1. INTRODUCTION

Data link layer is divided into two sub layers:

- **Logical link control (LLC) layer**: The upper sub layer is responsible for data link control i.e. for flow and error control.
- **Media access control (MAC) layer**: The lower sub layer is responsible for resolving access to the shared media.

If the channel is dedicated, we do not need the lower sub layer. Figure 12.1 shows these two sub layers in the data link layer.

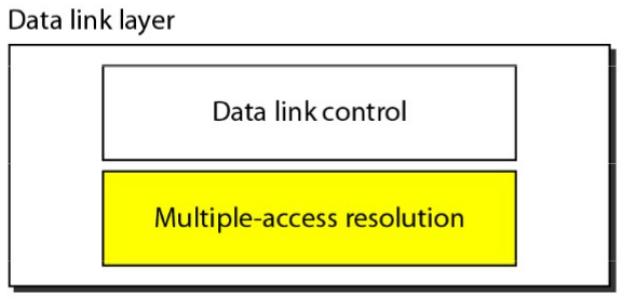

Figure 12.1 Data link layer divided into two functionality-oriented sub layers

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. The problem of controlling the access to the medium is similar to the rules of speaking in an assembly. The procedures guarantee that the right to speak is upheld and ensure that two people do not speak at the same time, do not interrupt each other, do not monopolize the discussion, and so on. The situation is similar for multipoint networks. Many formal protocols have been devised to handle access to a shared link. We categorize them into three groups. Protocols belonging to each group are shown in Figure 12.2.

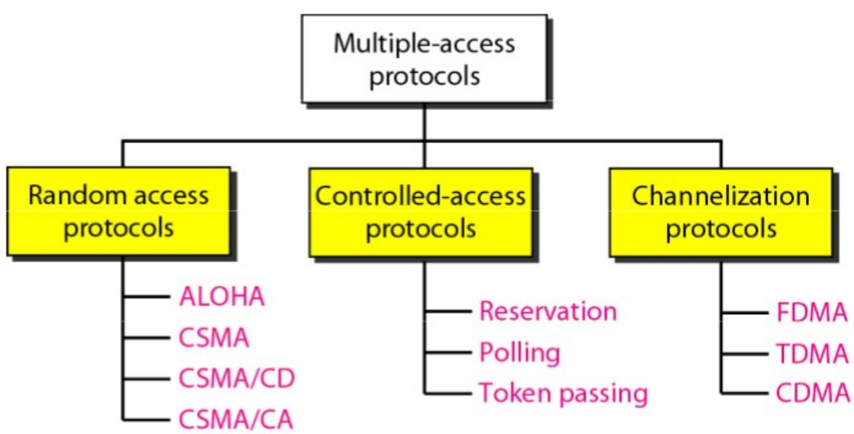

Figure 12.2 Taxonomy of multiple-access protocols discussed in this chapter

2. RANDOM ACCESS PROTOCOLS

In random access or contention methods, no station is superior to another station and none is assigned the control over another. No station permits, or does not permit, another station to send. At each instance, a station that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send. This decision depends on the state of the medium (idle or busy). In other words, each station can transmit when it desires on the condition that it follows the predefined procedure, including the testing of the state of the medium. Two features give this method its name.

- First, there is no scheduled time for a station to transmit. Transmission is random among the stations. That is why these methods are called random access.
- Second, no rules specify which station should send next. Stations compete with one another to access the medium. That is why these methods are also called contention methods.

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?

Following section explains each protocol under random access category:

2.1. ALOHA

ALOHA, the earliest random access method was developed at the University of Hawaii in early 1970. It was designed for a radio (wireless) LAN, but it can be used on any shared medium. It is obvious that there are potential collisions in this arrangement. The medium is shared between the stations. When a station sends data, another station may attempt to do so at the same time. The data from the two stations collide and become garbled. There are two variations of ALOHA protocol:

2.1.1. Pure ALOHA

The original ALOHA protocol is called *pure ALOHA*. This is a simple, but elegant protocol. The idea is that each station sends a frame whenever it has a frame to send. However, since there is only one channel to share, there is the possibility of collision between frames from different stations. Figure 12.3 shows an example of frame collisions in pure ALOHA.

There are four stations (unrealistic assumption) that contend with one another for access to the shared channel. The figure shows that each station sends two frames; there are a total of eight frames on the shared medium. Some of these frames collide because multiple frames are in contention for the shared channel. Figure 12.3 shows that only two frames survive: frame 1.1 from station 1 and frame 3.2 from station 3. We need to mention that even if one bit of a frame coexists on the channel with one bit from another frame, there is a collision and both will be destroyed. It is obvious that we need to resend the frames that have been destroyed during transmission.

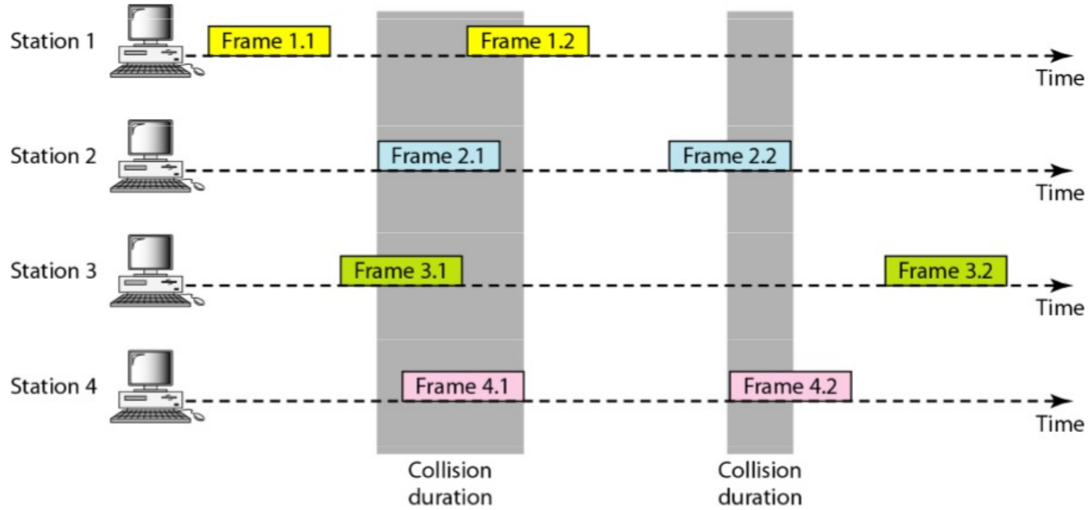

Figure 12.3 Frames in a pure ALOHA network

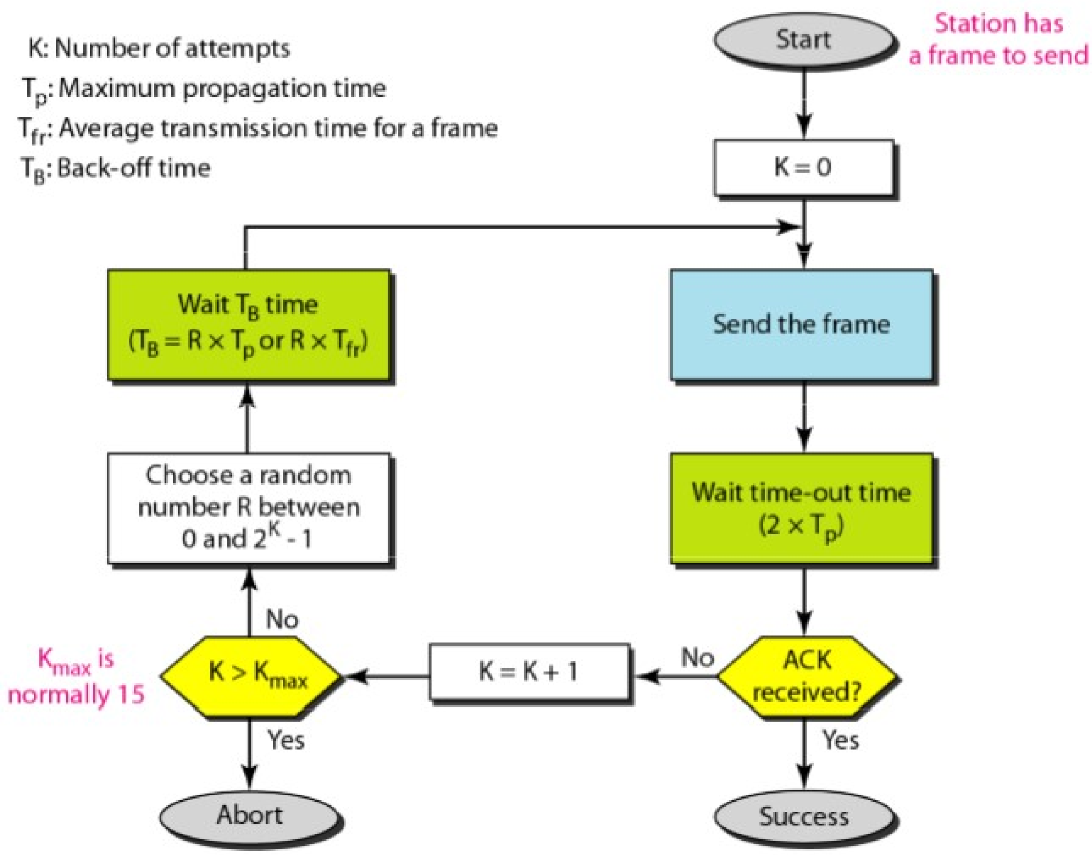

Figure 12.4 Procedure for pure ALOHA protocol

The pure ALOHA protocol relies on acknowledgments from the receiver. When a station sends a frame, it expects the receiver to send an acknowledgment. If the acknowledgment does not arrive after a time-out period, the station assumes that the frame (or the acknowledgment) has been destroyed and resends the frame. 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. Pure ALOHA dictates that when the time-out period passes, each station waits a random amount of time before resending its frame. The randomness will help avoid more collisions. We call this time the back-off time T_B. Pure ALOHA has a second method to prevent congesting the channel with retransmitted frames. After a maximum number of retransmission attempts K_{max} a station must give up and try later. Figure 12.4 shows the procedure for pure ALOHA based on the above strategy.

The time-out period is equal to the maximum possible round-trip propagation delay, which is twice the amount of time required to send a frame between the two most widely separated stations (2 x Tp) The back-off time T_B is a random value that normally depends on K (the number of attempted unsuccessful transmissions). One common formula for calculating T_B is the *binary exponential back-off*. In this method, for each retransmission, a multiplier in the range 0 to $2^K - 1$ is randomly chosen and multiplied by Tp (maximum propagation time) to find T_B. Note that in this procedure, the range of the random numbers increases after each collision. The value of K_{max} is usually chosen as 15.

Example 12.1

The stations on a wireless ALOHA networks are a maximum of 600 km apart. If we assume that signals propagate at 3×10^8 ms, we find $Tp = (600 \times 10^5) / (3 \times 10^8) = 2$ ms. Now we can find the value of T_B for different values 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 0 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.

Vulnerable time

Vulnerable time is the Length of time, in which there is a possibility of collision. We assume that the stations send fixed-length frames with each frame taking T_{fr} s to send.

$$\textit{Pure ALOHA vulnerable time} = 2 \times T_{fr}$$

2.1.2. Slotted ALOHA

Slotted ALOHA was invented to improve the efficiency of pure ALOHA. In slotted ALOHA we divide the time into slots of T_{fr} s(time to send each fixed size frame) and force the station to send only at the beginning of the time slot. Figure 12.5 shows an example of frame collisions in slotted ALOHA.

Because a station is allowed to send only at the beginning of the synchronized time slot, if a station misses this moment, it must wait until the beginning of the next time slot. This means that the station which started at the beginning of this slot has already finished sending its frame. Of course, there is still the possibility of collision if two stations try to send at the beginning of the same time slot.

Vulnerable time

Vulnerable time for slotted ALOHA is one-half that of pure ALOHA i.e.

$$\textit{Slotted ALOHA vulnerable time} = T_{fr}$$

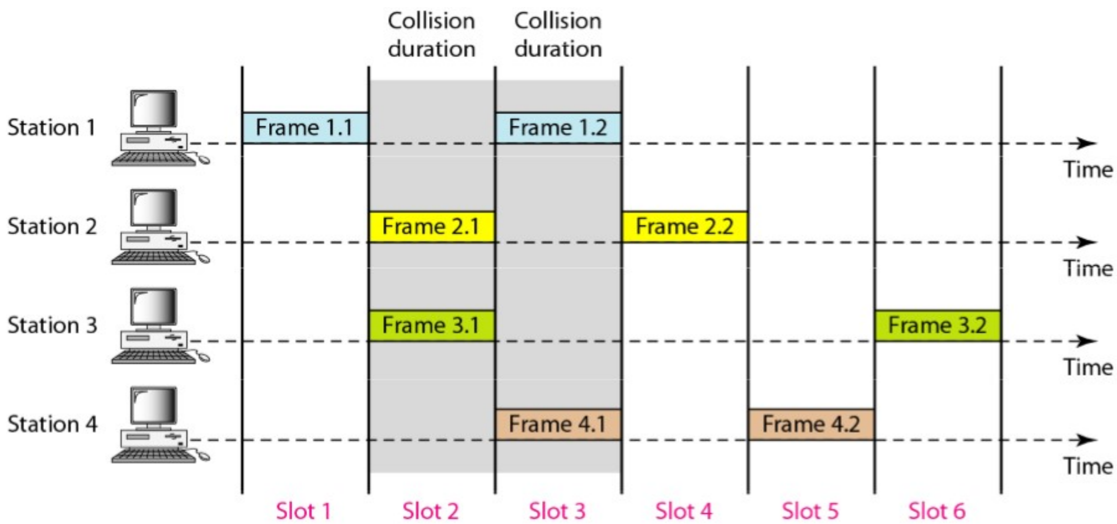

Figure 12.5 Frames in a slotted ALOHA network

2.2. Carrier Sense Multiple Access (CSMA)

To minimize the chance of collision and, therefore, increase the performance, the CSMA method was developed. The chance of collision can be reduced if a station senses the medium before trying to use it. Carrier sense multiple access (CSMA) requires that each station first listen to the medium (or check the state of the medium) before sending. In other words, 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.

Vulnerable Time

The vulnerable time for CSMA is the propagation time Tp. This is the time needed for a signal to propagate from one end of the medium to the other. When a station sends a frame, and any other station tries to send a frame during this time, a collision will result. But if the first bit of the frame reaches the end of the medium, every station will already have heard the bit and will refrain from sending.

Following sub sections explains different variations of CSMA protocols:

2.2.1. 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 to answer these questions:

- 1-persistent method,
- Non-persistent method, and
- P-persistent method.

Figure 12.6 shows the behavior of three persistence methods when a station finds a channel busy.

2.2.1.1. 1-Persistent Method

The 1-persistent method is simple and straightforward. In this method, after the station finds the line idle, it sends its frame immediately (with probability 1). This method has the highest chance of collision because two or more stations may find the line idle and send their frames immediately. Ethernet, a LAN standard uses this method.

2.2.1.2. Non-persistent Method

In the non-persistent 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 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.

2.2.1.3. p-Persistent Method

The p-persistent method is used if the channel has time slots with 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:

(i). with probability p, the station sends its frame.
(ii). 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 **(i)**.
   b. If the line is busy, it acts as though a collision has occurred and uses the backoff procedure.

Figure 12.6 shows the flow diagrams for these methods:

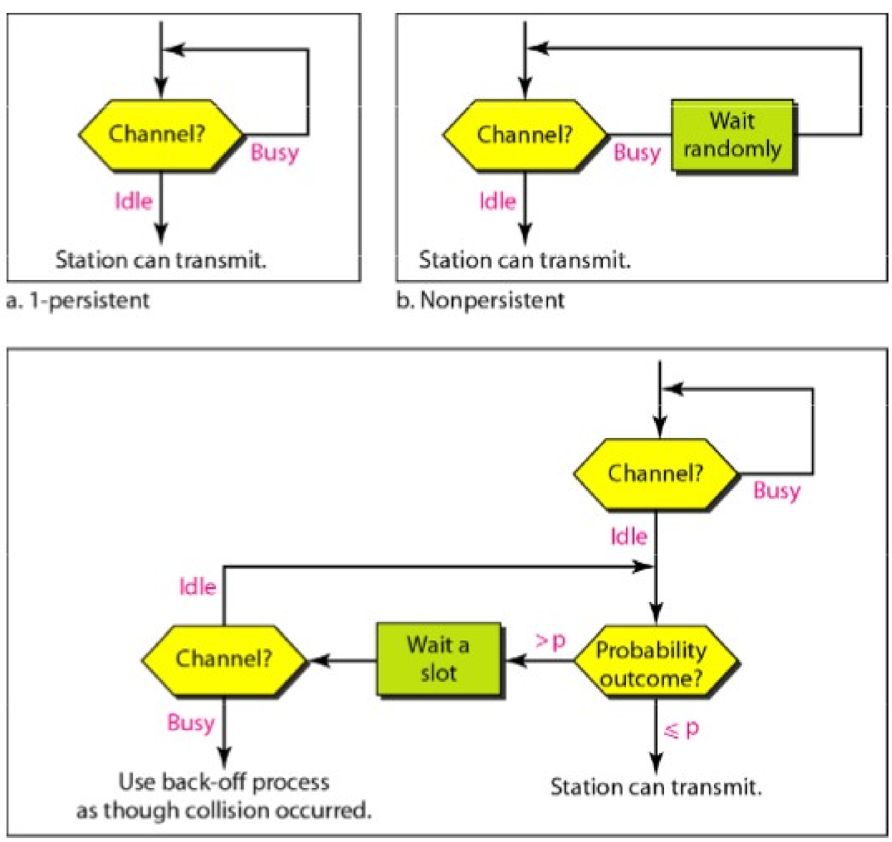

Figure 12.6 Flow diagram for three persistence methods

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

The CSMA method does not specify the procedure following a collision. Carriers sense multiple access with collision detection (CSMA/CD) augments the algorithm to handle the collision.

- In this method, a station monitors the medium after it sends a frame to see if the transmission was successful. If so, the station is finished.
- If, however, there is a collision, the frame is sent again.

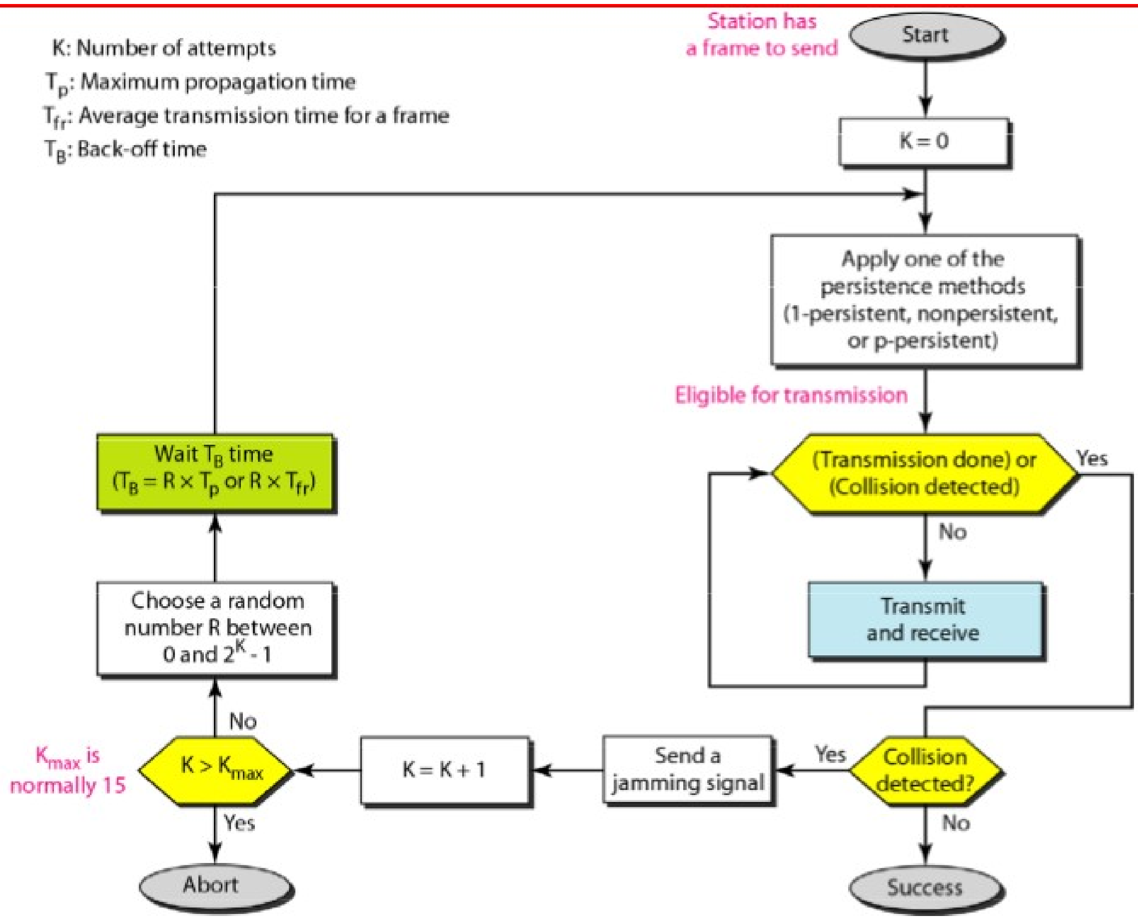

Figure 12.7 Flow diagram for the CSMA/CD

Flow diagram for CSMA/CD is depicted in Figure 12.7. It is similar to the one for the ALOHA protocol, but there are differences:

i. The first difference is the addition of the persistence process. We need to sense the channel before we start sending the frame by using one of the persistence processes we discussed previously (non-persistent, 1-persistent, or p-persistent). The corresponding box can be replaced by one of the persistence processes shown in Figure 12.6.

ii. The second difference is the frame transmission. In ALOHA, we first transmit the entire frame and then wait for an acknowledgment. In CSMA/CD, transmission and collision detection is a continuous process. We do not send the entire frame and then look for a collision. The station transmits and receives continuously and simultaneously (using two different ports). We constantly monitor in order to detect one of two conditions: either transmission is finished or a collision is detected. Either event stops transmission. When we come out of the loop, if a collision has not been detected, it means that transmission is complete; the entire frame is transmitted. Otherwise, a collision has occurred.

iii. The third difference is the sending of a short jamming signal that enforces the collision in case other stations have not yet sensed the collision.

Energy Level

Energy level of a channel is used to monitor the current status of a channel. The level of energy in a channel can have three values: zero, normal, and abnormal.

- At the zero level, the channel is idle.
- At the normal level, a station has successfully captured the channel and is sending its frame.
- At the abnormal level, there is a collision and the level of the 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. Figure 12.8 shows the situation.

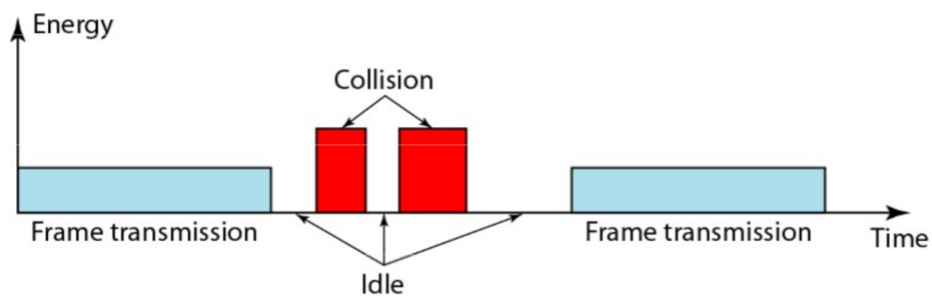

Figure 12.8 Energy level during transmission, idleness, or collision

Throughput

Let us call G the average number of frames generated by the system during one frame transmission time.

- The throughput for **pure ALOHA** is S =G x e-^{2G}. The maximum throughput **Smax =0.184** when G=(1/2).
- The throughput for **slotted ALOHA** is S =: G x e-^{G}. The maximum throughput **Smax = 0.368** when G=1.
- The throughput of **CSMA/CD** is greater than that of pure or slotted ALOHA. The maximum throughput occurs at a different value of G and is based on the persistence method and the value of p in the p-persistent approach.
    - For **1-persistent** method the maximum throughput is around **50** percent when G =1.
    - For **non-persistent** method, the maximum throughput can go up to **90** percent when G is between 3 and 8.