

ECE 333: Introduction to Communication Networks

Fall 2002

Lecture 16: Medium Access Control IV

- CSMA
- CSMA/CD

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Carrier Sense Multiple Access (CSMA)

In studying Aloha, we assumed that a node simply transmitted a packet and was informed afterwards if a collision occurred. In many multi-access channels, it is possible for a node to detect when other nodes are transmitting after a small propagation delay, this is referred to *carrier sensing*. In such cases it is silly for a node to begin transmission if it detects another transmission on the link.

A family of "Aloha"-like protocols for this situation are called *Carrier Sense Multiple Access (CSMA)* protocols. There are several different variations of CSMA - including *persistent CSMA*, *nonpersistent CSMA*, and *p-persistent CSMA*. In each of these protocols, users only transmit if they detect that the channel is idle. Collisions can still occur, if two users begin transmitting within close enough in time so that they cannot detect each other. If a collision occurs, we assume (as in Aloha) that the users find out about this after they finish transmitting their packets, in which case they wait a random time before retransmitting. The variations of CSMA differ in their behavior when the channel is detected to be busy.

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Persistent CSMA:

- 1) If channel is idle, transmit.
- 2) If channel is busy, wait until the channel is idle then transmit.
- 3) If a collision occurs, wait a random amount of time then go to 1.

Other variations of CSMA replace the first 2 steps as follows:

Non-persistent:

- 1) If channel idle, transmit.
- 2) If channel busy, wait a random amount of time and repeat step 1.

p – persistent¹: (for slotted system)

- 1) If channel idle, transmit with probability p . Wait one slot with probability $1 - p$, and repeat step 1.
- 2) If channel busy, wait for idle and go to step 1.

¹ “Persistent” is also called “1-persistent” (i.e. $p = 1$).

With persistent CSMA, if multiple stations are waiting for the channel to become idle, then a collision will occur. Using non-persistent or p-persistent CSMA will reduce this probability, but at the expense of longer delays.

The maximum time from when one node begins transmitting until another node can sense this is a fundamental performance parameter for all of these CSMA protocols. This time depends on the propagation delay as well a detection delay required for the receiver to determine that a transmission is occurring. Intuitively, one would expect the performance to degrade as the maximum propagation and detection delay increases.

Slotted Non-Persistent CSMA for Analysis

To better understand the performance of CSMA algorithms, we consider a slotted version of non-persistent CSMA. As in our analysis of Aloha, we again normalize time by the transmission time of a packet - we refer to each time unit as a *packet time*. Thus it takes 1 packet time to transmit a packet. Let β be the maximum propagation and detection delay (in packet times) between any two stations. Assume this is small relative to the transmission time of a packet, i.e. $\beta \ll 1$.

Consider time to be slotted and to consist of *mini-slots* of length β and packet slots of duration 1.



In this case the protocol operates as follows:

- 1) Each node with a packet to send listens for one mini-slot to see if channel is idle. If the channel is idle, the node transmits in the **next** mini-slot.
- 2) If mini-slot is busy or a collision occurs, the node becomes backlogged.
- 3) While backlogged, the node transmits after each idle mini-slot with probability q .

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Let λ denote the total arrival rate of new packets to all stations; thus $\lambda\beta$ is the average number of packets to arrive in a mini-slot. As in our analysis of Aloha, assume there are a large number of stations so that as the backlog increases, the arrival rate stays relatively constant.

The time axis can be divided into the following two types of "epochs".

- 1) A success or a collision followed by an idle mini-slot
- 2) An idle mini-slot.

In particular, there will never be two consecutive packet slots without an idle mini-slot between them. The first type of epoch has length $1+\beta$; the second has length β .

The average number of transmission attempts in a mini-slot (not following a packet slot) with a backlog of n is:

$$g(n) = \lambda\beta + nq.$$

Once again, we assume that the number of transmissions in a mini-slot has a Poisson distribution.

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Then the probability an epoch corresponds to a successful transmission is the probability of exactly one arrival during the mini-slot. From the Poisson assumption, this is given by $g(n)e^{-g(n)}$.

Likewise, the probability that an epoch corresponds to an idle mini-slot is $e^{-g(n)}$.

Thus an epoch has length β with probability $e^{-g(n)}$, and length $1 + \beta$ with probability $1 - e^{-g(n)}$. So,

$$\text{Expected length of an epoch} = \beta(e^{-g(n)}) + (1 + \beta)(1 - e^{-g(n)}) = \beta + (1 - e^{-g(n)})$$

Expected number of departures per epoch = 1 * Prob of success + 0.

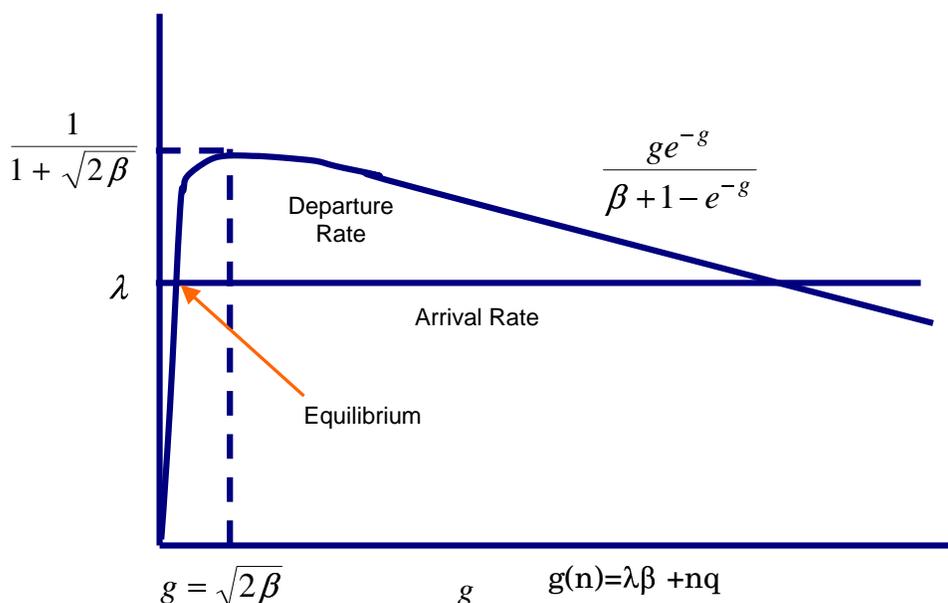
$$\Rightarrow \text{Expected number of departures per epoch} = g(n)e^{-g(n)}$$

Thus the throughput (number of departures per unit time) is given by

$$\begin{aligned} \text{Throughput} &= \frac{\text{Number of departures/epoch}}{\text{Number of frame times/epoch}} \\ &= \frac{g(n)e^{-g(n)}}{\beta + 1 - e^{-g(n)}} \end{aligned}$$

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The above expression for throughput versus $g(n)$ is plotted below. The maximum throughput for small β can be shown to be approximately $\frac{1}{1 + \sqrt{2\beta}}$. Note as β gets small, the maximum throughput is increasing towards 1.



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Comments on CSMA throughput:

When the outgoing rate is less than λ the number of backlogged stations tends to increase and vice versa \Rightarrow same stability problems as Aloha.

However, with CSMA, the departure rate has a broad maximum with respect to n and $g(n)$, making stability less critical.

Choosing $g(n)$ (through choice of q) to maximize the departure rate is a trade-off between time wasted on idle mini-slots and that on collisions.

For small β throughputs very close to one are possible, and optimization is not that critical.

The savings over slotted Aloha come from the smallness of β . (β should be less than a few tenths for good performance.)

In a shared bus with length L , and propagation speed, c_m , the maximum propagation delay is L/c_m . Thus, ignoring detection delays we have $\beta = LR/Fc_m$ where R is the transmission rate and F is the number of bits per frame. (Note β is proportional to the bandwidth-delay product, a quantity that was also important in studying ARQ protocols.) To avoid values of β that are too large, one should avoid large propagation delays and small packet sizes.

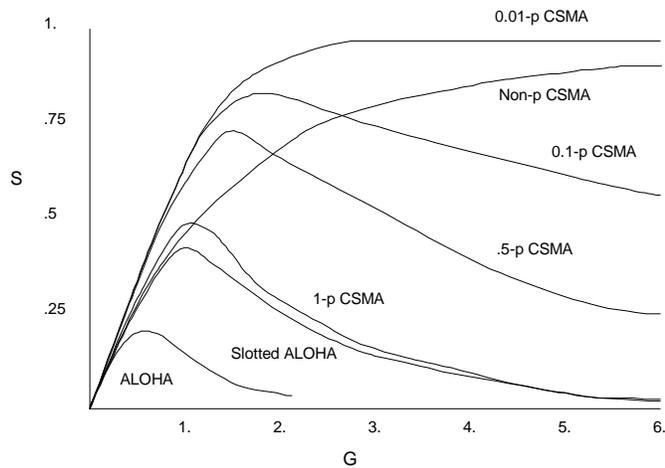
Unslotted CSMA

In practice CSMA is often implemented in an un-slotted version.

In theory, this can be shown to decrease the maximum throughput for (non-persistent) CSMA from $\frac{1}{1 + \sqrt{2\beta}}$ to $\frac{1}{1 + 2\sqrt{\beta}}$.

In practice, un-slotted CSMA has a smaller effective value of β . This means the reduction in throughput seen by un-slotted systems in Aloha essentially disappears in CSMA. Also, a slotted CSMA system requires users to be synchronized at a mini-slot level; for short mini-slots, this synchronization is difficult.

CSMA Plots (from *Computer Networks*, 3rd Ed. by A. Tanenbaum)



This shows the offered load versus throughput for various CSMA and Aloha approaches. These curves will also depend on the value of β . For very large value of β , Aloha will begin to outperform CSMA.

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CSMA

Clearly, CSMA is an improvement over Aloha.

Which persistence should be chosen?

This depends on what offered load we expect to operate at, and also depends on the average delay we desire.

All these random access schemes have a lower delay than TDMA until they get near their throughput limit.

The higher the total load ($G(n)$) at the operating point, the more backlogged stations and the higher the delay.

1 – Persistent can be shown to give the best delay characteristic at the same $G(n)$.

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CSMA with Collision Detection (CSMA/CD)

In some situations nodes can hear each other even when they are transmitting. (This is generally true for example on a shared bus, but not true in a wireless channel.) Thus if a collision occurs, all nodes can hear it within a maximum propagation delay of β .

Once a node knows that a collision is occurring, it can stop transmitting and minimize the amount of time wasted on a collision.

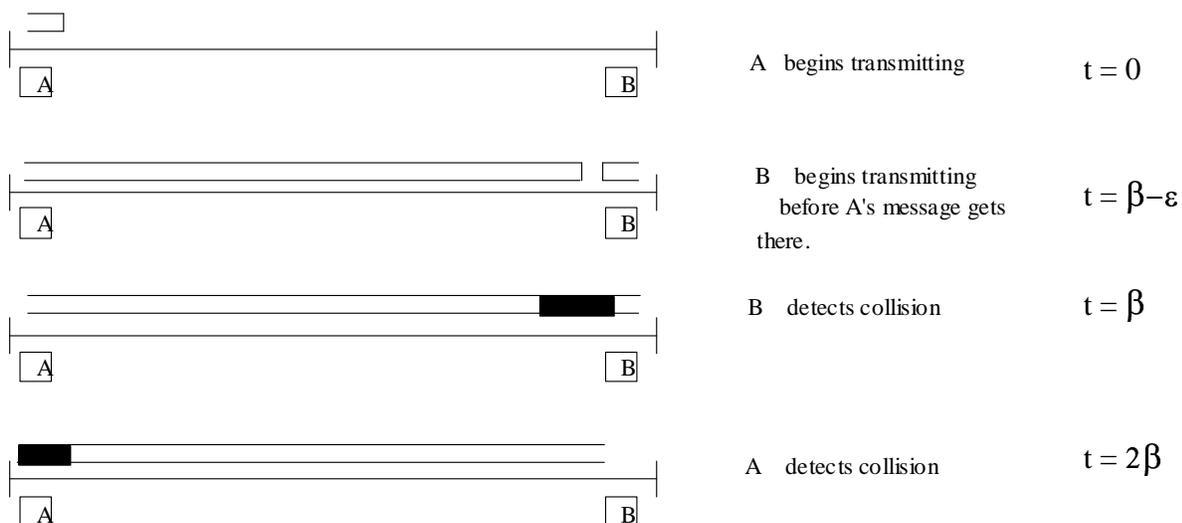
CSMA with this modification is referred to as CSMA/CD (CSMA with collision detection).

This name is a little misleading since CSMA also assumes collisions are eventually detected. However with CSMA/CD they are detected before the entire packet is transmitted.

Once a node begins transmitting how long before it will know whether or not a collision occurred?

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Collision Detection



So, it can take up to 2β seconds to detect a collision.

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Slotted (non-persistent) CSMA/CD

As with CSMA, CSMA/CD may be either slotted or un-slotted and can use any persistency variations of CSMA). In the following we consider a slotted, non-persistent version. Once again we view time as mini-slots of length β and packet slots of duration 1. Following this protocol,

- Nodes transmit packets only following one idle mini-slot.
- If more than one node starts to transmit in a mini-slot, a collision is detected at end of 2nd mini-slot and all nodes become idle for next mini slot.

This protocol can be thought of as using a slotted Aloha protocol in the mini-slots to make a reservation for the channel.

Notice there are now three types of epochs:

- 1) Successful transmission - length = $1 + \beta$
- 2) Collisions - length 3β
- 3) Idle slots - length β

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Using similar ideas as we have for Aloha and CSMA, the maximum throughput can be shown to be approximately

$$\frac{1}{1 + 3.31\beta}$$

For small β , this will be very close to 1.

As with CSMA, an un-slotted version of CSMA/CD is commonly used in practice. The throughput for un-slotted CSMA/CD can be approximated by a similar expression to the above and does not require synchronization.

Persistent CSMA/CD works reasonably well (as opposed to CSMA) - this is due to the fact that collisions are not very costly for CSMA/CD.

Again, the performance depends on a small β and thus decreases with increasing cable length, increasing data rate and decreasing packet size.

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