Data Link Layer, Part 5

Medium Access Control

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Preface

- In our earlier discussion about DLL, we assumed that a link is associated with two nodes.

- When a link/medium is shared among many nodes, the problem arises as to when each node should access the medium.

- This issue is addressed by a sublayer within the DLL: the medium access control (MAC) sublayer.
Two Approaches of MAC

1. First Come, First Serve
   - ALOHA Protocol
   - Slotted ALOHA Protocol
   - Carrier Sense Multiple Access (CSMA)
   - CSMA with Collision Detection (CSMA/CD)

2. Wait for Your Turn
   - Token Passing Ring
   - Slotted Ring
   - Token Passing Bus

Pure ALOHA

- Developed at University of Hawaii for ground-based radio (1971).
  - seven campuses on four of the islands
  - main campus and main computer center on Oahu
  - other campuses need access to the computer center
  - telephone connections expensive and unreliable
- Each station equipped with FM radio transceiver.
- Transmitters send packets to a hub (located on Oahu) on a shared frequency and the hub retransmits received packets on a second frequency.
• The retransmissions are for collision detection:

  A transmitter listens to the retransmission of its packet from the hub.

  If two or more transmissions to the hub collide, then the hub discards the corrupted transmission and none of the colliding transmitters would receive the retransmission of their respective packets from the hub.

  When this happens, each colliding transmitter waits a random time and then tries to send its packet again.

• Collisions can occur whenever any part of a transmitted packet overlaps.

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**Performance Analysis**

• \( P_0 \): probability that a frame does not suffer a collision

• \( S \): number of new frames generated per frame time

• \( G \): number of new and retransmitted frames generated per frame time

• \( S = GP_0 \)

• Assume both \( S \) and \( G \) are Poisson distributed

• Probability that \( k \) frames are generated within a given frame time is

\[
P[k] = \frac{G^k e^{-G}}{k!}
\]
Vulnerable Period

- For a given frame, the time window when no other frame may be transmitted if a collision is to be avoided.
- Length: 2 frame times

Let us compute $P_0$:

$$ P_0 = P\{\text{no other frames in a 2-frame interval}\} $$

$$ = (\lambda t)^k e^{-\lambda t} \frac{k!}{k!}, \text{ where } t = 2, \lambda = G, k = 0 $$

$$ = e^{-2G} $$

- Thus, $S = Ge^{-2G}$
- Maximum throughput can be obtained by

$$ S' = e^{-2G} - 2Ge^{-2G} = e^{-2G}(1 - 2G) = 0. $$

We have $G = 0.5$.

- That is, $S = GP_0 = 0.5e^{-2G} = 0.5e^{-1} \approx 0.184.$
**Slotted ALOHA**

- Divide time into discrete intervals, called slots, each slot corresponding to one frame time
- Stations may send only at the beginning of a slot
  - Even if a station is ready to send in the middle of a slot, it must defer its transmission to the beginning of the next slot
- As such, $S = Ge^{-G}$
- That is to say, $S' = e^{-G} - Ge^{-G} = e^{-G}(1 - G) = 0$.
- We have $G = 1$ and hence maximum $S = e^{-1} \approx 0.368$
- With appropriate discipline, the maximum throughput is doubled!

**Carrier Sense Multiple Access (CSMA)**

- Station listens to channel to see if another station is transmitting
- If so, the station waits until the channel is idle
- When the channel is idle, then the frame is transmitted
- If a collision occurs, the station waits random amount of time and retransmit
- Collisions are less common because there is a very small time window between when a station detects an idle channel and when its retransmission reaches other listeners.
  - The longer the propagation delay, the longer the window and the worse the performance
**CSMA/Collision Detection (CSMA/CD)**

- As a station transmits its own packet, it listens to the transmission and, if it detects a collision, it aborts that transmission with a jamming signal.
- This reduces the amount of wasted time due to collisions.
- How long after beginning transmission may it take a station to detect a collision?

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**Binary Exponential Backoff**

- To determine the number of slots to wait before resending:
  - On first collision, wait either 0 or 1 slots.
  - On second collision, wait either 0, 1, 2, or 3 slots.
  - On third collision, wait either 0 to 7 slots.
- In general, after \( n \) collisions, wait anywhere from 0 to \( 2^n - 1 \) slots, if \( n \leq 10 \); or between 0 and 1023 slots, if \( n > 10 \).
- After 16 collisions, give up and report that packet could not be sent.
**Ethernet**

- A broadcast-based LAN technology using CSMA/CD
  - "Ether" was a hypothetic medium that, falsely assumed by many 19th century physicists, conducts electromagnetic waves.
  - The name was chosen to emphasize the broadcast nature of technology.
- The official standard is IEEE 802.3.
- The Ethernet technology comprises two parts:
  1. a DLL/MAC layer that defines frame format, error detection method, CSMA/CD parameters, and so forth
  2. a family of physical layer standards

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**The “Classic” Ethernet**

- 10 Mbp over coaxial cables
  - Physical layer standard 10Base5 called “thick Ethernet”
  - Standard 10Base2 called “thin Ethernet”
10Base5

- each cable segment up to 500 meters
- 4 repeaters can be used to cascade 5 segments, resulting in a network of diameter 2,500 meters
- signal propagation delay in the cable is approximately 0.8 light speed
- each repeater introduces 0.5 μsec delay
- minimum frame length is 64 bytes; Why?

- the slot time in the exponential backoff algorithm is 51.2 μsec, the transmission time of 64 bytes at speed 10 Mbps

Frame Format

<table>
<thead>
<tr>
<th>64</th>
<th>48</th>
<th>48</th>
<th>16</th>
<th>368 to 12000</th>
<th>32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preamble</td>
<td>Destination</td>
<td>Source</td>
<td>frame data</td>
<td>CRC Checksum</td>
<td></td>
</tr>
</tbody>
</table>

- Preamble:
  - 7 10101010's followed by 10101011
  - marks the beginning of the frame and enables the receiver's clock to synchronize with the sender's
- Source Address:
  - 48 bits each; first 24 bits vendor ID; second 24 bits assigned by the vendor
  - all Ethernet addresses are globally unique
• Destination Address:
  - due to the broadcast nature of Ethernet, every frame will be seen by the physical layer modules at all stations
  - only the physical layer module at the destination station delivers the frame to its DLL layer
  - this filtering process is performed by hardware
  - the destination address of all 1’s is called the broadcast address; frames destined to the address will be delivered to the DLL modules of all stations
  - multicast (the transmission of a frame to a subset of stations) is also supported

• Length of Data: as its name suggests

• Frame Data:
  - 0 to 1500 bytes
  - when necessary, this field is padded to make the frame 64 byte long, from destination address to checksum

• CRC Checksum
  - using CRC-32 generator polynomial
10Base-T: Twisted-Pair Ethernet

- uses the star topology
- uses two pairs of twisted-pair telephone type cable
- each cable segment up to 100 meter
- retains the 5 segment/4 repeater rule of 10Base5

Fast Ethernet

- 100 Mpbs
- uses the original Ethernet MAC and frame format but operates at ten times the speed
- The network diameter is reduced by a factor of 10. Why?
- Again, different physical layer standards support different transmission media:
  - 100Base-T and 100Base-T4 for twisted pairs
  - 100Base-F for fibers
- All these physical layer standards use the star topology.
**Gigabit Ethernet**

- 1 Gbps
- Basically the original Ethernet MAC and frame format operating at 100 times the speed.
- However, this extremely high speed forces two changes:
  - A classic Ethernet frame has to be padded to a minimum length of 4K bits.
  - Allows burst transmission, that is, the transmission of multiple frames once a station gains the “right of the road.”
- Currently only Fiber is supported (1000Base-F); twisted-pair standards are under development.

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**MAC Approach Two: Wait for Your Turn**

- A token circulates among all stations.
- When the token arrives at a station, the station either seizes the token and sends (that is, broadcasts) a frame or passes the token to the next station.
• Token based MAC handles heavy traffic loads better than CSMA/CD.
  – Efficient: no waste of bandwidth due to collisions
  – Fair: stations access the medium in a round-robin manner
  – Predictable: a station can predict the next time the token returns to it (in CSMA/CD a station waits for a “random” period of time before retransmission)

• Token-based MAC has advantages in handling real-time traffic (for example, the control of assembly lines) and multimedia traffic (where delays can be irritating).

• Two LAN technologies based on this MAC methodology:
  1. 802.4 token bus
  2. 802.5 token ring

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A Word about LAN and MAC

• The MAC technologies discussed in this talk are inherently LAN technologies.

• However, the reverse is not always true; many emerging LAN technologies are not broadcast-based and hence do not involve the MAC issue.
  – ATM
  – Switched Ethernet