Wireless and Mobile Networks

**Background:**

- # wireless (mobile) phone subscribers now exceeds # wired phone subscribers (5-to-1)!

- # wireless Internet-connected devices equals # wireline Internet-connected devices
  - laptops, Internet-enabled phones promise anytime untethered Internet access

- two important (but different) challenges
  - *wireless*: communication over wireless link
  - *mobility*: handling the mobile user who changes point of attachment to network
Elements of a wireless network
Elements of a wireless network

- **Network infrastructure**
- **Wireless hosts**
  - laptop, smartphone
  - run applications
  - may be stationary (non-mobile) or mobile
    - wireless does not always mean mobility
Elements of a wireless network

- base station
  - typically connected to wired network
  - relay - responsible for sending packets between wired network and wireless host(s) in its "area"
    - e.g., cell towers, 802.11 access points
Elements of a wireless network

- **Network infrastructure**

- **Wireless link**
  - Typically used to connect mobile(s) to base station
  - Also used as backbone link
  - Multiple access protocol coordinates link access
  - Various data rates, transmission distance
# 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: <em>mesh net</em></td>
<td></td>
</tr>
<tr>
<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 other a given wireless node MANET, VANET</td>
<td></td>
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</table>
Wireless network characteristics
Wireless Link Characteristics (1)

Important differences from wired link ….

- **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 ground, arriving at destination at slightly different times.

… make communication across (even a point to point) wireless link much more challenging.
Wireless Link Characteristics (2)

• 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 can not 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 can not hear each other interfering at B
IEEE 802.11 Wireless LAN

802.11b
• 2.4-5 GHz unlicensed spectrum
• up to 11 Mbps

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: 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
WiFi (802.11) multiple access

CSMA/CA
Review: 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 more or longer turns
Review: 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 $K \cdot 512$ bit times, returns to Step 2
   - longer backoff interval with more collisions
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

- RTS(A)
- RTS(B)
- CTS(A)
- DATA (A)
- ACK(A)
- reservation collision
- defer
Wireless multiple access

Code Division Multiple Access (CDMA)
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) X (chipping sequence)

- **decoding**: inner-product of encoded signal and chipping sequence
CDMA encode/decode

**Sender**

- Data bits:
  - Slot 1: \(d_1 = -1\)
  - Slot 0: \(d_0 = 1\)

- Code:
  - Slot 1: 1 1 1 1 1 1 1
  - Slot 0: 1 1 1 1 1 1 1

\[ Z_{i,m} = d_i \cdot c_m \]

**Receiver**

- Received input:
  - Slot 1: 1 1 1 1 1 1 1
  - Slot 0: 1 1 1 1 1 1 1

- Code:
  - Slot 1: 1 1 1 1 1 1 1
  - Slot 0: 1 1 1 1 1 1 1

\[ D_i = \sum_{m=1}^{M} Z_{i,m} \cdot c_m \]

\[ d_0 = 1 \]
CDMA: two-sender interference

Sender 1
- Data bits: 1, 1, -1, 1, 1, 1, -1, 1
- Code: 2, 2, 2, 2, 2, 2, 2, 2

Sender 2
- Data bits: 1, 1, 1, 1, 1, 1, 1, 1
- Code: 2, 2, 2, 2, 2, 2, 2, 2

Receiver 1
- Using same code as sender 1, receiver recovers sender 1’s original data from summed channel data!

Channel sums together transmissions by sender 1 and 2

\[ Z_{i,m} = d_i^1 c_m \]

\[ d_i^1 = \sum_{m=1}^{M} Z_{i,m}^* c_m^1 \]
Summary of the wireless link layer

• Wireless medium is very different from wired
  • Signal attenuation (“fading”) much more important to handle
  • Hidden terminal problem

• Consequences of differences:
  • Link-layer ACKs
  • Transmission delays to control contention: SIFS, DIFS
  • Link reservation (RTS/CTS)

• Medium access control
  • Frequency division multiple access (AP channels in WiFi)
  • Random access (CSMA/CA for transmitting to/from WiFi AP)
  • Code division multiple access (simultaneous transmission in cellular networks)