# 4.2 Multiple Access Protocols

Many algorithms for allocating a multiple access channel are known. In the following sections we will study a small sample of the more interesting ones and give some examples of their use.

## 4.2.1 ALOHA

In the 1970s, Norman Abramson and his colleagues at the University of Hawaii devised a new and elegant method to solve the channel allocation problem. Their work has been extended by many researchers since then (Abramson, 1985). Although Abramson's work, called the ALOHA system, used ground-based radio broadcasting, the basic idea is applicable to any system in which uncoordinated users are competing for the use of a single shared channel.

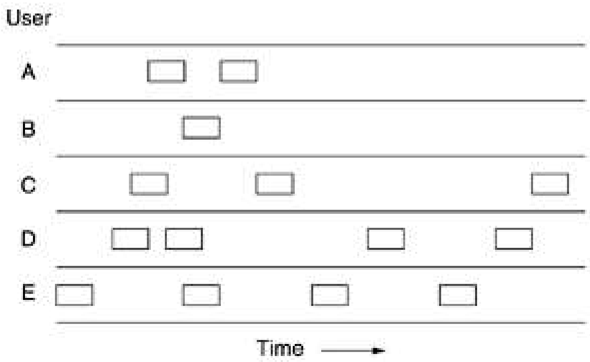
We will discuss two versions of ALOHA here: pure and slotted. They differ with respect to whether time is divided into discrete slots into which all frames must fit. Pure ALOHA does not require global time synchronization; slotted ALOHA does.

### *Pure ALOHA*

The basic idea of an ALOHA system is simple: let users transmit whenever they have data to be sent. There will be collisions, of course, and the colliding frames will be damaged. However, due to the feedback property of broadcasting, a sender can always find out whether its frame was destroyed by listening to the channel, the same way other users do. With a LAN, the feedback is immediate; with a satellite, there is a delay of 270 msec before the sender knows if the transmission was successful. If listening while transmitting is not possible for some reason, acknowledgements are needed. If the frame was destroyed, the sender just waits a random amount of time and sends it again. The waiting time must be random or the same frames will collide over and over, in lockstep. Systems in which multiple users share a common channel in a way that can lead to conflicts are widely known as **contention** systems.

A sketch of frame generation in an ALOHA system is given in Fig. 4-1. We have made the frames all the same length because the throughput of ALOHA systems is maximized by having a uniform frame size rather than by allowing variable length frames.

**_Figure 4-1. In pure ALOHA, frames are transmitted at completely arbitrary times._**




Whenever two frames try to occupy the channel at the same time, there will be a collision and both will be garbled. If the 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 later. The checksum cannot (and should not) distinguish between a total loss and a near miss. Bad is bad.

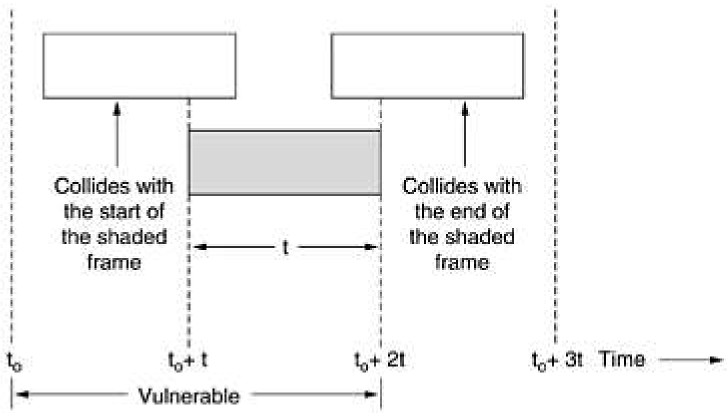
An interesting question is: What is the efficiency of an ALOHA channel? In other words, what fraction of all transmitted frames escape collisions under these chaotic circumstances? Let us first consider an infinite collection of interactive users sitting at their computers (stations). A user is always in one of two states: typing or waiting. Initially, all users are in the typing state. When a line is finished, the user stops typing, waiting for a response. The station then transmits a frame containing the line and checks the channel to see if it was successful. If so, the user sees the reply and goes back to typing. If not, the user continues to wait and the frame is retransmitted over and over until it has been successfully sent.

Let the ''frame time'' denote the amount of time needed to transmit the standard, fixed-length frame (i.e., the frame length divided by the bit rate). At this point we assume that the infinite population of users generates new frames according to a Poisson distribution with mean $N$ frames per frame time. (The infinite-population assumption is needed to ensure that $N$ does not decrease as users become blocked.) If $N > 1$, the user community is generating frames at a higher rate than the channel can handle, and nearly every frame will suffer a collision. For reasonable throughput we would expect $0 < N < 1$.

In addition to the new frames, the stations also generate retransmissions of frames that previously suffered collisions. Let us further assume that the probability of $k$ transmission attempts per frame time, old and new combined, is also Poisson, with mean $G$ per frame time. Clearly, $G \geq N$. At low load (i.e., $N \approx 0$), there will be few collisions, hence few retransmissions, so $G \approx N$. At high load there will be many collisions, so $G > N$. Under all loads, the throughput, $S$, is just the offered load, $G$, times the probability, $P_0$, of a transmission succeeding—that is, $S = GP_0$, where $P_0$ is the probability that a frame does not suffer a collision.

A frame will not suffer a collision if no other frames are sent within one frame time of its start, as shown in Fig. 4-2. Under what conditions will the shaded frame arrive undamaged? Let $t$ be the time required to send a frame. If any other user has generated a frame between time $t_0$ and $t_0 + t$, the end of that frame will collide with the beginning of the shaded one. In fact, the shaded frame's fate was already sealed even before the first bit was sent, but since in pure ALOHA a station does not listen to the channel before transmitting, it has no way of knowing that another frame was already underway. Similarly, any other frame started between $t_0 + t$ and $t_0 + 2t$ will bump into the end of the shaded frame.

***Figure 4-2. Vulnerable period for the shaded frame.***




The probability that $k$ frames are generated during a given frame time is given by the Poisson distribution:

**Equation 4**

$$\Pr[k] = \frac{G^k e^{-G}}{k!}$$

so the probability of zero frames is just $e^{-G}$. In an interval two frame times long, the mean number of frames generated is $2G$. The probability of no other traffic being initiated during the entire vulnerable period is thus given by $P_0 = e^{-2G}$. Using $S = GP_0$, we get

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

The relation between the offered traffic and the throughput is shown in Fig. 4-3. The maximum throughput occurs at $G = 0.5$, with $S = 1/2e$, which is about 0.184. In other words, the best we can hope for is a channel utilization of 18 percent. This result is not very encouraging, but with everyone transmitting at will, we could hardly have expected a 100 percent success rate.

## *Slotted ALOHA*

In 1972, Roberts published a method for doubling the capacity of an ALOHA system (Roberts, 1972). His proposal was to divide time into discrete intervals, each interval corresponding to one frame. This approach requires the users to agree on slot boundaries. One way to achieve synchronization would be to have one special station emit a pip at the start of each interval, like a clock.

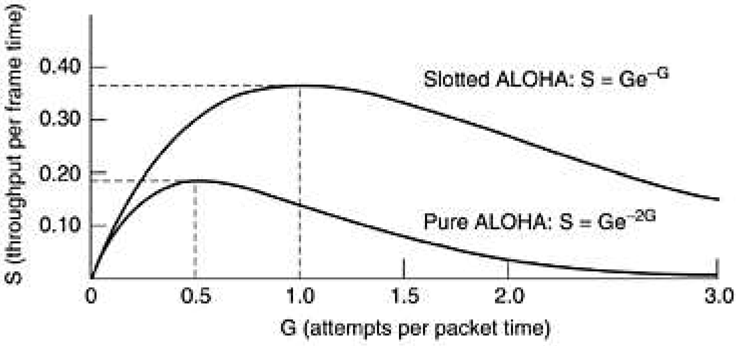
In Roberts' method, which has come to be known as **slotted ALOHA**, in contrast to Abramson's **pure ALOHA**, a computer is not permitted to send whenever a carriage return is typed. Instead, it is required to wait for the beginning of the next slot. Thus, the continuous pure ALOHA is turned into a discrete one. Since the vulnerable period is now halved, the probability of no other traffic during the same slot as our test frame is $e^{-G}$ which leads to

### Equation 4

$$S = Ge^{-G}$$

As you can see from Fig. 4-3, slotted ALOHA peaks at $G = 1$, with a throughput of $S = 1/e$ or about 0.368, twice that of pure ALOHA. If the system is operating at $G = 1$, the probability of an empty slot is 0.368 (from Eq. 4-2). The best we can hope for using slotted ALOHA is 37 percent of the slots empty, 37 percent successes, and 26 percent collisions. Operating at higher values of $G$ reduces the number of empties but increases the number of collisions exponentially. To see how this rapid growth of collisions with $G$ comes about, consider the transmission of a test frame. The probability that it will avoid a collision is $e^{-G}$, the probability that all the other users are silent in that slot. The probability of a collision is then just $1 - e^{-G}$. The probability of a transmission requiring exactly $k$ attempts, (i.e., $k - 1$ collisions followed by one success) is

***Figure 4-3. Throughput versus offered traffic for ALOHA systems.***




$$P_k = e^{-G}(1 - e^{-G})^{k-1}$$

The expected number of transmissions, *E*, per carriage return typed is then

$$E = \sum_{k=1}^{\infty} kP_k = \sum_{k=1}^{\infty} ke^{-G}(1 - e^{-G})^{k-1} = e^G$$

As a result of the exponential dependence of *E* upon *G*, small increases in the channel load can drastically reduce its performance.

Slotted Aloha is important for a reason that may not be initially obvious. It was devised in the 1970s, used in a few early experimental systems, then almost forgotten. When Internet access over the cable was invented, all of a sudden there was a problem of how to allocate a shared channel among multiple competing users, and slotted Aloha was pulled out of the garbage can to save the day. It has often happened that protocols that are perfectly valid fall into disuse for political reasons (e.g., some big company wants everyone to do things its way), but years later some clever person realizes that a long-discarded protocol solves his current problem. For this reason, in this chapter we will study a number of elegant protocols that are not currently in widespread use, but might easily be used in future applications, provided that enough network designers are aware of them. Of course, we will also study many protocols that are in current use as well.

## 4.2.2 Carrier Sense Multiple Access Protocols

With slotted ALOHA the best channel utilization that can be achieved is 1*/e.* This is hardly surprising, since with stations transmitting at will, without paying attention to what the other stations are doing, there are bound to be many collisions. In local area networks, however, it is possible for stations to detect what other stations are doing, and adapt their behavior accordingly. These networks can achieve a much better utilization than 1*/e.* In this section we will discuss some protocols for improving performance.

Protocols in which stations listen for a carrier (i.e., a transmission) and act accordingly are called **carrier sense protocols**. A number of them have been proposed. Kleinrock and Tobagi (1975) have analyzed several such protocols in detail. Below we will mention several versions of the carrier sense protocols.

### *Persistent and Nonpersistent CSMA*