Chapter 5
Link Layer and LANs

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Computer Networking:
A Top Down Approach
5th edition.
Jim Kurose, Keith Ross
Addison-Wesley, April 2009.
Link Layer

5.1 Introduction and services
5.2 Error detection and correction
5.3 Multiple access protocols
   Slotted ALOHA
   Unslotted ALOHA
   CSMA, CSMA/CD
5.4 Link-layer Addressing
5.6 Link-layer switches
5.5 Ethernet
6.3 IEEE 802.11 wireless LANs ("Wi-Fi")
5.7 PPP
5.8 Link virtualization: MPLS
5.9 A day in the life of a web request
Protocol Description

- $S_{in}$ - rate of new packets generated by the infinite population (Poisson Process)
- $G$ - rate of transmission attempts (new and old combined) (well approximated by Poisson) $G > S_{in}$
- $S_{out} = G P_0$, where $P_0$ is the probability that a frame does not suffer a collision $S_{out} = G e^{-G}$
\[ S_{\text{out}} = Ge^{-G} \]

- This quantity is maximized when \( G=1 \)
  
  "It is best to try to have 1 packet on average"

- The maximum value of \( S_{\text{out}} \) is \( 1/e \sim 0.37 \)
  
  - Note that, in that case, the channel is idle a fraction 0.37 of time, and collides 0.26 of time
We know that $S_{out}$ cannot be larger than 0.37 packets/slot.

If the system is stable we have $S_{in} = S_{out}$.

- system cannot be stable if $S_{in} > 0.37$ pkt/slot
Wait, there is worse!

- $S_{in} < 0.37$ pkt/slot is a necessary condition
  - But is it sufficient?
- No, without knowledge/coordination
  - For any $p$, the number of messages remaining to be transmitted ($B_t$) follows a Markov Chain.
    - Unfortunately, $B_t$ diverges for large $t$ with prob. 1
    - Key idea: you can never leave congested state
- Yes, if you implement some coordination
  - If $p = c/N$ where $N = B_t$, then $(B_t)$ converges
    - But needs to know population anytime to tune $p$.
  - Sometimes called, stabilized ALOHA
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From Slotted to pure ALOHA

- In reality synchronization is hard to achieve
- What if packets are not synchronized?
  - "Vulnerability period": interval such that an arrival will collide with the packet

<table>
<thead>
<tr>
<th>slotted ALOHA</th>
<th>Pure Aloha</th>
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<td><img src="image" alt="Diagram" /></td>
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- Vulnerability is *twice* larger if no synchronization
Analysis of Pure Aloha

What is the probability that no packets arrived during two slots?

- Since transm. are PoissonProcess($G$), $e^{-2G}$
- Hence $S_{out} = Ge^{-2G}$
\[ S_{\text{out}} = Ge^{-2G} \]

- This quantity is maximized when \( G = 1/2 \)
  “It is best to have 1/2 packet on average”
- The maximum value of \( S_{\text{out}} \) is \( 1/2e \approx 0.18 \)
- That means that more than 81% of your medium is wasted!
  - no matter how you tune the fixed probability
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**CSMA (Carrier Sense Multiple Access)**

**CSMA:** listen before transmit:
- If channel sensed idle: transmit entire frame
  - If channel sensed busy, defer transmission

- human analogy:
  - politeness 1.0: don’t speak if some already started!

- **Questions:**
  - Can this break the 0.18% efficiency barrier?
  - Can this avoid all collisions?
CSMA collisions

Collisions *can still occur:* propagation delay means two nodes may not hear each other’s transmission.

Collision: entire packet transmission time wasted.

Note: role of distance & propagation delay in determining collision probability.
CSMA/CD (Collision Detection)

**CSMA/CD**: carrier sensing, deferral as in CSMA
- collisions *detected* within short time
- colliding transmissions aborted, reducing channel wastage

- **collision detection:**
  - easy in wired LANs: measure signal strengths, compare transmitted, received signals
  - difficult in wireless LANs: received signal strength overwhelmed by local transmission strength

- **human analogy:**
  - Politeness 2.0: stop talking as soon as you collide
CSMA/CD collision detection

collision detect/abort time

t_0

t_1

Data Link Layer  5-15
Key question

- What to do after a collision is detected?
  - We have seen that ALOHA is stable only if probability is reduced as N grows.

- Think of human analogy
  - Politeness 3.0: wait (randomly) some amount of time before speaking again
Ethernet CSMA/CD algorithm

1. NIC receives datagram from network layer, creates frame
2. If NIC senses channel idle, starts frame transmission
   If NIC senses channel busy, waits until channel idle, then transmits
3. If NIC transmits entire frame without detecting another transmission, NIC is done with frame!
4. If NIC detects another transmission while transmitting, aborts and sends jam signal
5. After aborting, NIC enters \textit{exponential backoff}: after \textit{m}th collision, NIC chooses \( K \) at random from \( \{0,1,2,\ldots,2^m-1\} \). NIC waits \( K \cdot 512 \) bit times, returns to Step 2
Ethernet’s CSMA/CD (more)

Jam Signal: make sure all other transmitters are aware of collision; 48 bits

Bit time: .1 microsec for 10 Mbps Ethernet; for K=2, wait time is about 50 msec

Exponential Backoff:

- **Goal**: adapt retransmission attempts to estimated current load
  - heavy load: random wait will be longer
- first collision: choose K from \{0,1\}; delay is K \cdot 512 bit transmission times
- after second collision: choose K from \{0,1,2,3\}...
- after ten collisions, choose K from \{0,1,2,3,4,...,1023\}

See/interact with Java applet on AWL Web site: highly recommended!
CSMA/CD Analysis

- Can Exponential Backoff be sufficient to stabilize the system?
- In theory, NO
  - Let $B_t$ the # of stations with data to transmit
  - In fact $B_t = x_0 + x_1 + ... + x_i + ...$ where $x_i$ is the number of stations with a counter $K=i$
  - Still suffers from same unstability [Aldous86]
- In practice, YES
  - The number of stations is not so large
  - Higher level protocol reacts to congestion
CSMA/CD efficiency

- $t_{\text{prop}} = \text{max prop delay between 2 nodes in LAN}$
- $t_{\text{trans}} = \text{time to transmit max-size frame}$

\[
\text{efficiency} = \frac{1}{1 + 5\frac{t_{\text{prop}}}{t_{\text{trans}}}}
\]

- Efficiency goes to 1
  - as $t_{\text{prop}}$ goes to 0
  - as $t_{\text{trans}}$ goes to infinity

- Better performance than ALOHA: and simple, cheap, decentralized!
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+ “Taking Turns”

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“Taking Turns” MAC protocols

channel partitioning MAC protocols:
- share channel efficiently and fairly at high load
- inefficient at low load: delay in channel access, 1/N bandwidth allocated even if only 1 active node!

random access MAC protocols
- efficient at low load: single node can fully utilize channel
- high load: collision overhead

“taking turns” protocols
look for best of both worlds!
“Taking Turns” MAC protocols

Polling:
- master node “invites” slave nodes to transmit in turn
- typically used with “dumb” slave devices
- concerns:
  - polling overhead
  - latency
  - single point of failure (master)
“Taking Turns” MAC protocols

Token passing:
- control token passed from one node to next sequentially.
- token message
- concerns:
  - token overhead
  - latency
  - single point of failure (token)

Data Link Layer  5-24
Summary of MAC protocols

- **channel partitioning**, by time, frequency or code
  - Time Division, Frequency Division

- **random access** (dynamic),
  - ALOHA, S-ALOHA, CSMA, CSMA/CD
  - carrier sensing: easy in some technologies (wire), hard in others (wireless)
  - CSMA/CD used in Ethernet
  - CSMA/CA used in 802.11

- **taking turns**
  - polling from central site, token passing
  - Bluetooth, FDDI, IBM Token Ring