Lecture 6 Review

- What is the responsibility of the link layer?
- What services does the link layer provide?
- What different methods are there for error detection?
- Describe ARP
- Describe characteristics for Ethernet
- Describe characteristics of an Ethernet switch

Multiple Access Protocols

two types of "links":
- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch, host
- broadcast (shared wire or medium)
  - old-fashioned Ethernet
  - upstream HFC
  - 802.11 wireless LAN
Multiple access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

**multiple access protocol**

- distributed algorithm that determines how nodes share channel, i.e.,
  determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

**An ideal multiple access protocol**

given: broadcast channel of rate R bps
desiderata:

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

**MAC protocols: taxonomy**

Three broad classes:

- **channel partitioning**
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use

- **random access**
  - channel not divided, allow collisions
  - "recover" from collisions

- "taking turns"
  - nodes take turns, but nodes with more to send can take longer turns

**Channel partitioning MAC protocols: TDMA**

**TDMA: time division multiple access**

- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle
Channel partitioning MAC protocols: FDMA

**FDMA:** frequency division multiple access
- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle

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Random access protocols

- when node has packet to send
  - transmit at full channel data rate R.
  - no a priori coordination among nodes
- two or more transmitting nodes ⇒ “collision”.
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

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Slotted ALOHA

**Assumptions:**
- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

**Operation:**
- when node obtains fresh frame, transmits in next slot
  - if no collision: node can send new frame in next slot
  - if collision: node retransmits frame in each subsequent slot with prob. $p$ until success

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Slotted ALOHA

**Pros:**
- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

**Cons:**
- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization
Slotted ALOHA: efficiency

**Efficiency:**
long-run fraction of successful slots
(many nodes, all with many frames to send)

- Suppose: $N$ nodes with many frames to send, each transmits in slot with probability $p$.
- Prob that given node has success in a slot = $p(1 - p)^{N-1}$.
- Prob that any node has a success = $np(1 - p)^{N-1}$.
- Max efficiency: find $p^*$ that maximizes $np(1 - p)^{N-1}$.
- For many nodes, take limit of $np^*(1 - p^*)^{N-1}$ as $N$ goes to infinity, gives:
  \[ \text{max efficiency} = \frac{1}{e} = 0.37 \]

At best:
channel used for useful transmissions 37% of time!

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Pure (unslotted) ALOHA

- Unslotted Aloha: simpler, no synchronization.
- When frame first arrives:
  - Transmit immediately.
- Collision probability increases:
  - Frame sent at $t_0$ collides with other frames sent in $[t_0 - 1, t_0 + 1]$.

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Pure ALOHA efficiency

\[
P(\text{success by given node}) = \frac{p(1 - p)^{N-1} \cdot (1 - p)^{N-1}}{p(1 - p)^{2(N-1)}} = \frac{1}{2e} = 0.18
\]
even worse than slotted Aloha!

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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: don’t interrupt others!
CSMA collisions

Collisions can still occur:
- Propagation delay means two nodes may not hear each other's transmission.
- Distance and propagation delay play a role 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: the polite conversationalist.

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 binary (exponential) backoff:
   - After $m^{th}$ collision, NIC chooses $K$ at random from $\{0, 1, 2, \ldots, 2^{m-1}\}$.
   - NIC waits $K \times 512$ bit times, returns to Step 2.
   - Longer backoff interval with more collisions.
CSMA/CD efficiency

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

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

- 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!

"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)

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

- **multiple 40Mbps downstream (broadcast) channels**
  - single CMTS transmits into channels
- **multiple 30 Mbps upstream channels**
  - **multiple access**: all users contend for certain upstream channel time slots (others assigned)

**DOCSIS:** data over cable service interface spec

- FDM over upstream, downstream frequency channels
- TDM upstream: some slots assigned, some have contention
  - downstream MAP frame: assigns upstream slots
  - request for upstream slots (and data) transmitted random access (binary backoff) in selected slots

**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, token ring

**Wifi Introduction**
Mobility

wireless: communication over wireless link
mobility: handling the mobile user who changes point of attachment to network

Elements

Wireless hosts
Base station
Wireless link

Characteristics of selected wireless links

Wireless network taxonomy

<table>
<thead>
<tr>
<th>Infrastructure (e.g., APs)</th>
<th>single hop</th>
<th>multiple hops</th>
</tr>
</thead>
<tbody>
<tr>
<td>host connects to base station (WiFi, WiMAX, cellular) which connects to larger Internet</td>
<td>host may have to relay through several wireless nodes to connect to larger Internet: mesh net</td>
<td></td>
</tr>
<tr>
<td>no infrastructure</td>
<td>no base station, no connection to larger Internet (Bluetooth, ad hoc nets)</td>
<td>no base station, no connection to larger Internet. May have to relay to reach another a given wireless node MANET, VANET</td>
</tr>
</tbody>
</table>
Wireless links Characteristics

- **decreased signal strength**: radio signal attenuates as it propagates through matter (path loss)
- **interference from other sources**: standardized wireless network frequencies (e.g., 2.4 GHz) shared by other devices (e.g., phone); devices (motors) interfere as well
- **multipath propagation**: radio signal reflects off objects, arriving at destination at slightly different times

... make communication across (even a point to point) wireless link much more “difficult”

Wireless links Characteristics

- **SNR**: signal-to-noise ratio
  - larger SNR → easier to extract signal from noise (a “good thing”)
  
- **SNR versus BER tradeoffs**
  - given physical layer: increase power → increase SNR → decrease BER
  - given SNR: choose physical layer that meets BER requirement, giving highest throughput

  - SNR may change with mobility: dynamically adapt physical layer (modulation technique, rate)

Wireless network Characteristics

Multiple wireless senders and receivers create additional problems (beyond multiple access):

- **Hidden terminal problem**
  - B, A hear each other
  - B, C hear each other
  - A, C cannot hear each other means A, C unaware of their interference at B

- **Signal attenuation**
  - B, A hear each other
  - B, C hear each other
  - A, C cannot hear each other interfering at B
**Code Division Multiple Access (CDMA)**

- Unique “code” assigned to each user, i.e., code set partitioning
  - all users share same frequency, but each user has own “chipping” sequence (i.e., code) to encode data
  - allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)
- Encoded signal = (original data) × (chipping sequence)
- Decoding: inner-product of encoded signal and chipping sequence

**CDMA encode/decode**

**CDMA: two-sender interference**

**IEEE 802.11 wireless LANs (“Wi-Fi”)**
IEEE 802.11 wireless LAN

802.11b
- 2.4-5 GHz unlicensed spectrum - up to 11 Mbps
- direct sequence spread spectrum (DSSS) in physical layer
  all hosts use same chipping code

802.11a
- 5-6 GHz range - up to 54 Mbps

802.11g
- 2.4-5 GHz range - up to 54 Mbps

802.11n: multiple antennae
- 2.4-5 GHz range - up to 200 Mbps
  all use CSMA/CA for multiple access
  all have base-station and ad-hoc network versions

802.11 LAN architecture

wireless host communicates with base station
- base station = access point (AP)
- Basic Service Set (BSS) (aka "cell") in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels, association

- 802.11b: 2.4GHz-2.485GHz spectrum divided into 11 channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- host: must associate with an AP
  - scans channels, listening for beacon frames containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - may perform authentication [Chapter 8]
  - will typically run DHCP to get IP address in AP's subnet

802.11: passive/active scanning

passive scanning:
- beacon frames sent from APs
- association Request frame sent from selected AP to H1

active scanning:
- Probe Request frame broadcast from H1
- Probe Response frames sent from APs
- Association Request frame sent from H1 to selected AP
- Association Response frame sent from selected AP to H1
IEEE 802.11: multiple access

- avoid collisions: 2+ nodes transmitting at same time
- 802.11: CSMA - sense before transmitting
  - don’t collide with ongoing transmission by other node
- 802.11: no collision detection!
  - difficult to receive (sense collisions) when transmitting due to weak received signals (fading)
  - can’t sense all collisions in any case: hidden terminal, fading
  - goal: avoid collisions: CSMA/C(ollision)A(voidance)

IEEE 802.11 MAC Protocol: CSMA/CA

**802.11 sender**
1. if sense channel idle for DIFS then
   - transmit entire frame (no CD)
2. if sense channel busy then
   - start random backoff time
   - timer counts down while channel idle
   - transmit when timer expires
   - if no ACK, increase random backoff interval, repeat 2

**802.11 receiver**
- if frame received OK
  - return ACK after SIFS (ACK needed due to hidden terminal problem)

Avoiding collisions (more)

**idea:**
allow sender to “reserve” channel rather than random access of data frames: avoid collisions of long data frames

- sender first transmits small request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they’re short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

Collision Avoidance: RTS-CTS exchange
802.11 Frame: Addressing

Address 1: MAC address of wireless host or AP to receive this frame

Address 2: MAC address of wireless host or AP transmitting this frame

Address 3: MAC address of router interface to which AP is attached

Address 4: used only in ad hoc mode

802.11: mobility within same subnet

- H1 remains in same IP subnet: IP address can remain same
- switch: which AP is associated with H1?
  - self-learning (Ch. 5): switch will see frame from H1 and "remember" which switch port can be used to reach H1
802.11: advanced capabilities

Rate adaptation
- base station, mobile
dynamically change
transmission rate (physical
layer modulation technique)
as mobile moves, SNR varies

1. SNR decreases, BER increase as node moves
   away from base station
2. When BER becomes too high, switch to lower
   transmission rate but with lower BER

802.11: advanced capabilities

power management
- node-to-AP: “I am going to sleep until next beacon frame”
  ▶ AP knows not to transmit frames to this node
  ▶ node wakes up before next beacon frame
- beacon frame: contains list of mobiles with AP-to-mobile frames
  waiting to be sent
  ▶ node will stay awake if AP-to-mobile frames to be sent; otherwise sleep
    again until next beacon frame

802.15: personal area network

- less than 10 m diameter
- replacement for cables
  (mouse, keyboard,
  headphones)
- ad hoc: no infrastructure
- master/slaves:
  ▶ slaves request permission
to send (to master)
  ▶ master grants requests
- 802.15: evolved from
  Bluetooth specification
  ▶ 2.4-2.5 GHz radio band
  ▶ up to 721 kbps

Summary

- sharing a broadcast channel: multiple access
- Wireless links (capacity, distance)
- IEEE 802.11 (“Wi-Fi”) incl CSMA/CA
Status

- journey down protocol stack complete (except PHY)
- solid understanding of networking principles, practice
- Briefly covered wifi
- Next up: Security