TCOM 370 NOTES 99-12

LOCAL AREA NETWORKS AND THE ALOHA PROTOCOL

1. Local Area Networks

These are networks spanning *relatively short distances* (e.g. within one building) for local point-to-point and point-to-multipoint communications between a number of nodes (ranging from a few to a few dozen). Their key features are

(i) use of a **common shared medium,** e.g. a coaxial cable,
(ii) **relatively high data rates** (1 Mbps - 100 Mbps),
(iii) inexpensive interfaces to medium (e.g. < $100 for PC ethernet cards).

Examples of LANs include Ethernet, Token Ring, and Appletalk.

LANs can be built using a variety of **media**, **topologies**, and **access procedures.** Common *media* include coaxial cables, twisted pair wires (telephone wires), optical fiber, and wireless channels. Network *topology* may be a shared bus, ring of nodes, star connection to a hub, or a tree structure.

Media access control (MAC) protocols must be defined to allow a node on a common medium that is shared by many nodes to gain access to the medium. MAC protocols may in general exert *centralized* control or may *distribute* the access control function over the network of nodes without a central controlling node.

MAC protocols of the *asynchronous* kind are well-suited to LANs, where the needs of individual nodes are quite variable and unpredictable. In asynchronous access control, a fixed capacity is not assigned or dedicated to each connection, but is determined dynamically by the needs at any particular time.

Asynchronous medium access control may be exerted in several ways. In **"round robin"** control, stations or nodes take turns to transmit if they have a need to transmit. When a node gets an opportunity to transmit, it either uses it to transmit one or more frames (up to some maximum number or for some maximum duration) or relinquishes its turn. Control may be centralized, e.g. by polling, or distributed, e.g. by permission-to-transmit "token" passing in sequence. Round robin is more efficient as the load becomes high and many nodes have data to transmit.

[**Reservation** schemes allow nodes to reserve time slots for their use, as needed. This is useful when nodes are likely to have streams of data to transmit (e.g. voice, large file transfers) rather than bursts (e.g. interactive terminal traffic)].

Contention based access controls can work well for bursty traffic. They are asynchronous, distributed, random-access control techniques, simple to implement, and are generally efficient unless the network load is very high. The basic idea is to allow any node that wishes to do so, at any time, to transmit a frame. If it is successful in getting its frame through without interference from another node's transmission during its frame duration, then everything is fine. Otherwise, there is a mechanism for re-transmitting frames.

2. DLC Protocols and Standards

Layer 2, the data link control (DLC) layer of the OSI 7-layer reference model, is implemented in a specific way for LANs. The DLC layer is made up of two parts, a lower **MAC protocol** that regulates access and an upper **Logical Link Control (LLC) protocol** that supervises frame transfers.

IEEE Standard 802.2 defines a common LLC protocol for a number of access methods. The LLC protocol performs error and flow control and provides an interface to the network layer.

IEEE Standards 802.3 to 802.9 define specific MAC protocols for wired LANs. For example, **802.3** is the contention-based MAC protocol also known as **CSMA-CD (carrier-sense multiple access with collision detection)** and is almost the same as the original ***Ethernet*** protocol. It can be used for a bus network topology.

IEEE 802.4 and 802.5 are respectively token bus and token ring MAC protocols. IEEE 802.6 is a reservation protocol (DQDB, "dual queue dual bus"). Also, IEEE 802.11 defines wireless LAN protocols.

3. The ALOHA Random Access Protocol

The **ALOHA protocol** is an interesting example of a MAC protocol of the ***contention-type.*** It is the precursor of **Ethernet** and its subsequent standardization as IEEE 802.3 (CSMA-CD).

The ALOHA protocol was originally implemented (early 1970's) to allow distributed stations on the islands of Hawaii to communicate over a common radio channel. Specifically, all nodes used a *common* frequency band for their packet or frame transmissions to a satellite (the "uplink" band was a common frequency band for all nodes). The satellite in turn broadcast to *all* the nodes (on the "downlink" frequency band) each frame it received successfully. Successful receipt of a frame at the satellite means that there is ***no "collision" or overlap*** between a frame from one node and other frames from other nodes arriving at the satellite. When a frame is received correctly at the satellite, it broadcasts an ACK also. Of course each frame has the address of the destination node for which it is intended, as well as the address of the source node. If a sending node does not see on the downlink within a reasonable time an ACK for a frame it sent up, it assumes that a collision occurred and re-transmits the frame after some random delay. *Thus ALOHA depends on the ability of a node to detect or learn that a collision has occurred.* Another mechanism enabling this without ACK frames from the satellite is for the sending node to monitor the downlink frequency band to listen for its frame being re-broadcast by the satellite; this will only happen if its frame got to the satellite in the first place without collision or interference. The satellite ignores frames that are received corrupted by errors due to collisions or overlaps.

(In the original network, the "uplink" band of frequencies was centered on 407 MHz, and the satellite "downlink" operated at a center frequency of 413 MHz. The data rate was 9.6 Kbps).

The concept of the ALOHA system is applicable with modifications in other situations, such as a LAN of nodes attached to a common coaxial cable bus (the Ethernet concept). The basic characteristics of ALOHA are the following. The actual implementations may be different, but the underlying concepts are the same for all ALOHA systems.

- Fixed length frames, shared channel or medium.
- Frames carry address of destination node.
- Nodes transmit on common channel and listen to common channel for transmissions from other nodes.
- A node starts a frame transmission whenever it is ready to send, regardless of the state of the channel.
- A node can tell if its frame arrived at the destination node without collision, or if a collision occurred with another frame in an overlapping time interval thus corrupting both frames. (An ACK may be used, or the node listens to the downlink broadcast channel in the original ALOHA system for its own frame).

There are two basic types of ALOHA system, **pure ALOHA** and **slotted ALOHA.** In pure ALOHA a node can start transmission at any time. In slotted ALOHA, all nodes have synchronized clocks marking frame boundary times (the clock period is the time for one frame transmission) and a node wishing to transmit does so at the start of the next frame slot. In both cases, a node transmits without checking the state of the channel. (In ALOHA, a node cannot necessarily "listen" to the uplink transmissions of another node, because these transmissions are directed by the transmitting antennae to the satellite station and not to the other nodes.)

4. Efficiency and Throughput for ALOHA

In general, we define **efficiency** of a MAC protocol as the ***maximum fraction of time that the medium can be used successfully by the nodes,*** when the network is heavily loaded by many nodes. (The medium will be carrying no traffic for some fraction of the time and will be carrying overlapping frames for another fraction of the time).

The **efficiency** $\eta_{s\text{-}aloha}$ **for the slotted ALOHA** scheme may be obtained under some simple assumptions leading to a *statistical model* of the traffic imposed on the medium by the nodes.

Traffic Model:

A node will have a frame to transmit either because it has a new packet to transmit from a user connected to it, or because it has to re-transmit a packet that did not get through in the previous attempt to transmit.

We assume that as a result, *nodes generate frames starting at arbitrary and random times.* From the collection of all nodes, the random start-times of the frame stream form a sequence of *random time-points* on the time axis.

Let N_T be the number of such time-points in some time interval of length T. This is a random variable. We assume the following about this *point process* of frame starts:

- The statistical behavior of the point process of frame start time-points is the same for all time (during the time period over which the analysis is to be valid), i.e. we have **stationarity in time** of the statistics.

- For two non-overlapping time intervals of lengths T_1 and T_2, the numbers of points N_{T1} and N_{T2} are **independent** random variables.

- In a short time interval of length ΔT, the probability that there will be exactly 1 point is approximately proportional to ΔT, i.e. it is $c\Delta T$ for some constant c

- In a short time interval of length ΔT, the probability that there will be 0 points is approximately $1-c\Delta T$, and the probability of more than 1 point in a short time interval is negligible

Results:

Under these assumptions we can show that the **probability distribution of N_T is Poisson,** which means that

$$
\begin{aligned}
p_n(T) &= P\{\text{exactly n points in interval of length T}\} \\
&= P\{N_T=n\} \\
&= \frac{(cT)^n}{n!} e^{-cT}, \qquad n=0,1,2, \ldots
\end{aligned}
$$

From this, we find that the expected value of N_T is

$$E\{N_T\} = \sum_{n=1}^{\infty} n \frac{(cT)^n}{n!} e^{-cT}$$

$$= cT$$

Now suppose that we **measure time t in units of frame duration (frame slot),** and we consider in the above model **T=1** (frame duration).

Further, suppose that in the steady state ***for the whole network*** there are ***on the average* G *frame start-times per frame duration*** (including re-transmissions). Let there be ***on average* S *successful frame transmissions per frame slot.*** Clearly $S \le 1$, and $S \le G$.

- Since G is the average number of frame start-time points within 1 frame slot, we have G=cT with T=1, or **G=c**

Ley q be the probability of exactly one frame start-time point in a frame slot. We have $q=p_1(T) = ce^{-c}$ (with n=1 and T=1). This is the probability with which a frame slot will successfully carry a single frame (no collision, and the slot is not empty). With probability $1-q$ no frame is being conveyed; either the slot remains empty or it contains multiple frames from different nodes. Thus on the average ce^{-c} frames are being carried successfully per slot, and we have

$$S = c\, e^{-c}$$

and therefore

$$S = G\, e^{-G}$$

which has a ***maximum*** value S_{max} of e^{-1} when G=1. (Easily shown).

The efficiency of slotted ALOHA is

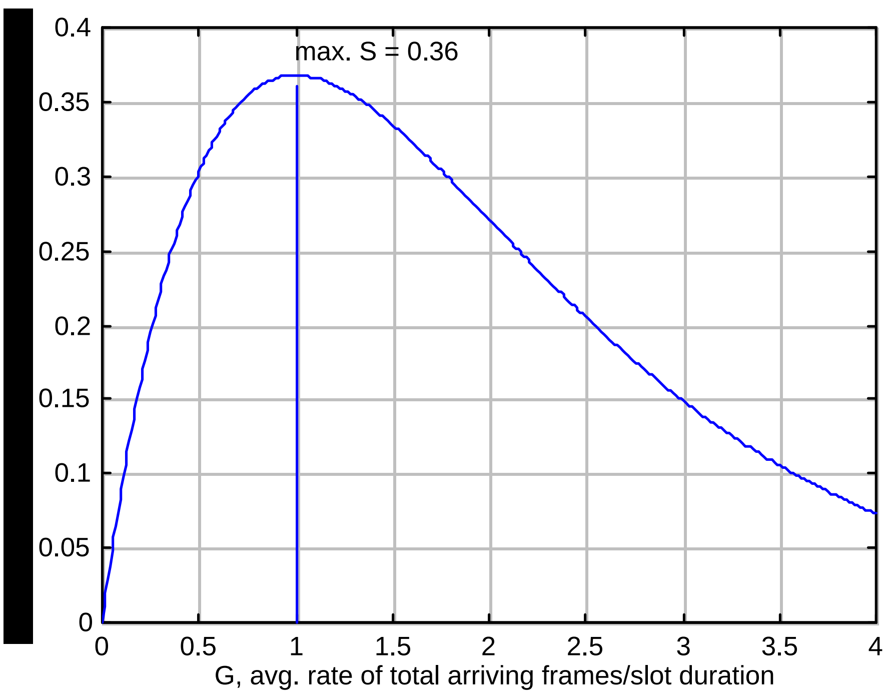
$$\eta_{\text{s-aloha}} = S_{max}$$

because S is the average fraction of time that the nodes are successfully using the channel.

Thus for **slotted ALOHA**

$$\eta_{\textbf{s-aloha}} = e^{-1} = 0.36$$

The figure below shows S as a function of G:



For **pure ALOHA,** given that one frame from some node has arrived at a time t, there will be no collision with this frame if *no other frame starts* within one frame duration *on both sides of* t. Thus we have to use T=2 in computing the probability of no overlap between frames from different nodes, within a time duration T=2. This gives for the probability of no overlap (no *other* frame starts) within a T=2 time duration, p= e^{-2c} $=e^{-2G}$. Thus *given* that some node has a frame starting at a certain time t, the probability that it will be transmitted successfully is p. Since on the average G frames are arriving per frame slot duration, we find that the average rate of successful utilization per slot duration of the common medium is $S= G\,p= G\,e^{-2G}$. For this S_{max} is $\frac{1}{2}e^{-1}$ and occurs with G=0.5, so for **pure ALOHA the efficiency** $\eta_{\textbf{p-aloha}}$ is

$$\eta_{\textbf{p-aloha}} = 0.18$$

Observation:

If a **slotted ALOHA** network is operating at *maximum efficiency* and there are a *large number* of nodes producing packets at random, uncoordinated times, then the average rate of frame arrivals on the medium from all the nodes *together* is 1 frame per slot duration and on the average 36% of the slots carry only a single frame, with the remainder empty or carrying multiple (collided) frames. In fact the *fraction of empty slots* is then also $p_0(1)=e^{-G}=0.36$. (For the Poisson model with cT=G=1, the probability of 0 arrivals in T=1 is the same as the probability of 1 arrival in T=1 units of time.) Therefore a fraction 0.28 of slots carry multiple (collided) frames.

To achieve these efficiencies in the slotted ALOHA scheme, the individual nodes need to be operating independently in a manner producing a total average load of G=1 frames per slot. Some regulation mechanism must be in place to obtain such operation; for instance, if each node knew how many nodes had frames to transmit, then they would each attempt to use a slot at an average rate that is the reciprocal of this number. Otherwise each node uses a random re-transmit delay, the statistics of which can be changed dynamically as it experiences different collision probabilities.