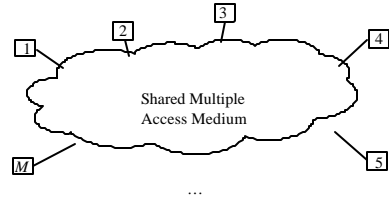


Local Area Networks and Medium Access Control Protocols

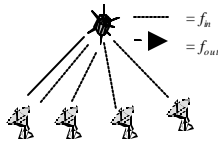
Multiple Access Networks

- Broadcast and multiple access technologies are very common for LANs and for wireless settings.

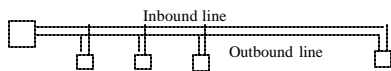


Multiple Access Communication: Examples

Satellite Channel

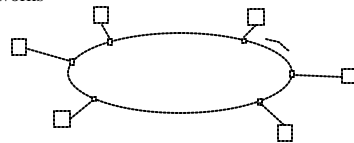


Multidrop telephone lines

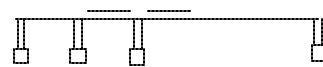


Examples (2)

Ring networks

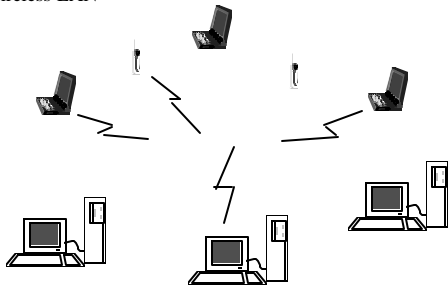


Multitapped Bus



Examples (3)

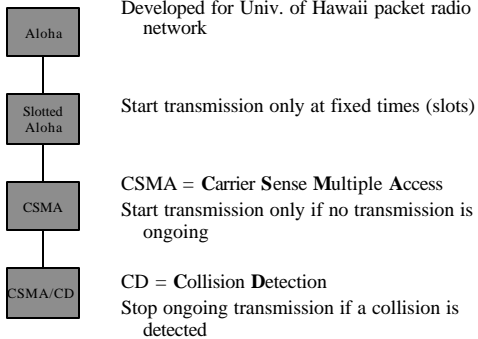
Wireless LAN



Multi-Access Protocols

- Protocols that resolve the resolution problem dynamically are called Multiple-Access (**Multi-Access**) Protocols
- **Contention Protocols** resolve a collision after it occurs. These Protocols execute a collision resolution protocol after each collision.
- **Collision-free Protocols** ensure that a collision never occurs.

Evolution of Contention Protocols



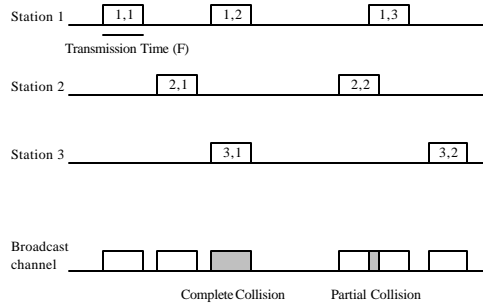
Contention Protocols

- ALOHA Protocols
 - (Pure) Aloha
 - Slotted Aloha
- CSMA (Carrier Sense Multiple Access)
 - Persistent CSMA
 - Non-persistent CSMA
 - CSMA/CD: Carrier Sense Multiple Access with Collision Detection (used in Ethernet)
- Etc...

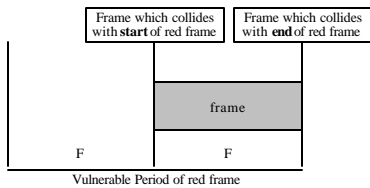
(Pure) ALOHA

- Topology:
 - Multiple transmitters (stations) share same medium.
- Aloha protocol:
 - Whenever station has data, it transmits immediately
 - Whenever a collision occurs, it is treated as transmission error, and frame is retransmitted.
 - Sender backs off for some random time after collision before it retransmits.

Collisions in Pure ALOHA



Collisions and Vulnerable Period

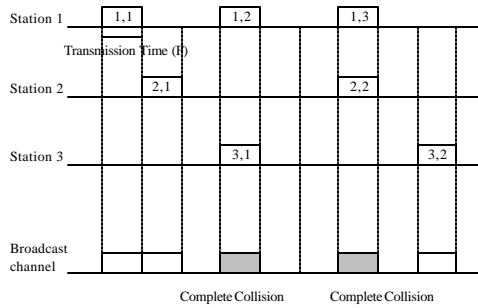


- A frame (dark frame) collides whenever another transmission begins in the vulnerable period of the frame.
- Vulnerable period has length of 2 frame times.

Slotted ALOHA

- Slotted Aloha Protocol
 - Time is divided into discrete time intervals (=slots)
 - A station can transmit only at the beginning of a frame
- As a consequence:
 - Frame either completely or do not collide at all
 - Vulnerable period = 1 frame time

Collisions in Slotted ALOHA



Performance of ALOHA

- What is the maximum throughput of the ALOHA protocol?
- Notation:
 - S Throughput:** Expected number of successful transmission per time unit
 - G Offered Load:** Expected number of transmission and retransmission attempts (from all users) per time unit.
- Normalization:
 - Frame transmission time is 1 => maximum throughput is 1

Modeling Assumptions

- Normalization: All frames have a fixed length of one time unit.
- Infinite user population
- Offered load is modeled as a **Poisson process** with rate G :

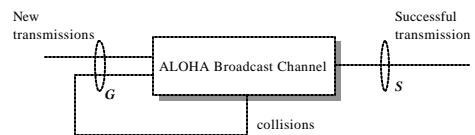
Prob[k packets are generated in t frame times] =

$$\frac{(Gt)^k}{k!} \times e^{-Gt}$$

Throughput of ALOHA

- Relation between throughput and offered load:

$$S = G * \text{Prob}[\text{frame suffers no collision}]$$



Performance of (pure) ALOHA

- Prob[frame suffers no collision]
 - = Prob[no other frame is generated during the vulnerable period of this frame]
 - = Prob[no frame is generated during a **2-frame period**]

=

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

- **Throughput in ALOHA:** $S = G \times e^{-2G}$

Results: Maximum Achievable Throughput

- Take derivative and set $\frac{\partial S}{\partial G} = 0$
- Maximum is attained at $G = 0.5$
- We obtain: $s_{\max} = 0.5 \times e^{-1} = \frac{1}{2e} = 0.184$
- Note: That is 18% of channel capacity!

Performance of Slotted ALOHA

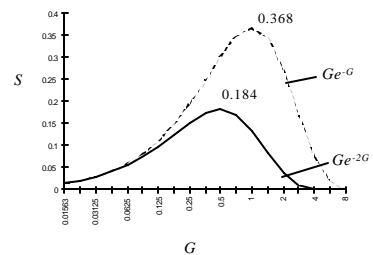
- Derivation is analogous to (pure) ALOHA:
 - $S = G * \text{Prob}[\text{frame suffers no collision}]$

- Prob[frame suffers no collision]
 - = Prob[no other frame is generated during a vulnerable period]
 - = Prob[no frame is generated during **1 frame period**] =

$$\frac{(1G)^0}{0!} \times e^{-1G} = e^{-1G}$$

- **Total throughput in Slotted ALOHA:** $S = G \times e^{-G}$
- **Achievable Throughput:** $s_{\max} = e^{-1} = \frac{1}{e} = 0.37$

Comparison of ALOHA and Slotted ALOHA



CSMA – Carrier Sense Multiple Access

- Improvement over ALOHA protocol:
 - If stations have **carrier sense capability** (stations can test the broadcast medium for ongoing transmission), and
 - If stations only transmit if the channel is idle,
 - Then many collisions can be avoided
- **Note:** This improves ALOHA only in cases with small delay bandwidth products. Why?

CSMA – Carrier Sense Multiple Access

- CSMA protocol
 - A station that wishes to transmit listens to the medium for an ongoing transmission
 - Is the medium busy?
 - Yes: Station backs off for a specified period
 - No: Station transmits
 - If a sender does not receive an acknowledgement after some period, it assumes that a collision has occurred.
 - After a collision a station backs off for a certain (random) time and retransmits.

CSMA - Variations

- Variations of CSMA protocol
- Each variant specifies what to do if the medium is found busy:
 - Non-persistent CSMA
 - 1-persistent CSMA
 - p -persistent CSMA

Non-Persistent CSMA

1. If the medium is idle, transmit immediately
2. If the medium is busy, wait a random amount of time and Repeat Step 1.

- Random back-off reduces probability of collisions.
- Wasted idle time if the back-off time is too long.
- May result in long access delays.

1-Persistent CSMA

1. If the medium is idle, transmit immediately
2. If the medium is busy, continue to listen until medium becomes idle, and then transmit immediately.

- What if two stations want to transmit when channel is busy?

p -Persistent CSMA

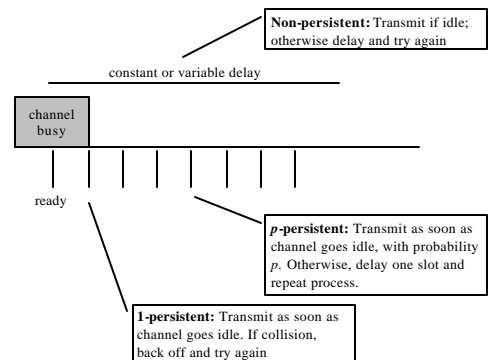
1. If the medium is idle, transmit with probability p , and delay for one time unit with probability $(1-p)$ (time unit = length of propagation delay)
2. If the medium is busy, continue to listen until medium becomes idle, and then go to Step 1.
3. If transmission is delayed by one time unit, continue with Step 1.

- Good trade-off between non-persistent and 1-persistent CSMA.

How to Select Probability p ?

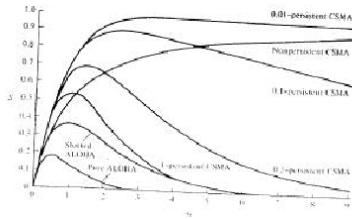
- Assume that N stations have a packet to send and the medium is busy.
- Expected number of stations that will attempt to transmit once the medium becomes idle: $N * p$
- If $N * p > 1$, then a collision is expected to occur (with retransmission, and so more collisions)
- **Therefore:** Network must make sure that $N * p < 1$, where N is the maximum number of stations that can be active at a time.

Comparison of CSMA Strategies



Comparison of ALOHA and CSMA

- Load vs. Throughput (very small delay-bandwidth product)



CSMA/CD

- CSMA has an inefficiency:
 - If a collision occurred, the channel is unstable until colliding packets have been fully transmitted
- CSMA/CD overcomes this as follows:
 - While transmitting, the sender is listening to medium for collision. Sender stops if collision has occurred.
- Note:
 - CSMA: Listen Before Talking
 - CSMA/CD: Listen While Talking

Operation CSMA/CD

- Generic CSMA/CD Protocol:
 - Use one of the CDMA persistence algorithms (non-persistent, 1-persistent, p-persistent) for transmission.
 - If a collision is detected during transmission, cease transmission and transmit a jam signal to notify other stations of collision.
 - After sending the jam signal, back off for a random amount of time, then start to transmit again.

Collision Detection in CSMA/CD

To detect a collision, in the worst case, it takes twice the maximum propagation delay of the medium.

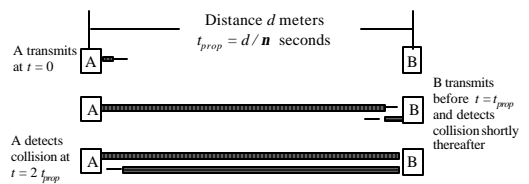


Figure 6.7

CSMA/CD: Restrictions

- Packet should be twice as long as time to detect a collision ($2 * \text{max. propagation delay}$)
- Otherwise, CSMA/CD does not have an advantage over CSMA

- Example: Ethernet
 - Ethernet requires a minimum packet size and restricts the maximum length of the medium.
 - **Question:** What is the minimum packet size in a 10Mbit/sec network with a maximum length of 500 meters?

Exponential Backoff Algorithm

- Ethernet uses an exponential backoff algorithm to determine when a station can retransmit after a collision.

Algorithm:

Set “slot time” equal to $2a$
After first collision, wait 0 or 1 slot times.
After i -th collision, wait random number between 0 and $2^i - 1$ time slots.
Do not increase random number range if $i = 10$.
Give up after 16 collisions

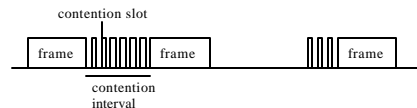
Performance of CSMA/CD

- Parameters and assumptions:
 - a : end-to-end propagation delay
 - l : packet transmission time (normalized)
 - N : Number of stations

- Time can be thought of as being divided in contention intervals and transmission intervals.

- Contention intervals can be thought of as being slotted with slot length of $2a$ (roundtrip propagation delay).

Performance of CSMA/CD



- Contention slots end in a collision
- Contention interval is a sequence of contention slots
- Length of a slot in contention interval is $2a$
- Probability that a station attempts to transmit in a slot is P

Performance of CSMA/CD

- Derivation of maximum throughput of CSMA/CD

– Let A be the probability that some station can successfully transmit in a slot. We get:

$$A = \left(\frac{N}{1}\right) \times P^1 \times (1-P)^{N-1} = N \times P \times (1-P)^{N-1}$$

– In the above formula, A is maximized when $P=1/N$. Thus:

$$A = \left(1 - \frac{1}{N}\right)^{N-1}$$

Performance of CSMA/CD

Prob[contention interval has a length of j slots] =
 Prob[1 successful attempt] * Prob[j-1 unsuccessful attempts] =

$$A \times (1-A)^{j-1}$$

- The expected number of slots in a contention interval is then calculated as:

$$\sum_{j=0}^{\infty} j \times A \times (1-A)^{j-1} = \frac{1}{A}$$

Performance of CSMA/CD

- Calculate the maximum efficiency of CSMA/CD with usual formula:

$$\frac{\text{FrameTime}}{\text{FrameTime} + \text{Overhead}} =$$

$$\frac{\text{FrameTime}}{\text{FrameTime} + \text{Average Contention Interval}} =$$

$$\frac{1}{1 + \frac{2a}{A}}$$