ECE 333: Introduction to Communication Networks Fall 2002

Lecture 14: Medium Access Control II

- Dynamic Channel Allocation
  - Pure Aloha

In the last lecture we began discussing medium access control protocols for allocating a shared broadcast channel. We classified these protocols as either static or dynamic, and considered some basic types of static allocations (these are referred to as channelization approaches in Leon-Garcia's book, see Section 6.5). Such approaches are suitable for fixed rate traffic, but provide poor performance for highly variable traffic. In this lecture, we begin considering dynamic approaches for channel allocation.

Dynamic Channel Allocation:

Many different dynamic allocation strategies have been developed. They can be broadly classified as:

- **Contention resolution approaches** - users transmit a packet when they have data to send- if multiple users transmit at the same time a **collision** occurs and the packets must be retransmitted according to some rule.
- **Perfectly scheduled approaches -** Users transmit contention free according to a schedule that is dynamically formed based on which users have data to send, e.g. polling, reservations.

Various combinations of these approaches also exist. We will look at several specific examples in the next few lectures, beginning with a basic contention resolution approach today.

As we look at different approaches keep in mind the following two performance criteria:

1. The delay at low load.
2. The throughput (channel efficiency) at high load.

Multiaccess model

We will consider a (simplified) multiaccess model with the following key assumptions:

1) **User Model**: There are N users or stations. Frames randomly arrive at each station to be transmitted. The arrivals at each station are independent of each other.

2) **Channel model:** All communication is over a single channel and there is no other means of communicating between users.

3) **Transmission model:** Whenever frames overlap in time the frame is garbled and can't be received. If no other frames overlap with a frame it is successfully received, i.e. the only errors are due to collisions.

4) **Feedback model:** All stations are able to detect collisions (or successes) after sending a full frame. There are several ways collisions can be detected. For example, in a system with a central repeater (e.g., a satellite), a station can listen for the return of its message. (In many cases this feedback may be delayed, but we ignore this for now.)

(We will look at variations of these assumptions later.)

Aloha Protocols

Suppose when a user has data to send, the user simply transmits the frame. In our model, if no other user happened to have a frame to transmit then this frame would be successfully received. What if a collision occurs? The user could simply retransmit, but this would not help, because the other user involved in the collision would also retransmit, resulting in another collision. One way to avoid the problem is to wait a random amount of time before retransmitting.

The above idea is the basis for the ***Aloha*** MAC protocol. The Aloha protocol was developed at the University of Hawaii in the 1970's by Norman Abramson. This protocol has served as the basis for many other contention-based protocols.

(Pure) Aloha:

- Users transmit whenever they have data.
- Senders wait to see if a collision occurred (after whole message has been sent).
- If collision occurs, each station involved waits a **random amount of time** then tries again.

Questions:

- Is this a good protocol (i.e. what is the performance)?
- How should the random time for waiting be chosen?

Aloha Performance

Intuitively, one would expect performance to depend on the system load. As more and more users try to send information, more collisions occur and more of the bandwidth of the channel will be wasted on collisions. A common way to describe the performance of a dynamic allocation scheme is to look at how much **average throughput** is achieved as a function of the **average offered load** on the system.

At low offered load, the probability of a collision will be small; so, most messages get through without a collision. However, the throughput is also low, since there isn't much traffic. In this case, the throughput will be approximately the same as in a static allocation (e.g. TDMA), but the delay will be much smaller, since users can transmit immediately when a frame arrives.

At very high offered load, almost every message will experience a collision, and once again, the throughput will be low. In this case the throughput will be lower than in a static allocation, due to the collisions.

What happens in between these points?

Aloha Throughput

To analyze the throughput of Aloha, we consider a model with **an infinite number of users** that generate **fixed length frames.** We assume that each new frame belongs to a new user, and that the overall arrival of frames is a Poisson process with rate λ frames/sec. Let $\boldsymbol{T}$ indicate the time to transmit one frame. It will be convenient to normalize time by $\boldsymbol{T}$. Let $\boldsymbol{S}$ be arrival rate of frames in "frame times" of $\boldsymbol{T}$ seconds, i.e.

$$S = \lambda T$$

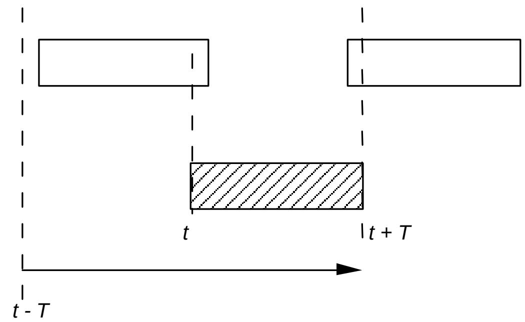
A transmission will be attempted at any time if either a new frame arrives or a frame is retransmitted. Assume that the start of transmissions at any time is also modeled as a Poisson process with rate $\boldsymbol{G}$ attempts per frame time. (This assumption can be shown to be a reasonable approximation for some common retransmission strategies.)

Thus the number of transmission attempts in a frame time will be a Poisson random variable, with mean $\boldsymbol{G}$ (attempts/frame time). Note that $S \leq G$, with equality only if there are no collisions. Assuming the system is stable then the average rate of successful transmission must equal the average arrival rate. Thus, denoting the probability of a successful transmission by P_0, we have

$$S = GP_0.$$

Probability of Success

If a transmission starts at some time t, there is an interval of time around t during which if another transmission starts, it will result in a collision. The length of this contention interval is twice the frame time, as shown below.



Thus the probability a frame is successfully transmitted, P_0, is the probability no other frames begin transmission during the contention window. This is the probability of 0 arrivals from a Poisson process with rate ***S***, during 2 frame times. From the properties of the Poisson process (cf. Lec. 12), the number of arrivals in 2 frame times is a Poisson random variable with mean 2***S***. Thus

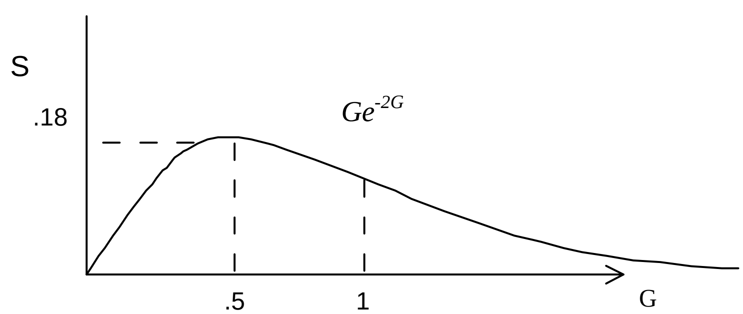
$$P_0 = \frac{(2G)^0 e^{-2G}}{0!} = e^{-2G}.$$

Aloha Throughput

From the above we have

$$S = GP_0 = Ge^{-2G}$$

This is plotted as a function of G below.



The maximum of this curve represents the maximum throughput for a stable system. To find the maximum we set the derivative of $S(G)$ equal to zero as follows:

$$\frac{dS}{dG} = \frac{d}{dG} Ge^{-2G} = e^{-2G} - 2Ge^{-2G} = 0$$

Solving we find that $G^* = 0.5$, and thus the maximum throughput is $S_{\max} = 1/(2e) \approx 0.18$.

To summarize, we have considered a simplified analysis of a pure Aloha, and found that the maximum throughput is limited to be at most $1/(2e)$.

Note we have not taken into account how the offered load changes with time, or specified the details of how the retransmission time is adjusted.

Despite these shortcomings, this analysis does correctly predict the maximum throughput of a pure Aloha system.

In the next lecture, we will look at an improvement on this system, and then return to address some of the above issues.