Media Access Control Protocols

Unit 6

Types of link

- Dedicated link Point to point link
  e.g. Internet using Point-to-point protocol
- Not dedicated link Broadcast Link
  e.g. Cellular phone

Data Link Layer

- Divided into two sub-layers according to the function.

1. Logical Link Control (LLC) Layer
2. Media Access Control (MAC) Layer

Logical Link Control (LLC) sub-layer

- Upper layer of data link layer
- Responsible for frame synchronization, flow and error control

MAC sub-layer

Background

- In the data link layer protocols we have studied earlier, we assumed that a link was associated with only two nodes (dedicated nodes).
- When a channel is shared among many nodes, the problem arises as to when each node should access the channel. This is the multiple-access problem.
- Many solutions exist!
- Networks with multi access channels
  - LANs (copper and fiber)
  - satellite networks
  - packet radio network

Media Access Control (MAC) Sub-Layer

- Lower layer of data link layer
- Responsible for **multiple access resolution** i.e. when nodes or stations are connected and use a common/shared link, called a multipoint or broadcast link, we need multiple access protocol to access to the link

Multiple access protocols

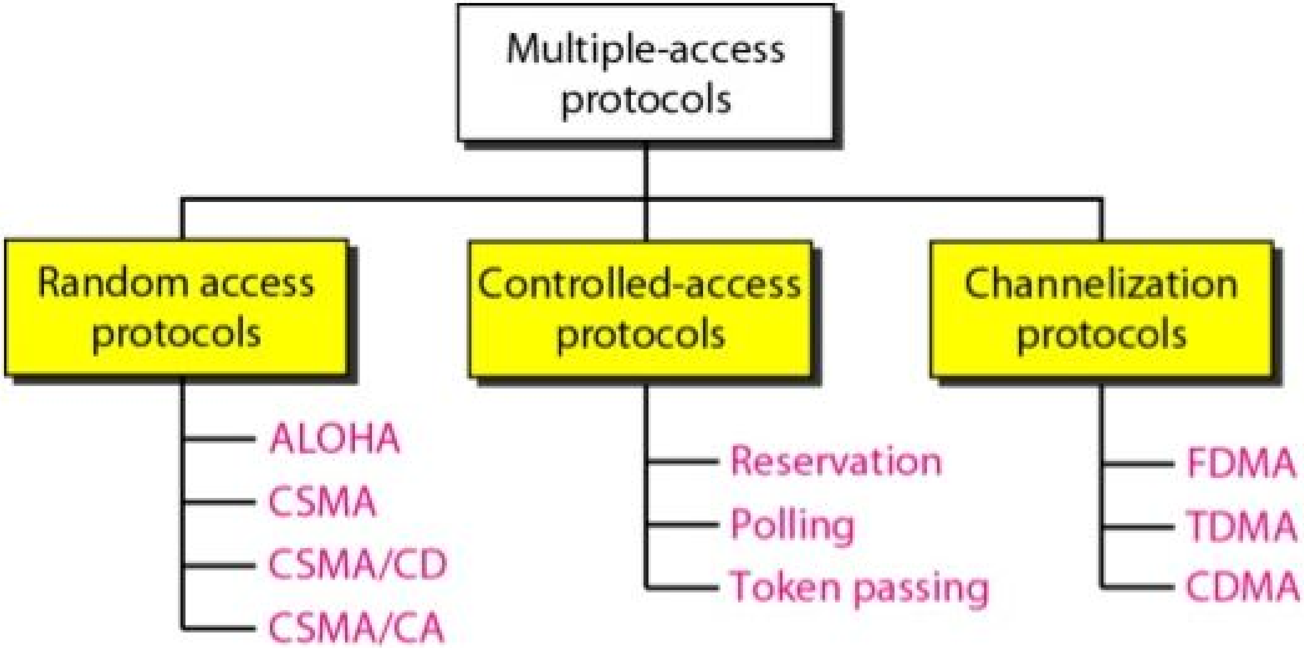


Figure: Types of Multiple Access Protocol

Random Access/Contention Method

- All stations have equal priority to send frame over the channel and no stations have control over another stations.
- At each instance, a stations that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send. The decision is based on the state of medium, busy or idle.

Two features of this protocol

1. There is no schedule time for a station to transmit. Transmission is random among the stations. Hence, named **random access.**
2. No rules specify which station should send next. Stations compete with each another to access the medium. Hence, the name **contention method**

Problem

- When more than one stations tries to send data, there is an access conflict-collision and the frames will be collide and destroyed.
- To avoid these each stations follows a procedure that answers the following questions:
  - ❖ When can the stations access the medium?
  - ❖ What can the station do if the medium is busy?
  - ❖ How can the stations determine the success or failure of the transmission?
  - ❖ What can the station do if there is an access conflict?

Random Access Protocols

- ALOHA
- Carrier Sense Multiple Access with Collision Detection (CSMA/CD)
- Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

ALOHA

- It was developed in the 1970s by Norman Abramson and his colleagues at the University of Hawaii.
- The original system used for ground based radio broadcasting, but the system has been implemented in satellite communication systems.
- In the ALOHA system, a node transmits whenever data is available to send. If another node transmits at the same time, a collision occurs, and the frames that were transmitted are lost. However, a node can listen to broadcasts on the medium, even its own, and determine whether the frames were transmitted.

- Two types:

1. Pure ALOHA
2. Slotted ALOHA

Pure ALOHA

- In pure ALOHA, the stations transmit frames whenever they have data to send.
- When two or more stations transmit simultaneously, there is collision and the frames are destroyed.
- In pure ALOHA, whenever any station transmits a frame, it expects the acknowledgement from the receiver.
- If acknowledgement is not received within specified time, the station assumes that the frame (or acknowledgement) has been destroyed.
- If the frame is destroyed because of collision the station waits for a random amount of time and sends it again. This waiting time must be random otherwise same frames will collide again and again.
- Therefore pure ALOHA dictates that when time-out period passes, each station must wait for a random amount of time before resending its frame. This randomness will help avoid more collisions.

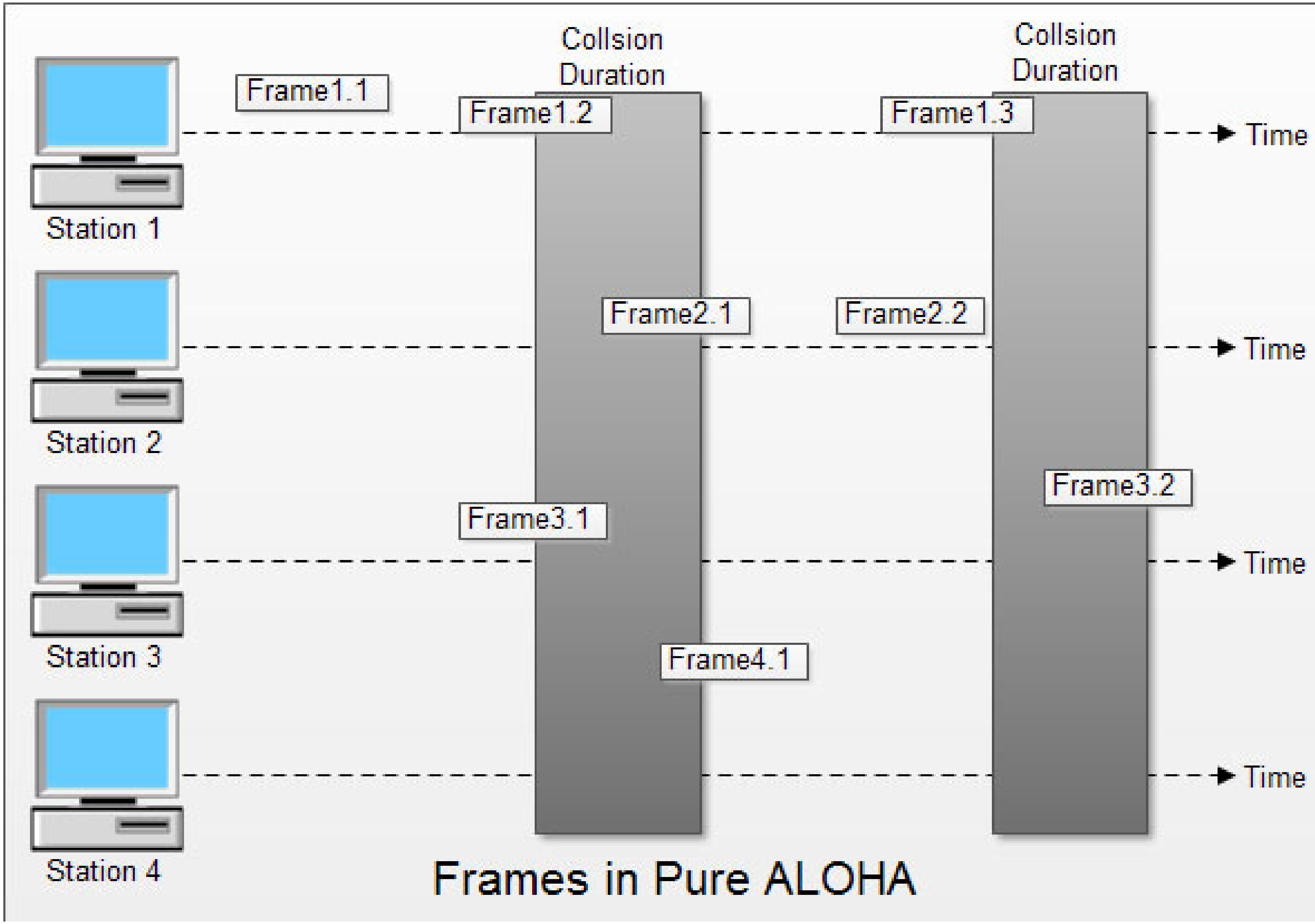
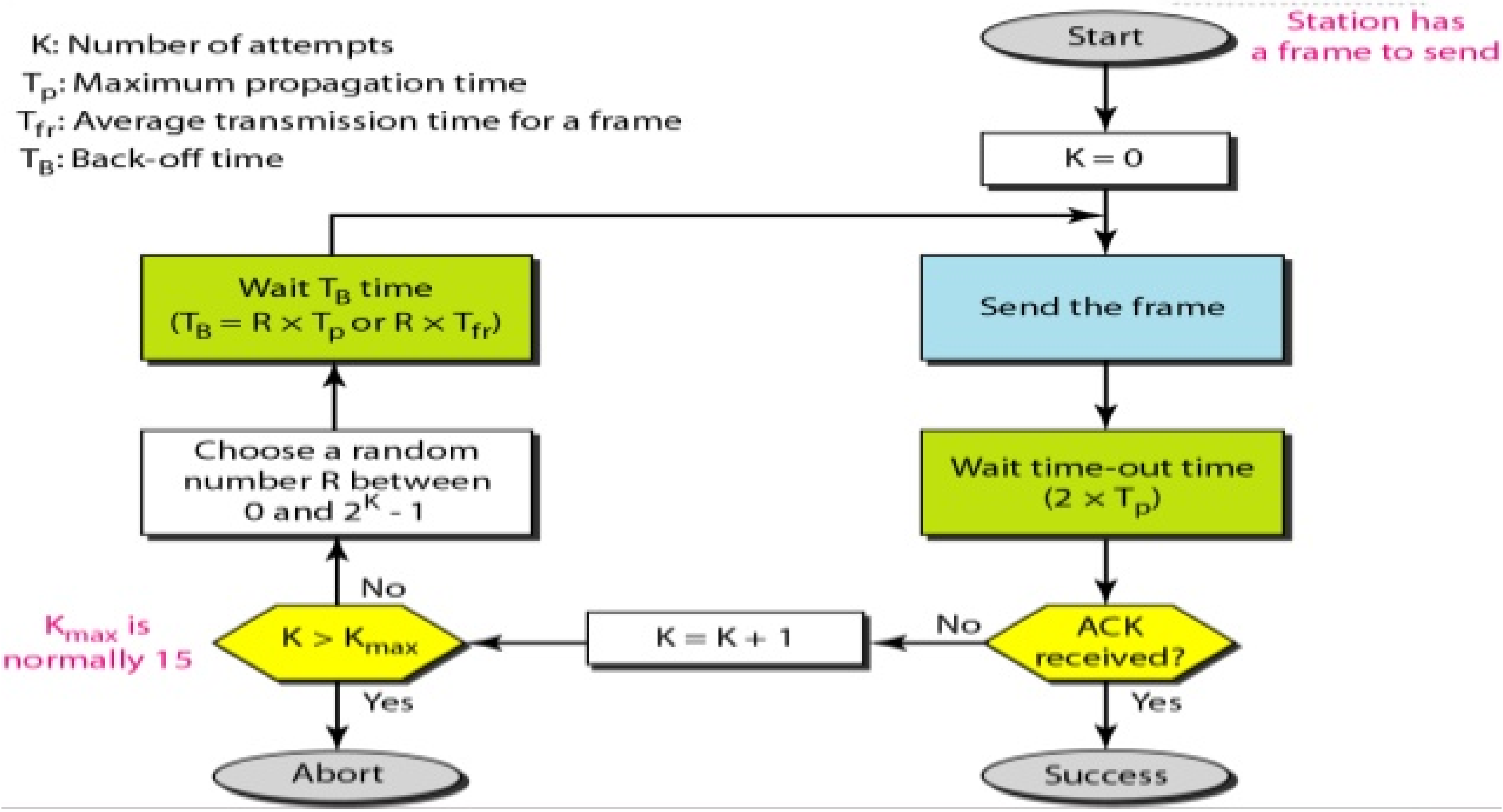


Figure: Collision example in Pure Aloha

- In figure there are four stations that are contended with one another for access to shared channel. All these stations are transmitting frames. Some of these frames collide because multiple frames are in contention for the shared channel. Only two frames, frame 1.1 and frame 2.2 survive. All other frames are destroyed.
- Whenever two frames try to occupy the channel at the same time, there will be a collision and both will be damaged. If first bit of a new frame overlaps with just the last bit of a frame almost finished, both frames will be totally destroyed and both will have to be retransmitted.

Figure : Procedure for pure ALOHA protocol

- Pure ALOHA has second method to prevent congesting the channel with retransmission. After a maximum number of retransmission attempts $K_{max.}$ A station must give up and try later.



Example

- The station on wireless network on ALOHA is 600 km apart. If we assume a signal propagate at 3 * 10^8 m/s the T_p = d/v = (600*1000)/ (3*10^8) = 2 ms. We find TB for different value of k:

a. For $K = 1$, the range is {0, 1}. The station needs to generate a random number with a value of 0 or 1. This means that T_B is either ms (0 x 2) or 2 ms (1 x 2), based on the outcome of the random variable.

b. For $K = 2$, the range is {0, 1, 2, 3}. This means that T_B can be 0, 2, 4, or 6 ms, based on the outcome of the random variable.

c. For $K = 3$, the range is {0, 1, 2, 3, 4, 5, 6, 7}. This means that T_B can be 0, 2, 4, … , 14 ms, based on the outcome of the random variable.

d. We need to mention that if $K > 10$, it is normally set to 10.

Vulnerable Time

- The length of time, in which there is possibility of collision.
- Vulnerable time of pure ALOHA = 2 * T_{fr}

  where

  T_{fr} = time to send a fixed-length frame by a station

This means that no station should send later than T_{fr} before the station starts transmission and no stations starts sending during T_{fr} period that the station is sending.

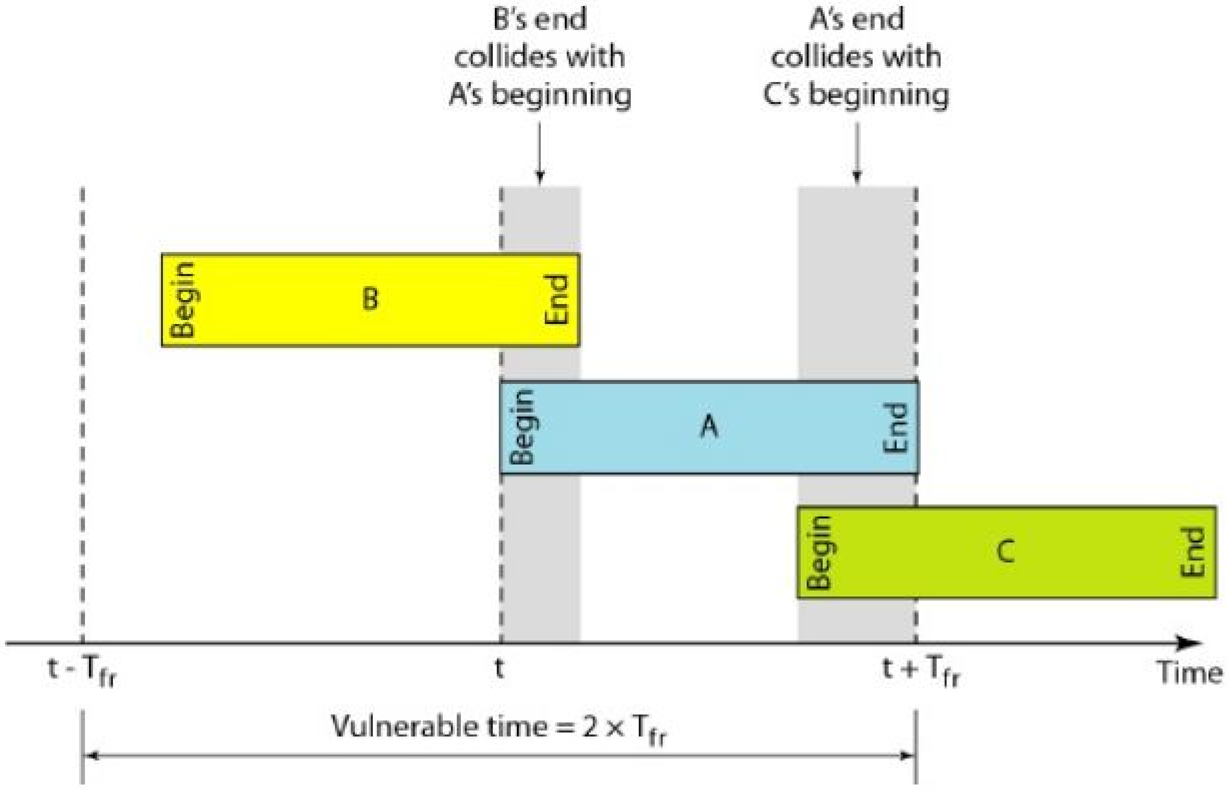


Figure: Vulnerable Time for pure ALOHA protocol

Example

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

Solution

- Average transmission time T_{fr} is 200 bits/200kbps or 1ms. The vulnerable time = 2ms. This means no station should send later than 1 ms before this station starts transmission and no station should start sending during the 1 ms period that this station is sending.

Throughput

- Let G average number of frames generated by the station in one frame transmission time.
- Throughput, $S = G * e^{-2G}$
- Maximum S = 0.184 when G = ½
- That is if one-half frame is generated in one frame transmission time (in other word, one frame in two transmission time) then, 18.4 percent of these frame can reach the destination successfully.

Example

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

Solution

The frame transmission time is *2001200* kbps or 1 ms.

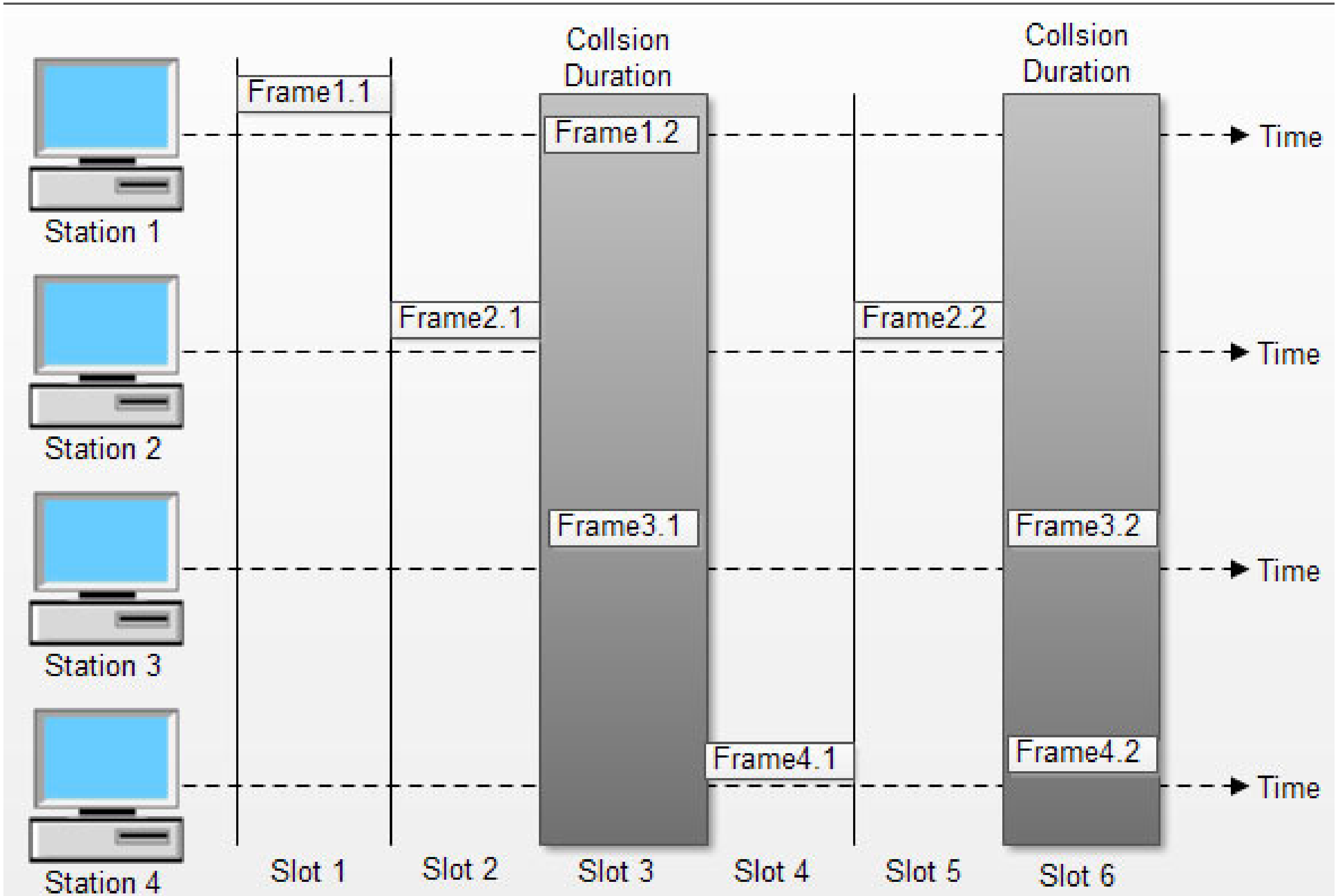
a. If the system creates 1000 frames per second, this is 1 frame per millisecond. The load is 1. In this case S = G x e^{-2G} or S = 0.135 (13.5 percent). This means that the throughput is 1000 x 0.135 = 135 frames. Only 135 frames out of 1000 will probably survive.

b. If the system creates 500 frames per second, this is (1/2) frame per millisecond. The load is *(112)*. In this case S = G x 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 x 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

- Slotted ALOHA was invented to improve the efficiency of pure ALOHA as chances of collision in pure ALOHA are very high.
- In slotted ALOHA, the time of the shared channel is divided into discrete intervals called slots.
- The stations can send a frame only at the beginning of the slot and only one frame is sent in each slot.



Frames in Slotted ALOHA

- In slotted ALOHA, if any station is not able to place the frame onto the channel at the beginning of the slot *i.e.* it misses the time slot then the station has to wait until the beginning of the next time slot.
- In slotted ALOHA, there is still a possibility of collision if two stations try to send at the beginning of the same time slot as shown in figure above.

- Vulnerable time = T_{fr}
- Throughput , $S = G * e^{-2G}$ Smax= .368 when G=1
- i.e. if one frame is generated during one frame transmission time, then 36.8 percent of these frames reach their destination success

Carrier Sense Multiple Access (CSMA)

- CSMA protocol was developed to overcome the problem found in ALOHA i.e. to minimize the chances of collision, so as to improve the performance.
- CSMA protocol is based on the principle of 'carrier sense'. The station senses the carrier or channel before transmitting a frame. It means the station checks the state of channel, whether it is idle or busy.
- Even though devices attempt to sense whether the network is in use, there is a good chance that two stations will attempt to access it at the same time.
- The chances of collision still exist because of propagation delay. The frame transmitted by one station takes some time to reach other stations. In the meantime, other stations may sense the channel to be idle and transmit their frames. This results in the collision.

Vulnerable Time for CSMA

- The vulnerable time for CSMA = propagation time (T_p).
- Propagation time is the time needed for a signal to propagate from one end of medium to the other.
- When a station sends a frame, and any other stations tries to send a frame during this time, a collision will result.

Three Different Type of CSMA Protocols

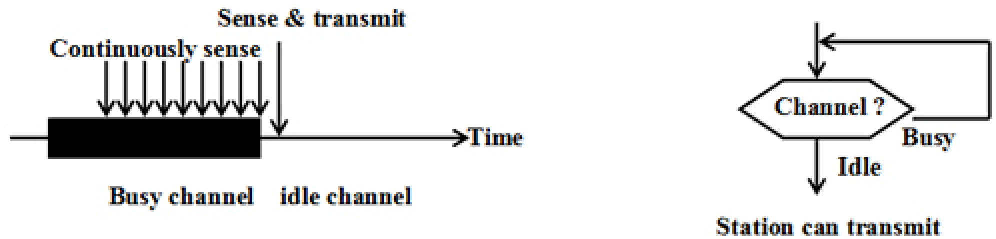
(I) 1-persistent CSMA

(ii) Non- Persistent CSMA

(iii) p-persistent CSMA

1-persistent Method

- In this method, station that wants to transmit data continuously senses the channel to check whether the channel is idle or busy.
- If the channel is busy, the station waits until it becomes idle.
- When the station detects an idle-channel, it immediately transmits the frame with probability 1. Hence it is called 1-persistent CSMA.
- This method has the highest chance of collision because two or more stations may find channel to be idle at the same time and transmit their frames.
- When the collision occurs, the stations wait a random amount of time and start allover again.



1-persistent CSMA

Drawback of I-persistent

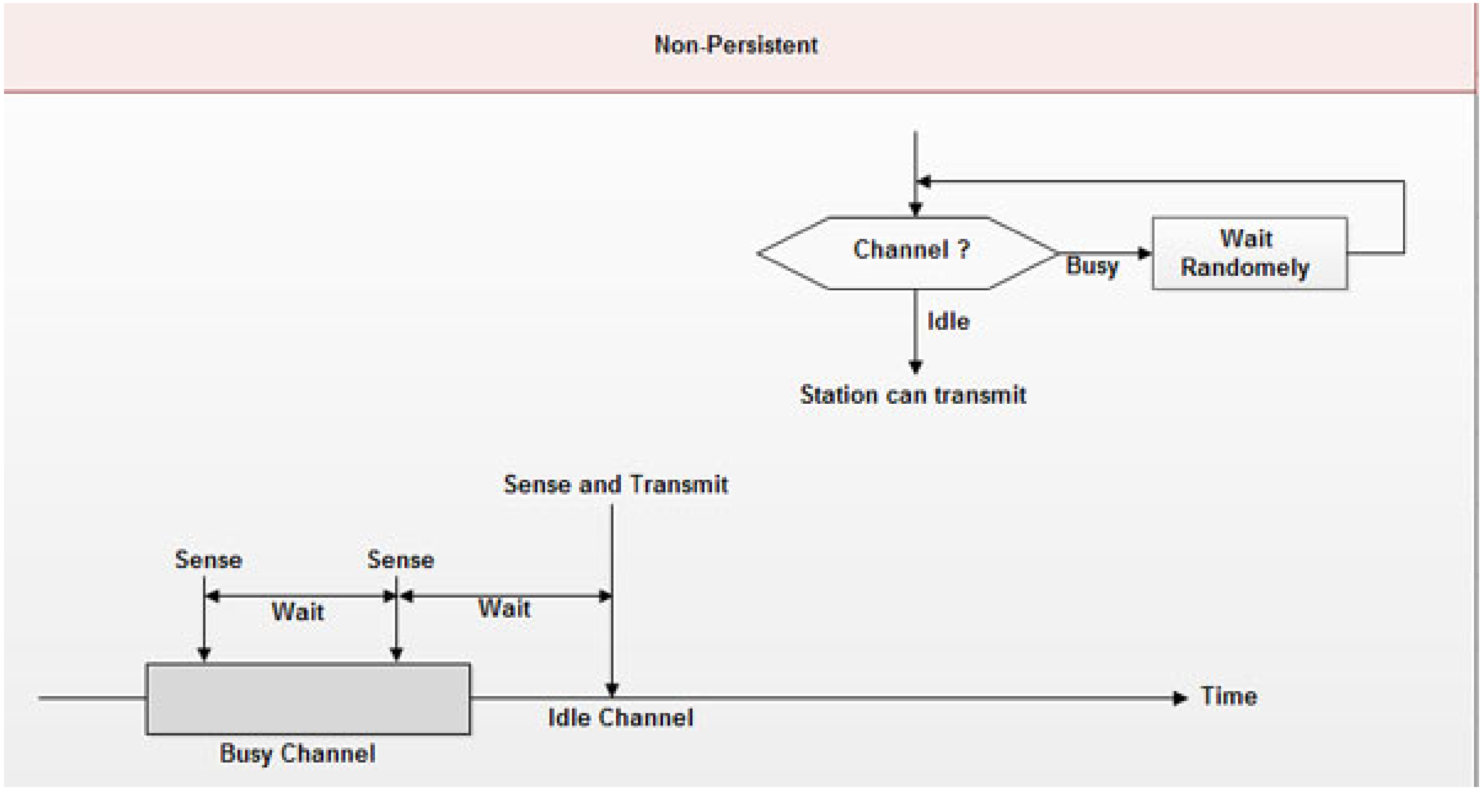
- The propagation delay time greatly affects this protocol. Let us suppose, just after the station I begins its transmission, station 2 also became ready to send its data and senses the channel. If the station I signal has not yet reached station 2, station 2 will sense the channel to be idle and will begin its transmission. This will result in collision.

- Even if propagation delay time is zero, collision will still occur. If two stations became ready in the middle of third station's transmission, both stations will wait until the transmission of first station ends and then both will begin their transmission exactly simultaneously. This will also result in collision.

Non-persistent Method

In this scheme:

- A station that has a frame to send senses the channel.
- If the channel is idle, it sends immediately.
- If the channel is busy, it waits a random amount of time and then senses the channel again.
- In non-persistent CSMA the station does not continuously sense the channel for the purpose of capturing it when it detects the end of previous transmission.


Non-Persistent
Channel ?
Busy
Wait Randomely
Idle
Station can transmit
Sense and Transmit
Sense
Sense
Wait
Wait
Time
Idle Channel
Busy Channel

Advantage

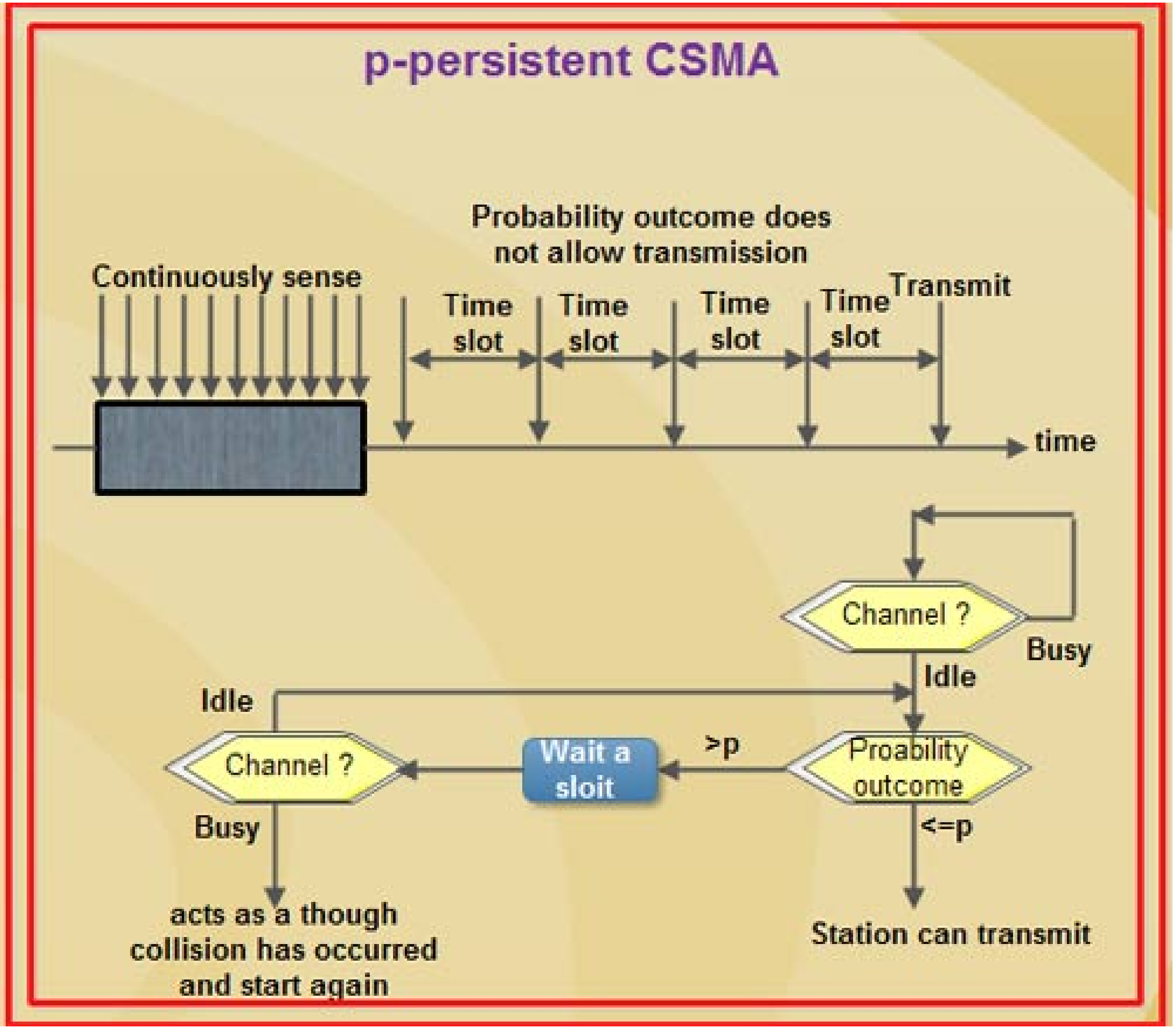
- It reduces the chance of collision because the stations wait a random amount of time. It is unlikely that two or more stations will wait for same amount of time and will retransmit at the same time.

Disadvantage

- It reduces the efficiency of network because the channel remains idle when there may be stations with frames to send. This is due to the fact that the stations wait a random amount of time after the collision.

P-persistent Method

- This method is used when channel has time slots such that the time slot duration is equal to or greater than the maximum propagation delay time.
- Whenever a station becomes ready to send, it senses the channel.
- If channel is busy, station waits until next slot.
- If channel is idle, it transmits with a probability p.
- With the probability q=1-p, the station then waits for the beginning of the next time slot.
- If the next slot is also idle, it either transmits or waits again with probabilities p and q.
- This process is repeated till either frame has been transmitted or another station has begun transmitting.
- In case of the transmission by another station, the station acts as though a collision has occurred and it waits a random amount of time and starts again.


p-persistent CSMA
Probability outcome does not allow transmission
Continuously sense
Time slot
Time slot
Time slot
Time slot
Transmit
time
Channel ?
Busy
Idle
Idle
Channel ?
Wait a sloit
>p
Proability outcome
<=p
Busy
acts as a though collision has occurred and start again
Station can transmit

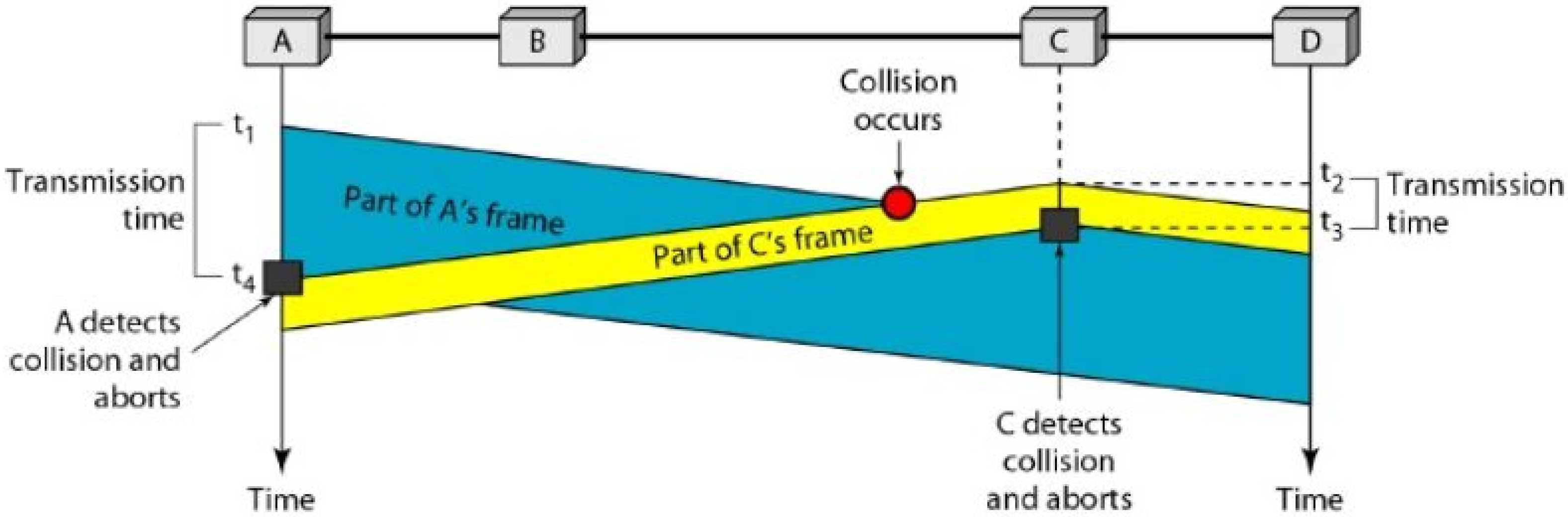
Advantage

- It reduces the chance of collision and improves the efficiency of the network.

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

- It is the modification of pure CSMA.
- It is MAC protocol that defines how network devices respond when two devices attempt to use a data channel simultaneously and encounter a data collision. The CSMA/CD rules define how long the device should wait if a collision occurs.

Collision and Abortion in CSMA/CD



Main Procedure

- The following procedure is used to initiate a transmission. The procedure is complete when the frame is transmitted successfully or a collision is detected during transmission.

1. Is my frame ready for transmission? If yes, it goes on to the next point.
2. Is medium idle? If not, wait until it becomes ready.
3. Start transmitting and monitor for collision during transmission
4. Did a collision occur? If so, go to collision detected procedure.
5. Reset retransmission counters and end frame transmission.

Collision Detection Procedure

- The following procedure is used to resolve a detected collision. The procedure is complete when retransmission is initiated or the retransmission is aborted due to numerous collisions.

1. Continue transmission (with a jam signal instead of frame header/data/CRC) until minimum packet time is reached to ensure that all receivers detect the collision
2. Increment retransmission counter
3. Was the maximum number of transmission attempts reached? If so, abort transmission.
4. Calculate and wait random backoff period based on number of collisions.
5. Re-enter main procedure at stage 1.

Jam Signal

- The **jam signal** or **jamming signal** is a signal that carries a 32-bit binary pattern sent by a data station to inform the other stations of the collision and that they must not transmit.

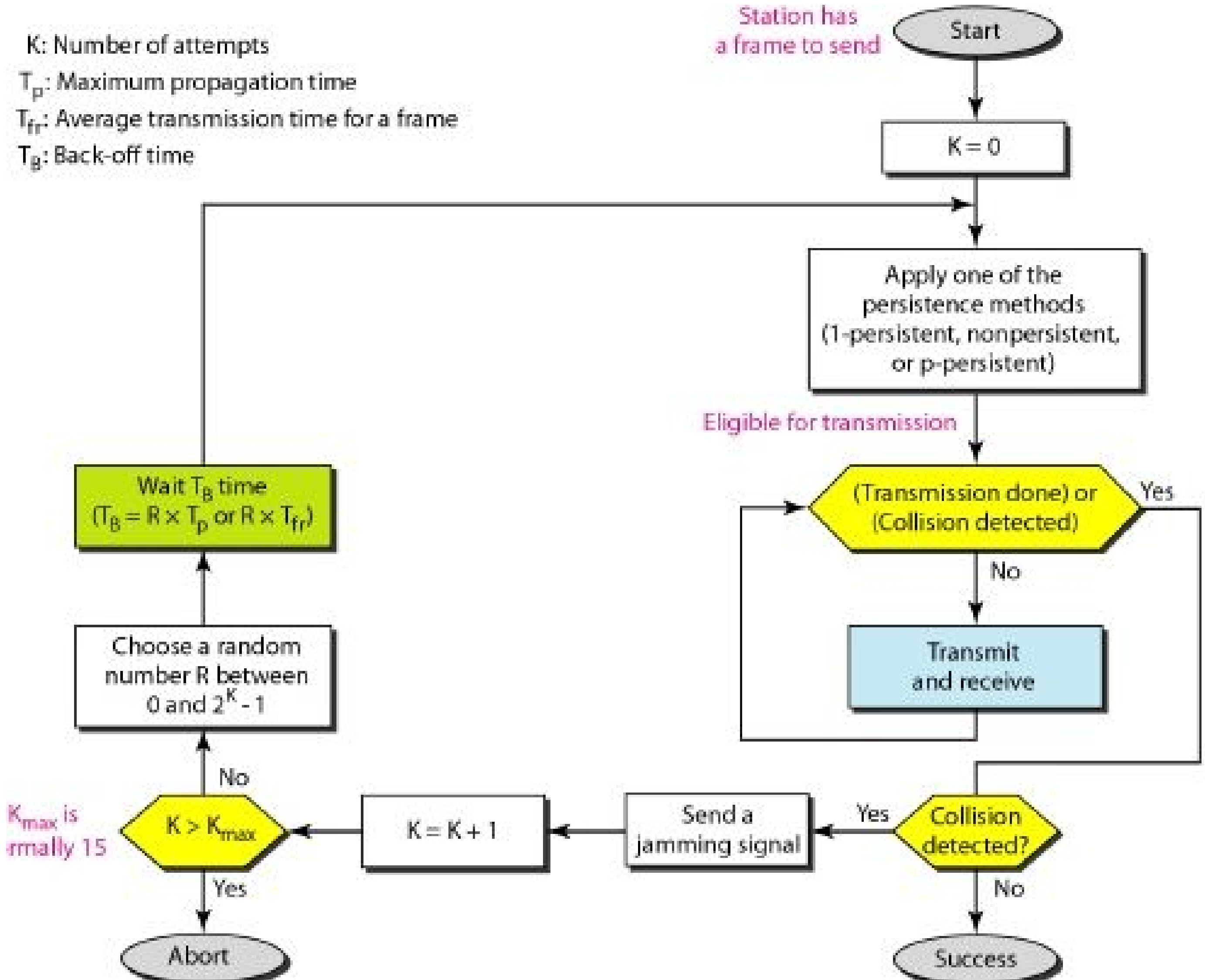


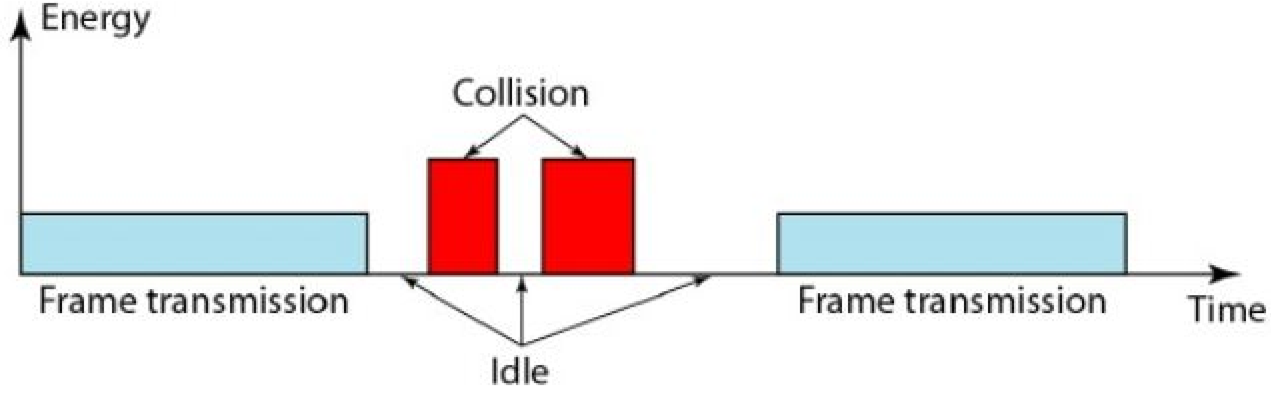
Figure: Flow Diagram of CSMA/CD

Energy Level

Energy level in a channel can have three levels: zero, normal and abnormal.

- At the zero level, the channel is idle.
- At the normal level, the station has successfully captured the channel and is sending its frame.
- At the abnormal level, there is a collision and the level of energy is twice the normal level.

A station that has a frame to send or is sending a frame needs to monitor the energy level to determine if the channel is idle, busy or in collision mode.



Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

- CSMA/CA is a network multiple access method in which carrier sensing is used, but nodes attempt to avoid collisions by transmitting only when the channel is sensed to be "idle“.
- CSMA/CA protocol is used in wireless networks because they cannot detect the collision so the only solution is collision avoidance.
- CSMA/CA avoids the collisions using three basic techniques.

(i) Inter-frame space

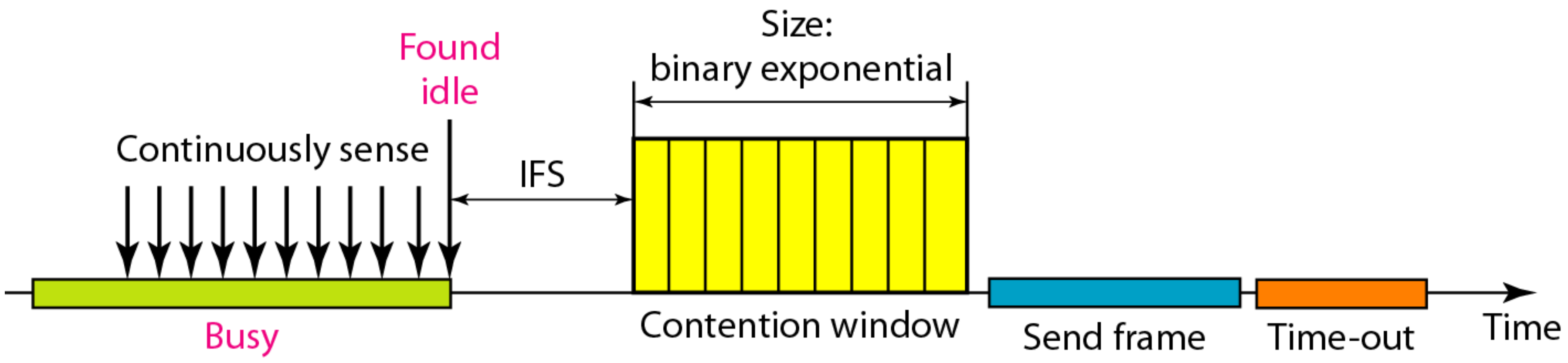
(ii) Contention window

(iii) Acknowledgements

Interframe Space (IFS)

- 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 to be idle, it may be possible that same distant station may have already started transmitting and the signal of that distant station has not yet reached other stations.
- Therefore the purpose of IFS time is to allow this transmitted signal to reach other stations.
- If after this IFS time, the channel is still idle, the station can send, but it still needs to wait a time equal to contention time.
- IFS variable can also be used to define the priority of a station or a frame.

Figure: Timing in CSMA/CA



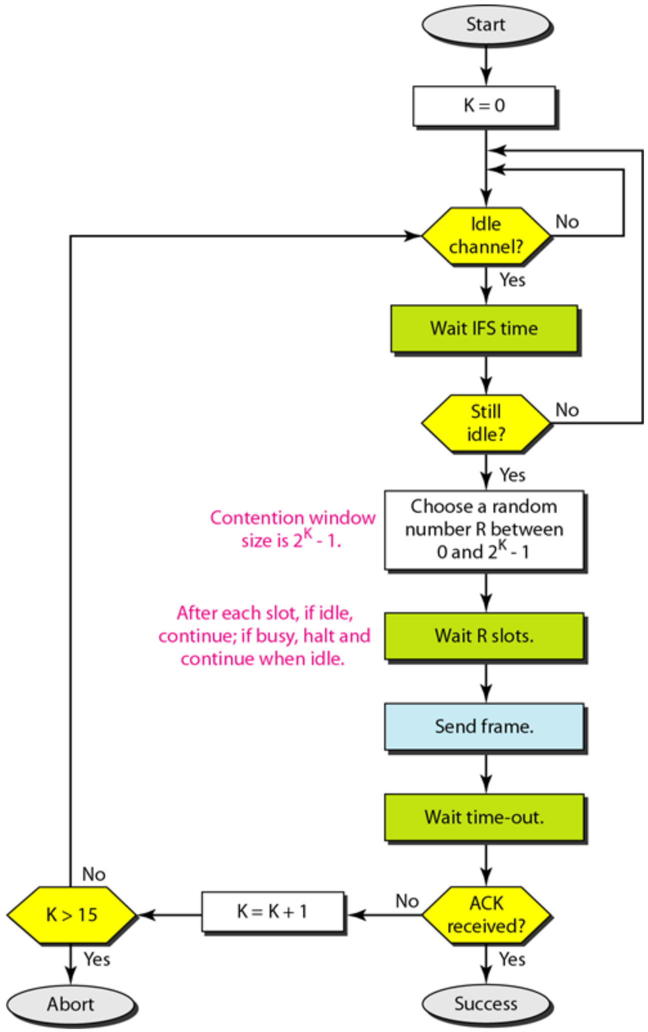
Contention Window

- Contention window is an amount of time divided into slots.
- A station that is ready to send chooses a random number of slots as its wait time.
- The number of slots in the window changes according to the binary exponential back-off strategy. It means that it is set of one slot the first time and then doubles each time the station cannot detect an idle channel after the IFS time.
- This is very similar to the p-persistent method except that a random outcome defines the number of slots taken by the waiting station.
- In contention window the station needs to sense the channel after each time slot.
- If the station finds the channel busy, it does not restart the process. It just stops the timer & restarts it when the channel is sensed as idle.

Acknowledgment

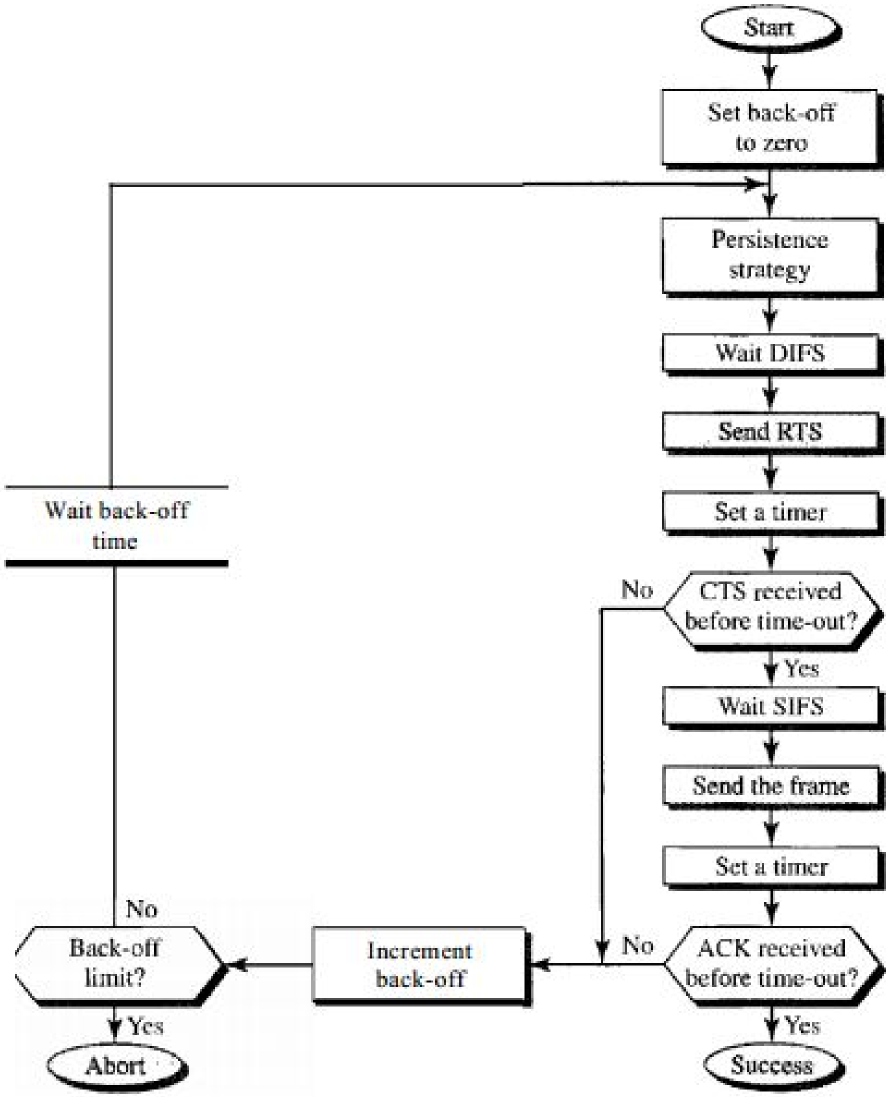
- Despite all the precautions, collisions may occur and destroy the data.
- The positive acknowledgment and the time-out timer can help guarantee that receiver has received the frame.

Figure: Flow diagram of CSMA/CA



- This is the CSMA protocol with collision avoidance.
- The station ready to transmit, senses the line by using one of the persistent strategies.
- As soon as it find the line to be idle, the station waits for an IFG (Interframe gap) amount of time.
- If then waits for some random time and sends the frame.
- After sending the frame, it sets a timer and waits for the acknowledgement from the receiver.
- If the acknowledgement is received before expiry of the timer, then the transmission is successful.
- But if the transmitting station does not receive the expected acknowledgement before the timer expiry then it increments the back off parameter, waits for the back off time and re-senses the line.

CSMA/CA



Start
Set back-off to zero
Persistence strategy
Wait DIFS
Send RTS
Set a timer
CTS received before time-out?
No
Yes
Wait SIFS
Send the frame
Set a timer
ACK received before time-out?
No
Yes
Success
Increment back-off
Back-off limit?
No
Yes
Abort
Wait back-off time

1. Before sending a frame, the source station senses the medium by checking the energy level at the carrier frequency.
   a. The channel uses a persistence strategy with back-off until the channel is idle.
   b. After the station is found to be idle, the station waits for a period of time called the distributed interframe space (DIFS); then the station sends a control frame called the request to send (RTS).
2. After receiving the RTS and waiting a period of time called the short interframe space (SIFS), the destination station sends a control frame, called the clear to send (CTS), to the source station. This control frame indicates that the destination station is ready to receive data.
3. The source station sends data after waiting an amount of time equal to SIFS.
4. The destination station, after waiting an amount of time equal to. SIFS, sends an acknowledgment to show that the frame has been received. Acknowledgment is needed in this protocol because the station does not have any means to check for the successful arrival of its data at the destination. On the other hand, the lack of collision in *CSMAICD* is a kind of indication to the source that data have arrived.

Collision Avoidance

- 802.11 standard uses **Network Allocation Vector (NAV)** for collision avoidance.

The procedure used in NAV is explained below:

1. Whenever a station sends an RTS frame, it includes the duration of time for which the station will occupy the channel.
2. All other stations that are affected by the transmission creates a timer called network allocation vector (NAV).
3. This NAV (created by other stations) specifies for how much time these stations must not check the channel.
4. Each station before sensing the channel, check its NAV to see if has expired or not.
5. If its NA V has expired, the station can send data, otherwise it has to wait.

- There can also be a **collision during handshaking** *i.e.* when RTS or CTS control frames are exchanged between the sender and receiver. In this case following procedure is used for collision avoidance:

1. When two or more stations send RTS to a station at same time, their control frames collide.
2. If CTS frame is not received by the sender, it assumes that there has been a collision.
3. In such a case sender, waits for back off time and retransmits RTS.