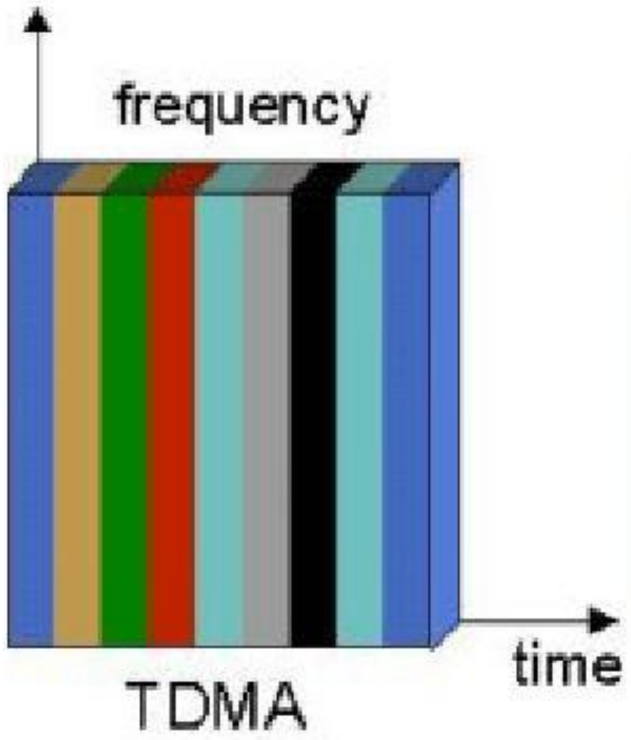
FDMA

- In FDMA, the available bandwidth is divided into **frequency** bands.
- Each station is allocated a band to send its data.
- This band is reserved for that station for all the time.
- The frequency bands of different stations are separated by small bands of unused frequency.
- These unused bands are called guard bands that prevent station interferences.



TDMA

- In TDMA, the bandwidth of channel is divided among various stations on the basis of time.
- Each station is allocated a time slot during which it can send its data.
- Each station must know the beginning of its time slot.
- TDMA requires synchronization between different stations.
- Synchronization is achieved by using some synchronization bits at the beginning of each slot.



CDMA

- Unlike TDMA, in CDMA all stations can transmit data simultaneously.
- CDMA allows each station to transmit over the entire frequency spectrum all the time.
- Multiple simultaneous transmissions are separated using coding theory.
- In CDMA, each user is given a unique code sequence.

Working of CDMA

- Let us assume that we have four stations: 1, 2, 3 and 4 that are connected to the same channel.
- The data from station 1 is d1, from station 2 is d2 and so on.
- The code assigned to station 1 is c1, station 2 is c2 and so on.
- These assigned codes have two properties:

1. If we multiply each code by another, we get 0.
2. If we multiply each code by itself, we get 4, (no. of stations).

Working of CDMA

- When these four stations send data on the same channel, then station 1 multiplies its data by its code i.e. d1.c1, station 2 multiplies its data by its code i.e. d2.c2 and so on.
- The data that goes on the channel is the sum of all these terms:
    - d1.c1 + d2.c2 + d3.c3 + d4.c4
- Any station that wants to receive data from the channel multiplies the data on the channel by the code of the sender.

Working of CDMA

- For e.g.: suppose station 2 wants to receive data from station1.
- It multiplies the data on the channel by c1, (code of station 1).
- Because (c1.c1) is 4, but (c2.c1), (c3.c1) and (c4.c1) are all 0s, station 2 divides the result by 4 to get the data from station 1.
  - data = (d1.c1 + d2.c2 + d3.c3 + d4.c4).c1
  - = d1.c1.c1 + d2.c2.c1+ d3.c3.c1+ d4.c4.c1
  - = d1.4 + 0 + 0 + 0
  - = (d1.4) / 4 = d1

Controlled Access

- In controlled access, the stations consult one another to find which station has the right to send. A station cannot send unless it has been authorized by other stations. We discuss three popular controlled-access methods.

1. Reservation
2. Polling
3. Token Passing

Controlled Access: Reservation

1. **Reservation:**

- In the reservation method, a station needs to make a reservation before sending data. Time is divided into intervals. In each interval, a reservation frame precedes the data frames sent in that interval.
- **How it Works:**
- If there are N stations in the system, there are exactly N reservation minislots in the reservation frame. Each minislot belongs to a station. When a station needs to send a data frame, it makes a reservation in its own minislot. The stations that have made reservations can send their data frames after the reservation frame.

Controlled Access: Reservation

- In the following figure shows a situation with five stations and a five-minislot reservation frame. In the first interval, only stations 1, 3, and 4 have made reservations. In the second interval, only station 1 has made a reservation.

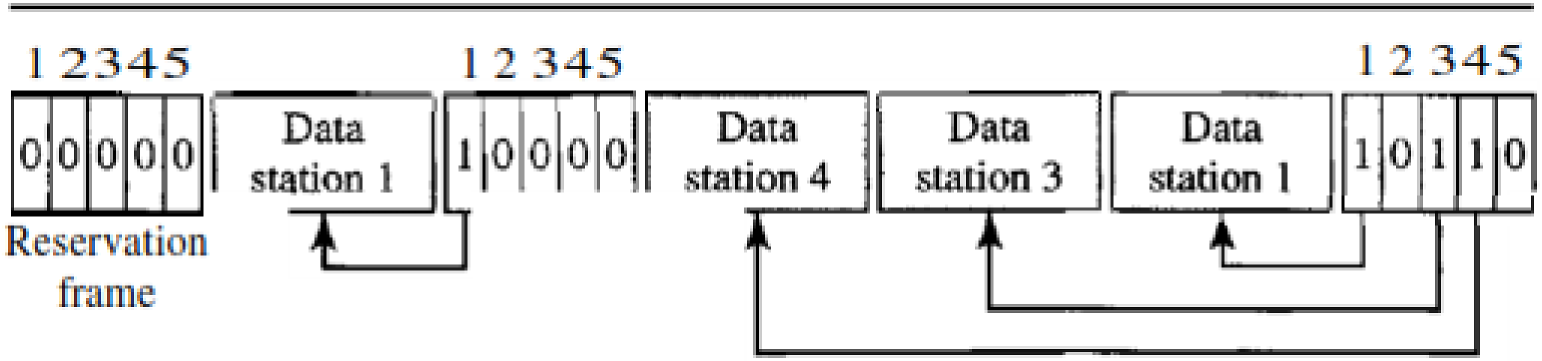


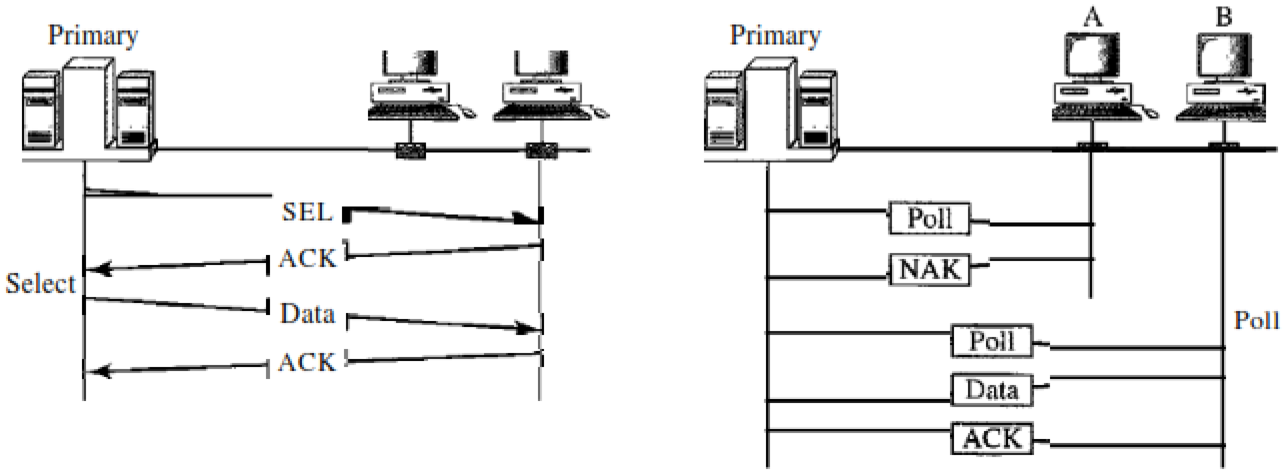
Fig: Reservation access method

Controlled Access: Polling

- Polling works with topologies in which one device is designated as a primary station and the other devices are secondary stations.
- All data exchanges must be made through the primary device even when the ultimate destination is a secondary device.
- The primary device controls the link; the secondary devices follow its instructions.
- It is up to the primary device to determine which device is allowed to use the channel at a given time. The primary device, therefore, is always the initiator of a session.

Controlled Access: Polling

- If the primary wants to receive data, it asks the secondaries if they have anything to send; this is called **poll function**. If the primary wants to send data, it tells the secondary to get ready to receive; this is called **select function**.



- Fig: Select and poll functions in polling access method

Controlled Access: Token Passing

- In the token-passing method, the stations in a network are organized in a logical ring. In other words, for each station, there is a predecessor and a successor. The predecessor is the station which is logically before the station in the ring; the successor is the station which is after the station in the ring.
- **How it works:**
- In this method, a special packet called a token circulates through the ring. The possession of the token gives the station the right to access the channel and send its data.
- When a station has some data to send, it waits until it receives the token from its predecessor. It then holds the token and sends its data. When the station has no more data to send, it releases the token, passing it to the next logical station in the ring.

Controlled Access: Token Passing

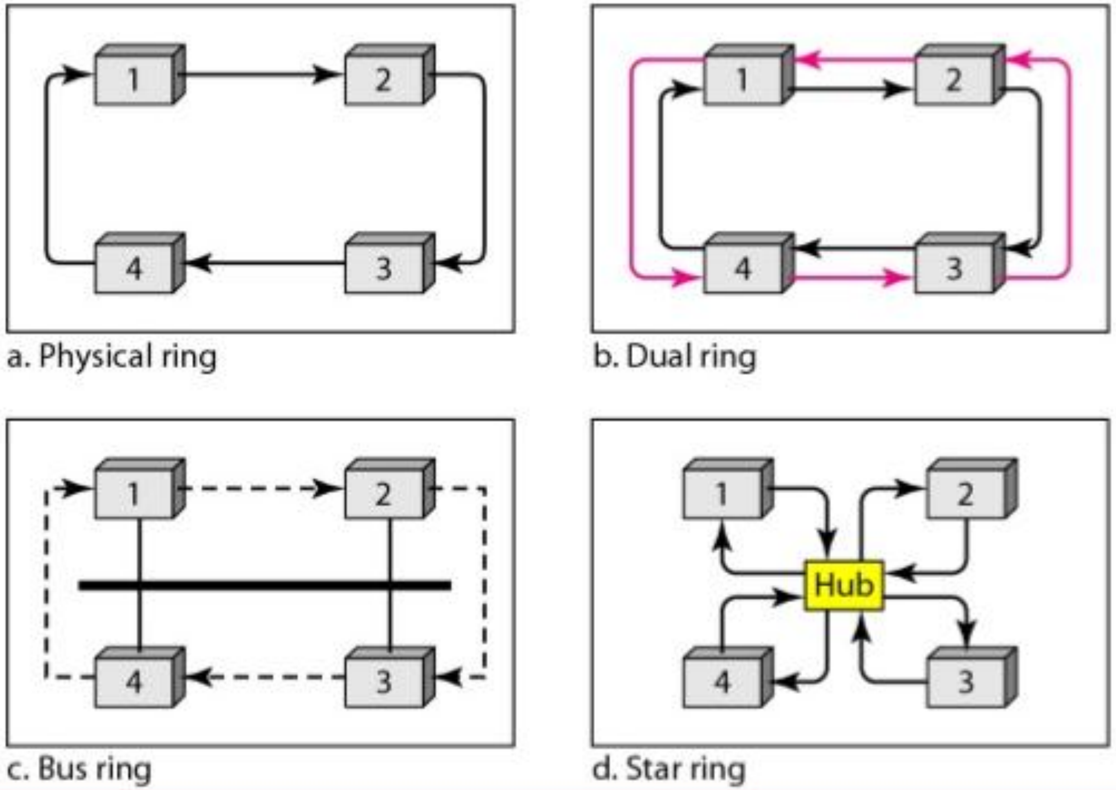


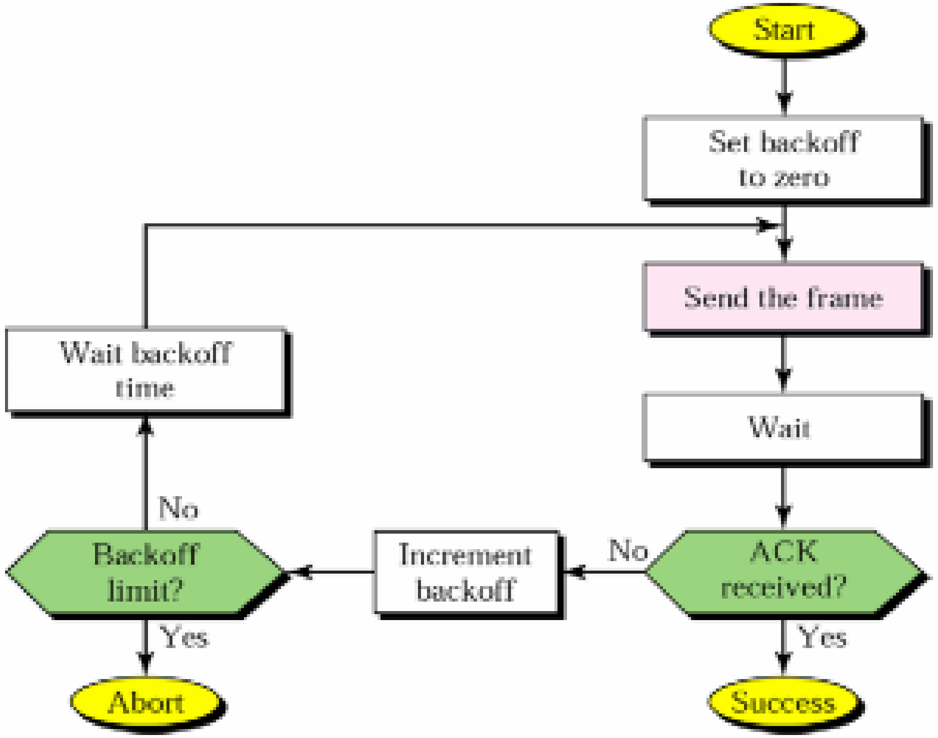
Fig: Logical ring and physical topology in token-passing access method

Random Access Protocl: ALOHA

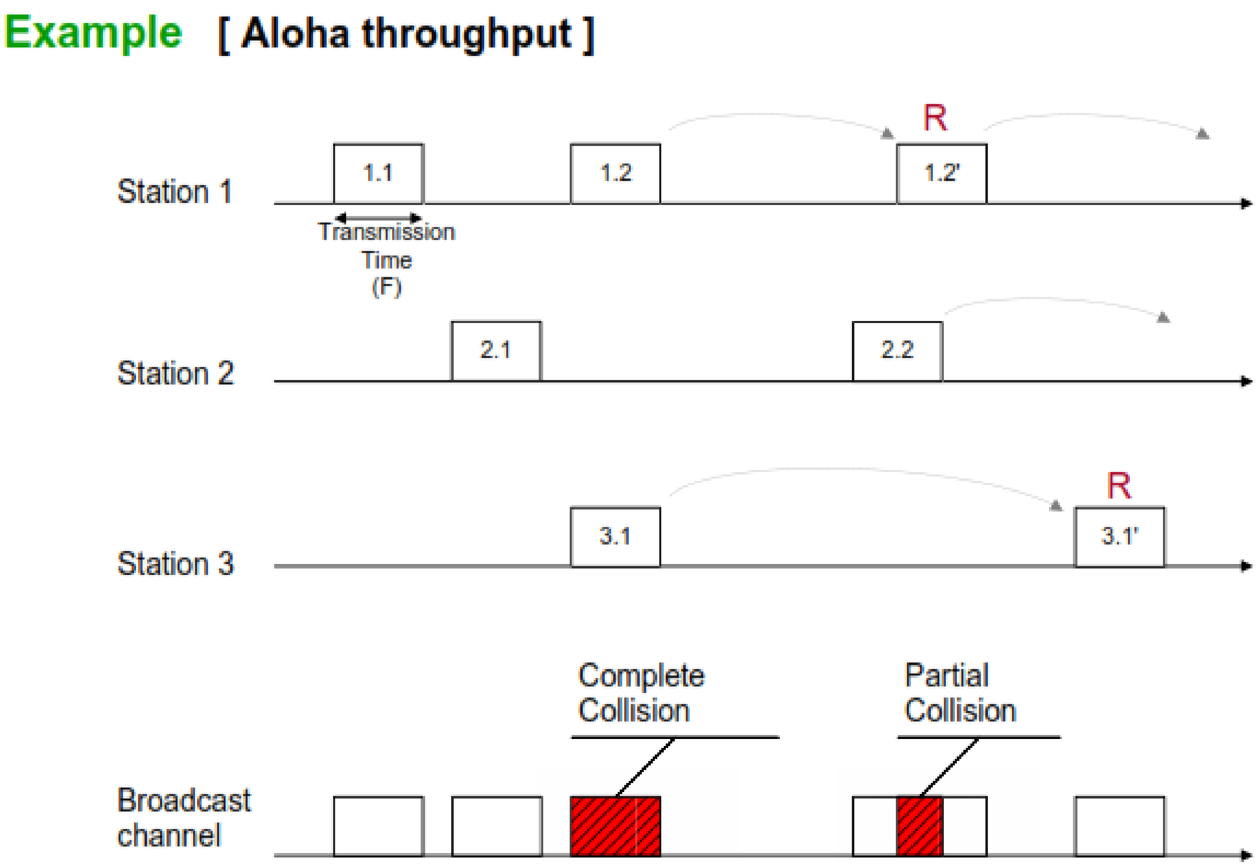
ALOHA – the earliest random-access method (1970s) – still used in wireless cellular systems for its simplicity

- a station transmits whenever it has data to transmit, producing smallest possible delay – receiver ACKs data
- if more than one frames are transmitted at the same time, they interfere with each other (collide) and are lost
- if ACK not received within timeout (2*propagation delay), the station picks random backoff time
  - station retransmits frame after backoff time

ALOHA- Flow chart



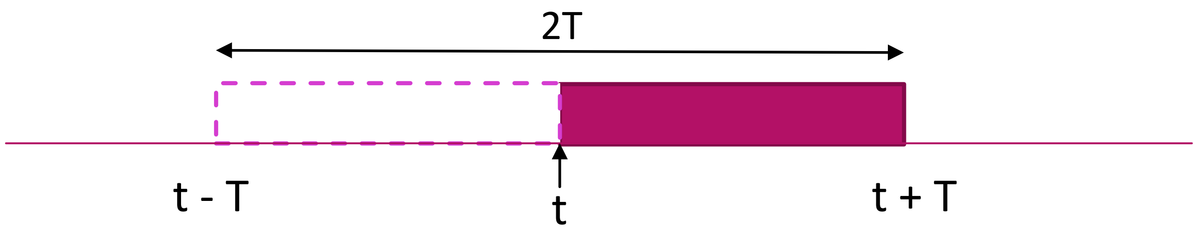
ALOHA Throughput



R= Transmission Rate

ALOHA Throughput

- The throughput is the fraction of time, the channel carries useful information, namely non-colliding packets.
- Under all number of frames, the throughput, S, is just the product of average number of frames, G and the probability, P, of a transmission succeeding—that is,
- $$S = GP$$
- Consider a packet scheduled for transmission at some time 't'. This packet will be successful if no other packet is scheduled for transmission in the interval (t-T, t+T) (this period of 2T is called the vulnerable period). The probability of this happening, that is, the probability of success, is that no packet is scheduled in an interval of length 2T.



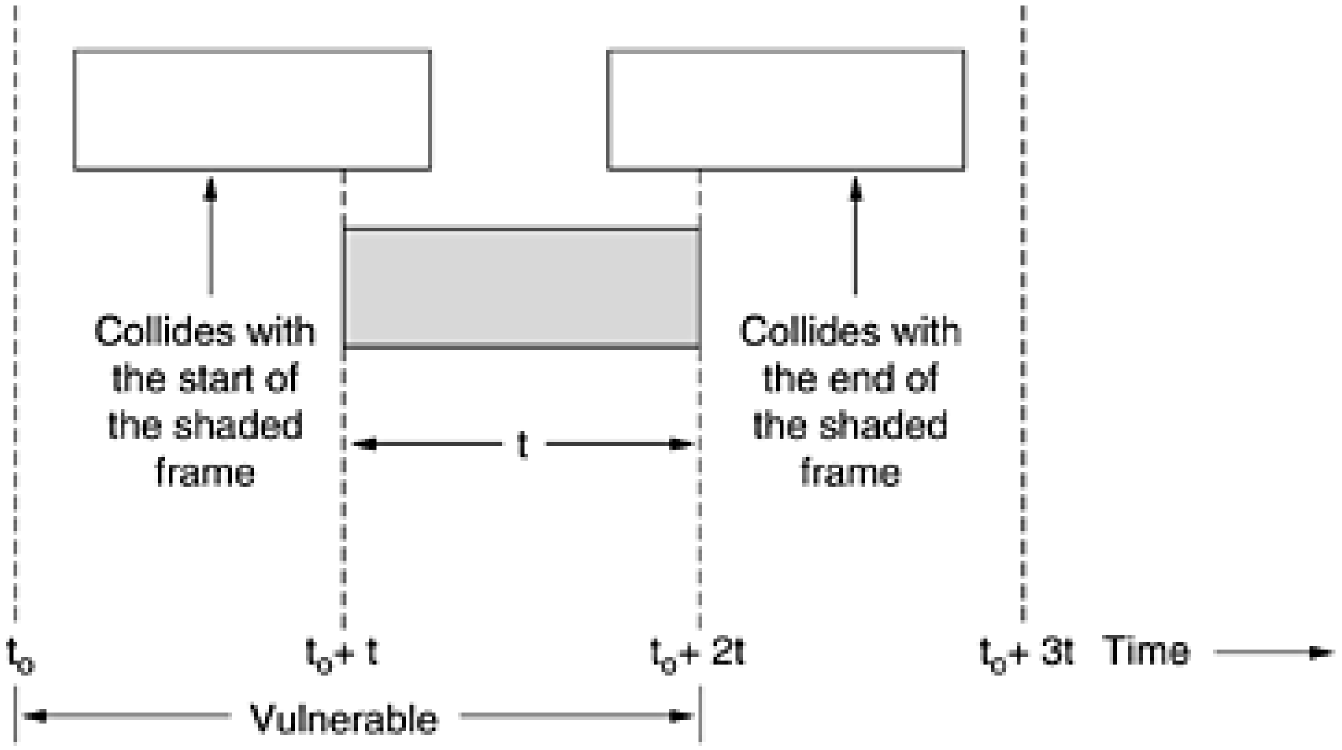
ALOHA Throughput- cont.

- Using Poisson distribution, Probability of generating ‘k’ interfering frames (when average number of frames = G) is,
- **P (k) = ($\boldsymbol{G^k . e^{-G}}$) / k!**
- The vulnerability of pure ALOHA is 2 time frames. For the time duration of two time frames on an average 2G frames are produced. Thus, probability that no other traffic is initiated in this duration (2T) is, that is probability of successful transmission without interference, is;
- →P (0) = ($(2G)^0 * e^{-2G}$) / 0!
- →P = e^{-2G}
- Using S = GP, we get
- Throughput,
  - **S = G$\boldsymbol{e^{-2G}}$**

maximum throughput for pure ALOHA

- We see that throughput S depends on occurrence of frames/frame time, G, to get maximum throughput, we differentiate the throughput equations with respect to G.
- Pure ALOHA:
- S = Ge^{-2G}
- S' = e^{-2G}+ G*(-2) e^{-2G} [differentiation (S) = S']
- For maxima, above equation is to be equated to zero. Therefore,
- dS/dG = e^{-2G} – G*(2) e^{-2G} = 0
- Gmax = 1/2
- Thus, **S = 0.5/e**

Vulnerable period

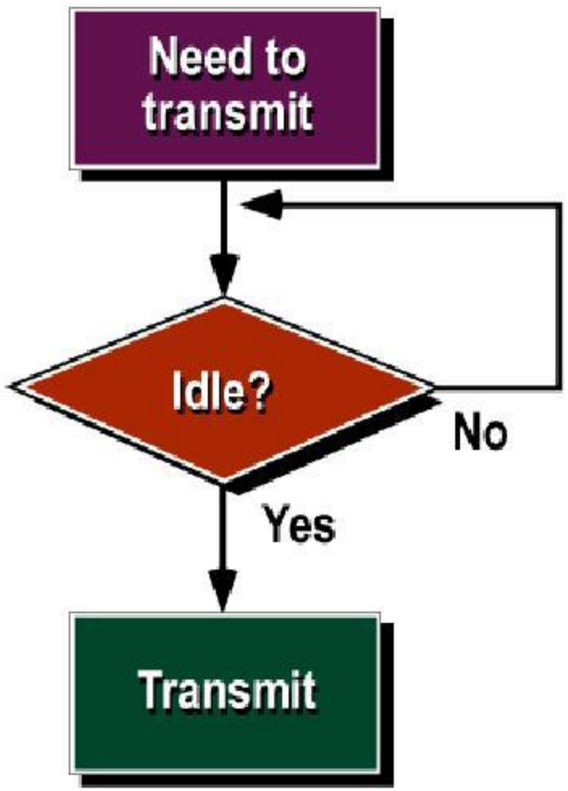


Carrier Sense Multiple Access (CSMA)

- CSMA was developed to overcome the problems of ALOHA i.e. to minimize the chances of collision.
- CSMA is based on the principle of “carrier sense”.
- The station sense the carrier or channel before transmitting a frame.
- It means the station checks whether the channel is idle or busy.
- The chances of collision reduces to a great extent if a station checks the channel before trying to use it.

Carrier Sense Multiple Access (CSMA)

- The chances of collision still exists because of propagation delay.
- The frame transmitted by one station takes some time to reach the other station.
- In the meantime, other station may sense the channel to be idle and transmit its frames.
- This results in the collision.

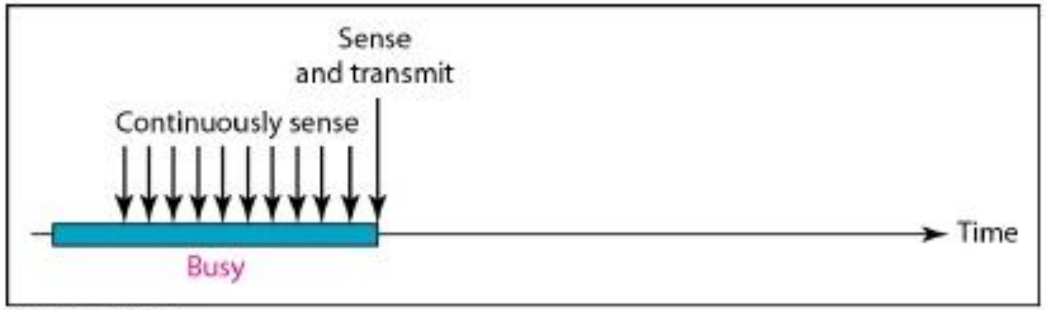


Persistence Methods

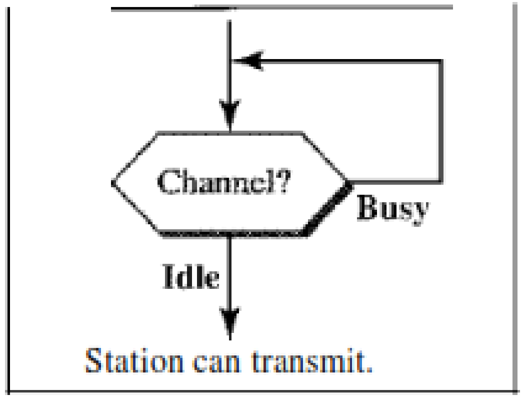
- What should a station do if the channel is busy? What should a station do if the channel is idle?
- Three methods have been devised for CSMA:
  - I-persistent method,
  - the nonpersistent method
  - the p-persistent method.

I-Persistent

- **I-Persistent:** The I-persistent method is simple and straightforward. In this method, after the station finds the line idle, it sends its frame immediately (with probability I).
- This method has the highest chance of collision because two or more stations may find the line idle and send their frames immediately.



a. 1-persistent

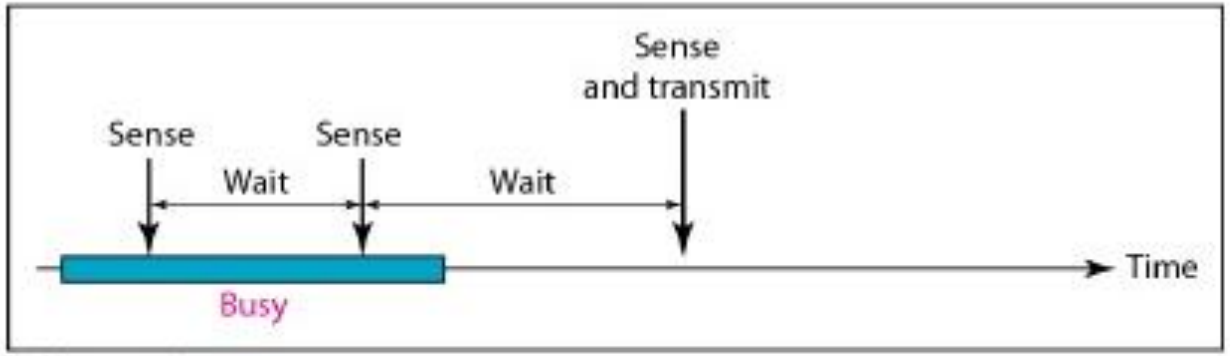


a. 1-persistent

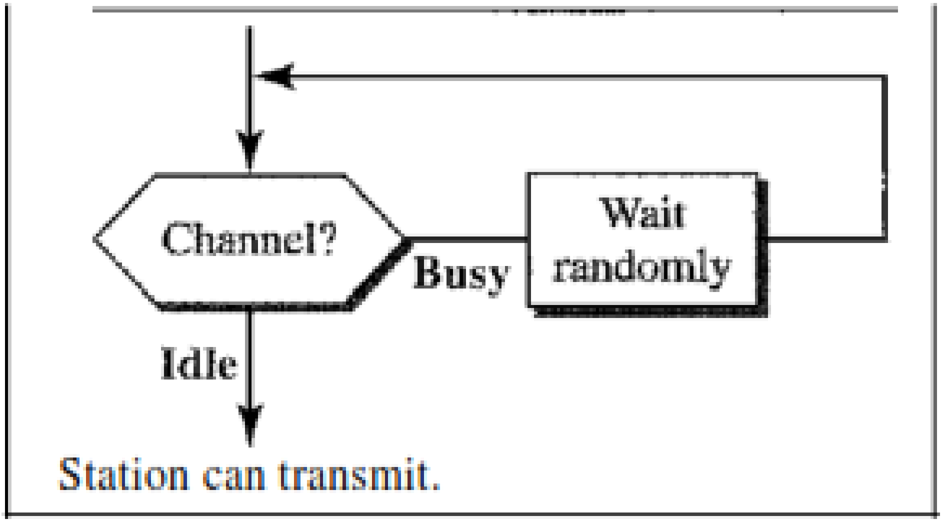
Nonpersistent

- **Nonpersistent:** In the nonpersistent method, 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 nonpersistent 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.

Nonpersistent



b. Nonpersistent

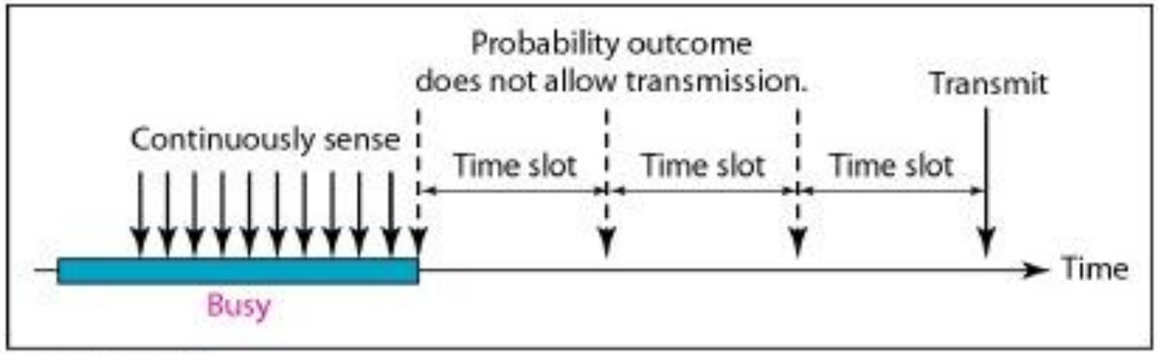


b. Nonpersistent

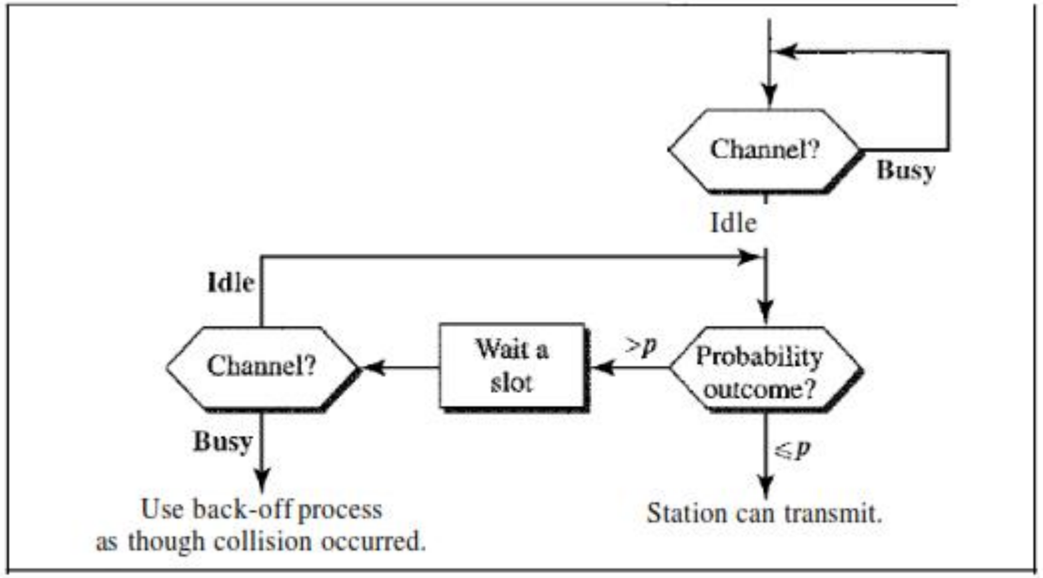
p-Persistent

- **p-Persistent:** The p-persistent method is used if the channel has time slots with a slot duration equal to or greater than the maximum propagation time. The p-persistent approach combines the advantages of the other two strategies. It reduces the chance of collision and improves efficiency.
- In this method, 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.

p-Persistent:



c. p-persistent



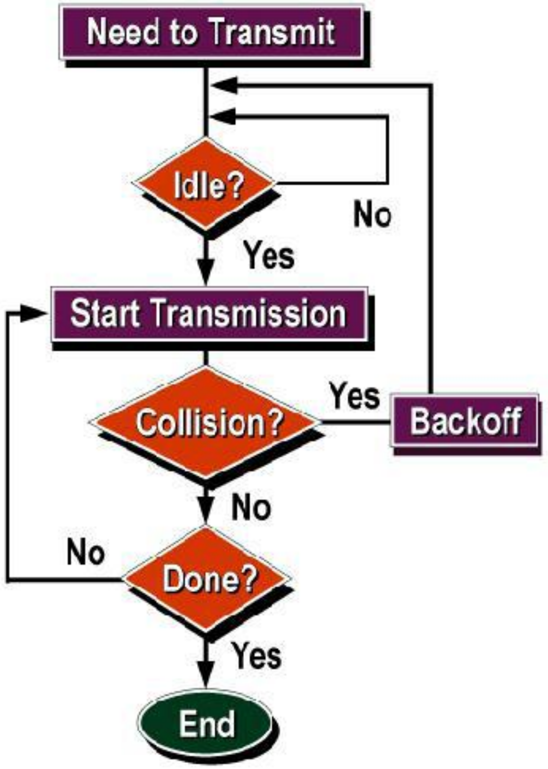
c. p-persistent

CSMA with Collision Detection (CSMA/CD)

- In this protocol, the station senses the channel before transmitting the frame. If the channel is busy, the station waits.
- Additional feature in CSMA/CD is that the stations can detect collisions.
- The stations abort their transmission as soon as they detect collision.
- This feature is not present in CSMA.
- The stations continue to transmit even though they find that collision has occurred.

CSMA with Collision Detection (CSMA/CD)

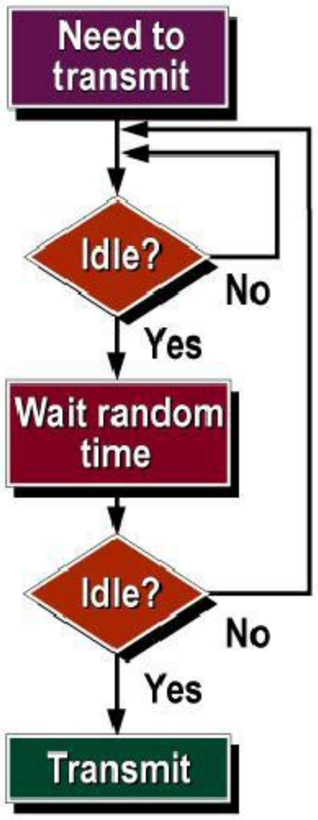
- In CSMA/CD, the station that sends its data on the channel, continues to sense the channel even after data transmission.
- If collision is detected, the station aborts its transmission and waits for a random amount of time & sends its data again.
- As soon as a collision is detected, the transmitting station release a jam signal.
- Jam signal alerts other stations. Stations are not supposed to transmit immediately after the collision has occurred.



CSMA with Collision Avoidance (CSMA/CA)

- This protocol is used in wireless networks because they cannot detect the collision.
- So, the only solution is collision avoidance.
- It avoids the collision by using three basic techniques:

1. Interframe Space (IFS)
2. Contention Window
3. Acknowledgements



(CSMA/CA) : Interframe Space

- Whenever the channel is found idle, the station does not transmit immediately.
- It waits for a period of time called Interframe Space (IFS).
- When channel is sensed idle, it may be possible that some distant station may have already started transmitting.
- Therefore, the purpose of IFS time is to allow this transmitted signal to reach its destination.
- If after this IFS time, channel is still idle, the station can send the frames.

(CSMA/CA) : Contention Window

- Contention window is the amount of time divided into slots.
- Station that is ready to send chooses a random number of slots as its waiting time.
- The number of slots in the window changes with time.
- It means that it is set of one slot for the first time, and then doubles each time the station cannot detect an idle channel after the IFS time.
- In contention window, the station needs to sense the channel after each time slot.

(CSMA/CA) : Acknowledgment

- Despite all the precautions, collisions may occur and destroy the data.
- Positive acknowledgement and the time-out timer helps guarantee that the receiver has received the frame.