Lecture 4A

Multiple Access Control Protocols

Multiple Access Control Protocols

- A single transmission medium is shared by multiple users
- Requires use of a medium access control protocol (MAC) as part of the data link layer
- Thus the link layer is divided into
  - LLC (logical link control): this is typically a simple connectionless protocol without acknowledgements
  - MAC
    - 802.3 CSMA / CD "Ethernet"
    - 802.5 Token Ring "IBM's token ring, FDDI"
    - 802.11 Wireless LAN (WiFi)
    - 802.15 Bluetooth etc.
    - 802.16 Broadband Wireless (WiMAX)
    - Others
- Types of MAC algorithms
  - Random Access (Contention)
  - Reservation / Scheduling / Collision Free
  - Channelization (frequency division, time-division, code division)

The Aloha Protocol

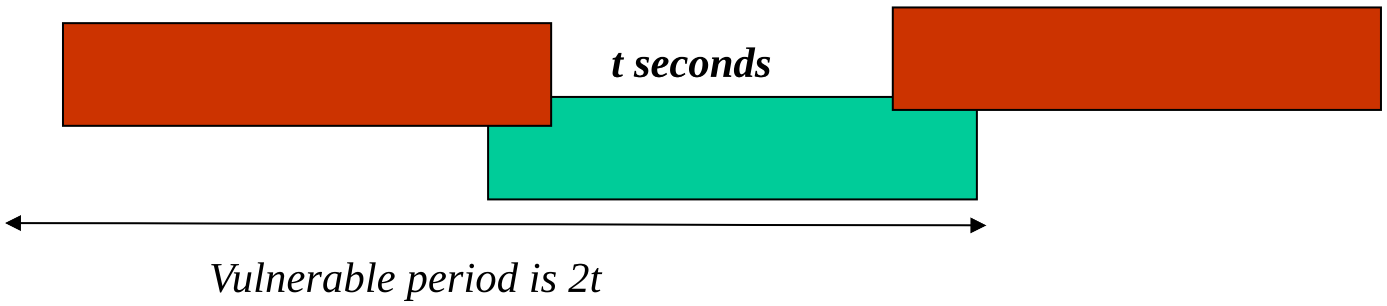
- First proposed at the University of Hawaii
- Allowed stations to communicate with a central computer using a shared radio channel
  - All stations broadcast at the same frequency
  - Stations only infrequently communicated with the central computer
  - The central computer used a second dedicated frequency to inform stations of success or failure
- This first protocol (called *pure Aloha*) operated as follows:
  - Transmit a packet on the shared channel whenever you have a packet to transmit
  - Determine if the transmission was successful
  - If the transmission was successful, you are done
  - If the transmission was unsuccessful, then try again after some random amount of time

Analyzing Pure Aloha

- Note that determining if the transmission was successful is important
- In the original system, this was done by the central computer sending an acknowledgement of success or failure on a second channel
- In a satellite system, this is done by the satellite simply rebroadcasting on a second channel whatever it receives on a first channel
- Thus, a station can determine the success or failure itself by listening to the rebroadcast a fixed time after its transmission
- A straightforward analysis of Pure Aloha shows that the maximum throughput is 18.4%
- *Throughput is generally defined as the rate in bits/second or packets/second that information actually gets through*
- For multiple access protocols, the concern is the reduction in throughput due to collisions and the overhead of headers is usually not considered

Abramson's Analysis

- Simplifying assumptions
  - All packets of length L bits. Transmission rate is R bits /sec.
  - t = L/R is the transmission time of a packet.
  - G is normalized offered traffic (packets / t seconds), including retransmissions. *What does normalized offered traffic of 1 mean?*
  - S is normalized new traffic successfully transmitted (also must be the throughput)
- **Vulnerable period** of a transmission is 2 times the transmission interval (due to another packet *starting* t time before or during current transmission of t) or 2t.



- Abramson considered the normalized offered load G to be a Poisson process with rate 2G / 2t seconds. Thus in 2t seconds we have:

- *P*(k transmissions in time 2t) = $\frac{(2G)^k}{k!} e^{-2G}$ for $k = 0,1,2,\ldots$

- *Note that P*(*k* = 0) = e^{-2G}

- The throughput S can be viewed as the offered load G times the probability that no other packets collided with an arriving packet in 2t seconds:

  S = G *P*[0 transmissions in 2t seconds]

- Resulting equation is S = G e^{-2G}
- This results in a maximum value of S of 18.4%

- Resulting equation is $S = G e^{-2G}$
- This results in a maximum value of S of approximately 18.4 %
- $dS/dG = G(-2e^{-2G}) + e^{-2G}$
  $0 = -2G + 1$, therefore maximum at $G = ½$ with value
  $S = 1/(2e)$ which is approximately 18.4 %
- The expected delay can also be determined. This is based on:
  The average number of transmission attempts per packet is
  $G/S = e^{2G}$ attempts per packet.
  Thus the average number of unsuccessful attempts is
  $e^{2G} – 1$
- Operating at the maximum possible value of S, we have $G = ½$ and unsuccessful attempts of $e – 1$, and thus an average delay of:

  e packet times to send a packet

Slotted Aloha

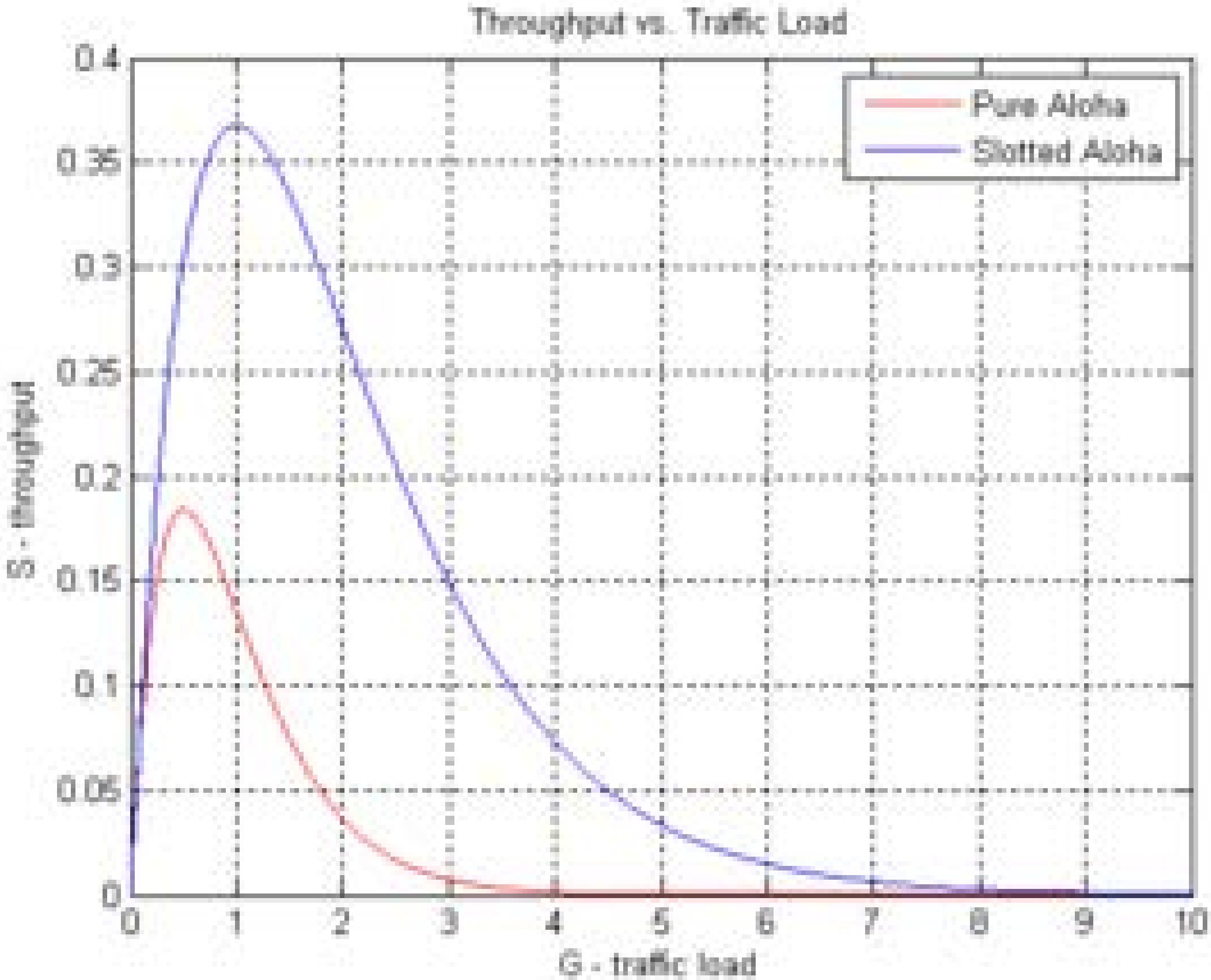
- The problem of pure Aloha was the vulnerable time of other transmissions beginning and conflicting with a given transmission
- Use a system where transmission is not totally random but can only start at the beginning of a slot, which is a fixed interval of time, and know to every transmitting station

- If slot time is the same as the packet time, then slotted Aloha reduces the collision by a half and has a maximum throughput of 1/e which is approximately 36.7% . ***Can you do this analysis?***

Slotted Aloha Analysis

- Resulting equation is $S = G e^{-G}$
- This results in a maximum value of S of approximately 36.7 %
- $dS/dG = G(-e^{-G}) + e^{-G}$
  $0 = -G + 1$, therefore maximum at $G = 1$ with value
  $S = 1/(e)$ which is approximately 36.7 %
- The expected delay can also be determined. This is based on: The average number of transmission attempts per packet is $G/S = e^{G}$ attempts per packet.Thus the average number of unsuccessful attempts is $e^{G} – 1$
- Operating at the maximum possible value of S, we have $G = 1$ and unsuccessful attempts of $e – 1$, and thus an average delay of:

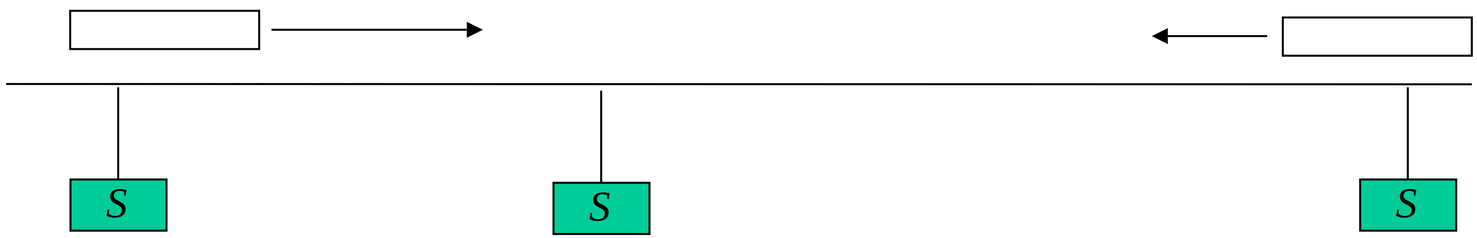
  e packet times to send a packet
- *Note that this delay is the same as pure Aloha but at a much different offered rate*



Throughput vs. Traffic Load
Pure Aloha
Slotted Aloha
S - throughput
G - traffic load
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
1
2
3
4
5
6
7
8
9
10

Carrier Sense Multiple Access and Collision Detect CSMA / CD

S: station on the bus

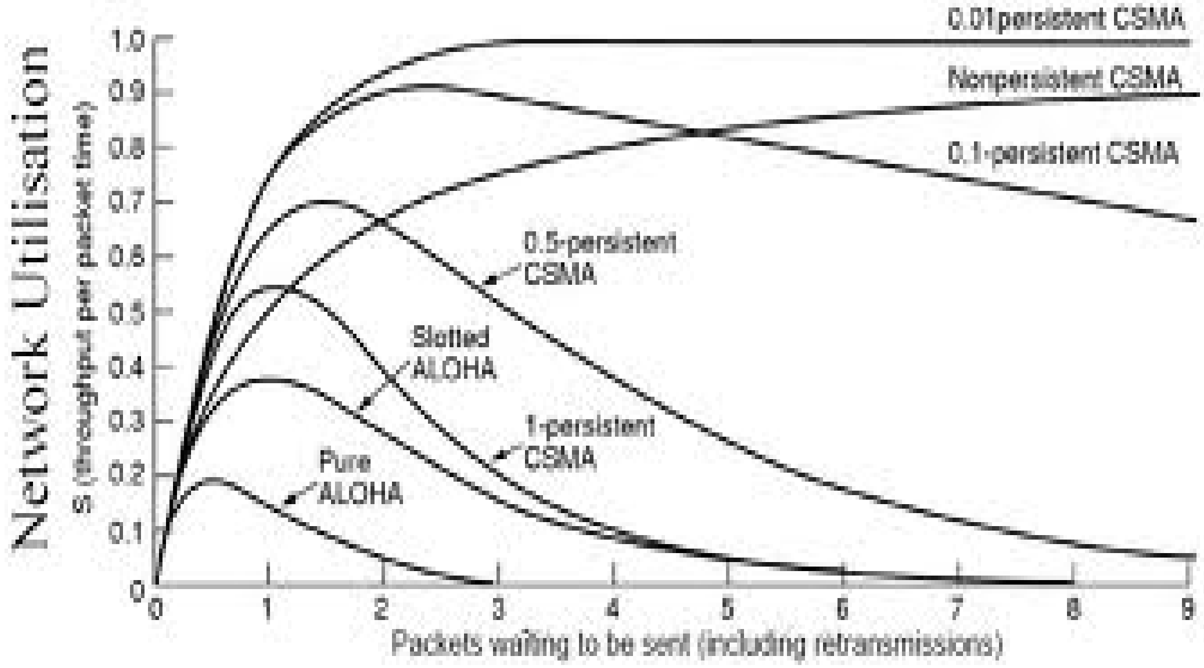


CSMA: Sensing the media and avoiding transmissions if some one else is transmitting

One way propagation time $\boldsymbol{t_{prop}}$ *is sufficient to capture the channel*

CD: 2 way propagation time or roundtrip propagation time $2t_{prop}$ *is sufficient to ensure that there will be no collisions*

- Persistent CSMA or 1-persistant CSMA
  - Listen first, if line is idle, transmit message
  - If busy, wait (keep listening) till it becomes idle.
  - Conflict occurs if someone else starts to transmit before they realize you are transmitting (this is known by t_{prop})
  - *One way propagation delay* $\boldsymbol{t_{prop}}$ *is a factor that affects the performance.*
- Non-persistent CSMA
  - Listen first, if line is idle, transmit message
  - If busy, wait random period time and repeat. (not greedy)
- p-persistent CSMA
  - Listen first , if idle, send with a probability p. If did not transmit try again In the next slot.
  - if busy, wait for line to be idle and repeat the previous part.
- *These CSMA schemes transmit entire packets.*
- *If you are told (after sending your packet) that there was a collision of the packet, then backoff and retry a “random” amount of time later*



Network Utilisation
S (throughput per packet time)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
6
7
8
9
Packets waiting to be sent (including retransmissions)
0.01persistent CSMA
Nonpersistent CSMA
0.1-persistent CSMA
0.5-persistent
CSMA
Slotted
ALOHA
1-persistent
CSMA
Pure
ALOHA

CSMA-CD

- Carrier Sense Multiple Access with Collision Detect
  - Collision is detected in time $2t_{prop}$ and then aborted.
  - Thus, it can provide quicker recovery for longer packets.
  - Ethernet uses CSMA / CD and we will discuss details later.

- Simplistic analysis based on breaking time up in mini-slots of length $2t_{prop.}$ Stations either transmit, or they contend in a mini-slot.

- Suppose we assume that n stations contend in a slot with probability of transmission p. Then probability of k transmissions in a slot is given by the binomial density function and is:

$$\binom{n}{k} p^k (1-p)^{n-k}$$

- The probability of a successful transmissions $P_{maxsuccess}$ is when exactly one station transmits or simply:

$$P_{maxsuccess} = np(1-p)^{n-1}$$

Analysis for Contention Slots

- We can maximize this probability of success with respect to p and it turns out to be when p = 1/n (take the derivative of the previous function and find its maximum.
- We have $P_{maxsuccess} = (1 – 1/n)^{n-1}$ and this approaches 1/e when n is large. (recall that $(1-p)^L \approx e^{-Lp}$ for small p.)
- Thus if probability of success in each slot is 1/e then by the geometric distribution, the mean number of slots until a successful transmission is q/p + 1 = 1/p = e. (note q = 1-p)
- So this is the number of contention slots until the channel is acquired.

- This can be used to explore the efficiency of CSMA / CD and CSMA / CD is better that the previous versions without collision detect.

- pure ALOHA, slotted ALOHA, CSMA and CSMA/CD are contention based protocols
  - try. If collide, retry.
  - No guarantee of performance.
  - What happens if the network load is high?
- Reservation or Collision free protocols:
  - pay constant overhead to achieve performance guarantee
  - Good when network load is high

- Reservation Systems: collision free protocols:
  - bit-map method.
    - control frame contain N bits (contention slots), each station sets 1 bit to indicate whether it has a frame to send or not
    - at the end of the control frame, every station knows all the stations that want to send; the stations can send in order.
    - example:

0 1 2 3   0 1 2 3

4 Contention slots → 0 1 0 1   frame 1   frame 3   1 0 0 0   frame 0

- Performance: let the frame size be d bits long for each frame
  - d/(d+1) channel utilization rate for high load. (note that there is a 1 bit overhead on average for each frame sent).

    (N-1) d + N delay for high load (excluding queuing delay at own station
  - d/(d + N) channel utilization for low load.

    N bits delay for low load.

- Collision free protocols: binary countdown
  - each station sends the address bits in some order (from highest order bit to the lowest order bit).
  - The bits in each position from different stations are ORed.
  - As soon as a station sees that a high-order bit position that is 0 is overwritten by 1, it gives up.
  - Eventual, only one station (with largest station number among all the competitors) gets the channel.
  - example:

    station 2 (0010) 0 (gives up) first slot

    station 4 (0100) 0 (gives up) first slot

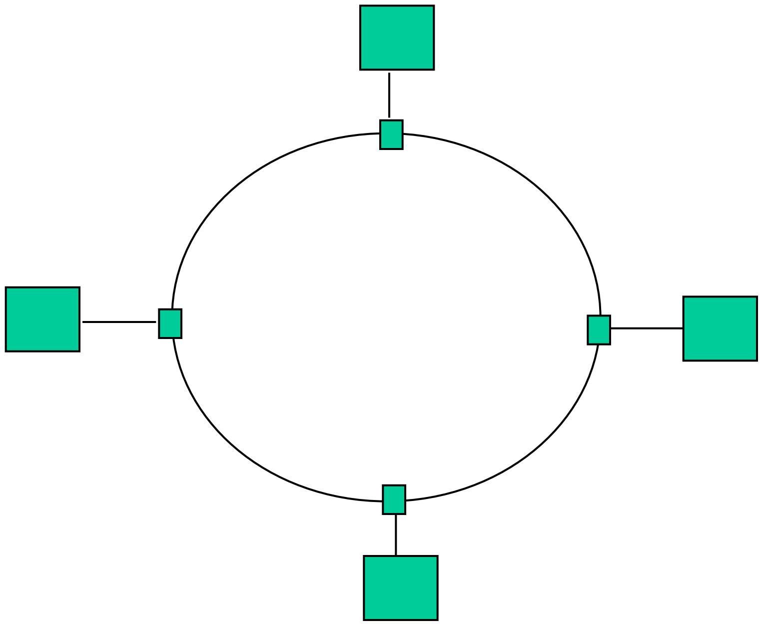
    station 9 (1001) 1 0 0 (gives up) third slot

    station 10 (1010) 1 0 1 0 (finished address, send data) fourth slot

  - Performance:
    - channel utilization rate: $d/(d+ \log_2 N)$ for high load
    - $\log_2 N$ bits delay for low load.
    - Contention field can serve as the address field.

Collision free protocols

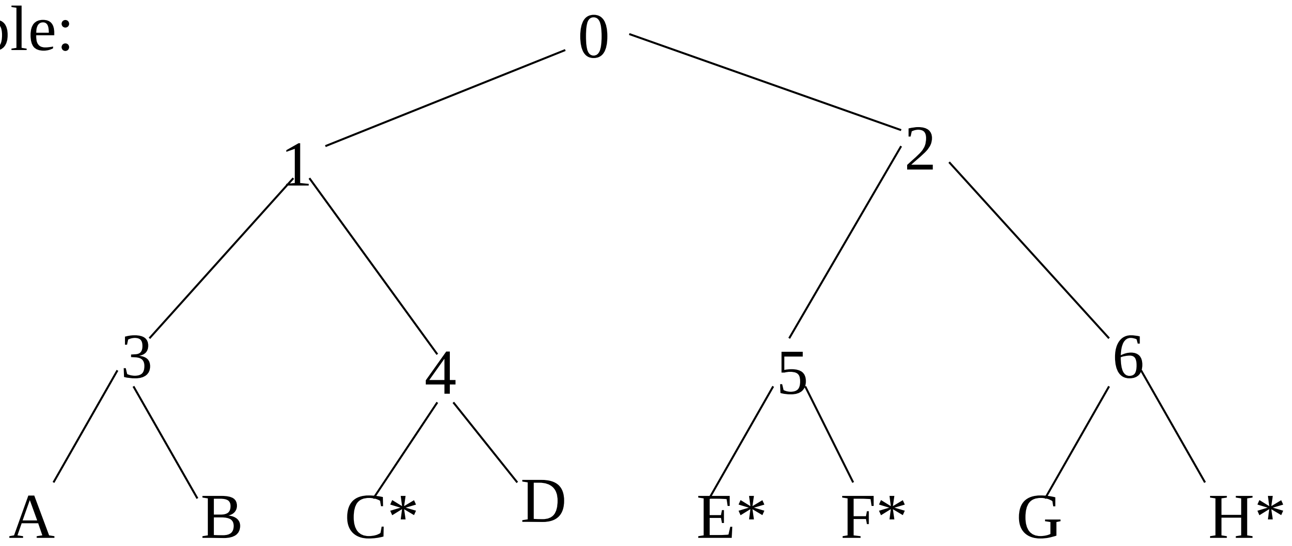
- IBM Token Ring
  - Token passing.
    - There is only one token in the network.
    - The token is passed through every node in the network.
    - Only the node that has the token can transfer data.



- Limited contention protocols:
  - **collision based protocols (ALOHA,CSMA/CD) are good when the network load is low.**
  - **collision free protocols (bit map, binary countdown) are good when load is high.**
  - **How about combining their advantages -- limited contention protocols.**
    - Behave like the ALOHA scheme under light load
    - Behave like the bitmap scheme under heavy load.

- Limited contention protocols:
  - adaptive tree walk protocol
    - trick: partition the group of station and limit the contention for each slot.
      - under light load, every one can try for each slot like aloha
      - under heavy load, only a small group can try for each slot
      - how do we do it
        - » treat stations as the leaf of a binary tree.
        - » first slot (after successful transmission), all stations (under the root node) can try to get the slot.
        - » if no conflict, fine.
        - » if conflict, only nodes under a subtree get to try for the next one. (depth first search)

Example:



Slot 0: C*, E*, F*, H* (all nodes under node 0 can try), conflict
slot 1: C* (all nodes under node 1 can try), C sends
slot 2: E*, F*, H*(all nodes under node 2 can try), conflict
slot 3: E*, F* (all nodes under node 5 can try), conflict
slot 4: E* (all nodes under E can try), E sends
slot 5: F* (all nodes under F can try), F sends
slot 6: H* (all nodes under node 6 can try), H sends.