CS 332
Computer Networks
Wireless Networks

Professor Szajda
Background:

• # wireless (mobile) phone subscribers now exceeds # wired phone subscribers!

• computer nets: laptops, smartphones, tablets promise anytime untethered Internet access

• two important (but different) challenges
  ‣ communication over wireless link
  ‣ handling mobile user who changes point of attachment to network
Chapter 6 outline

6.1 Introduction

Wireless

• 6.2 Wireless links, characteristics
  ‣ CDMA

• 6.3 IEEE 802.11 wireless LANs (“wi-fi”)

• 6.4 Cellular Internet Access
  ‣ architecture
  ‣ standards (e.g., GSM)

Mobility

• 6.5 Principles: addressing and routing to mobile users
• 6.6 Mobile IP
• 6.7 Handling mobility in cellular networks
• 6.8 Mobility and higher-layer protocols

6.9 Summary
Elements of a wireless network

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

- **Network infrastructure**
  - 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
Characteristics of selected wireless link standards

<table>
<thead>
<tr>
<th>Data rate (Mbps)</th>
<th>Indoor (10-30m)</th>
<th>Outdoor (50-200m)</th>
<th>Mid-range outdoor (200m – 4 Km)</th>
<th>Long-range outdoor (5Km – 20 Km)</th>
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</thead>
<tbody>
<tr>
<td>802.15</td>
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<tr>
<td>802.11b</td>
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<tr>
<td>802.11a,g</td>
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<td>802.11n</td>
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<tr>
<td>802.16 (WiMAX)</td>
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<tr>
<td>UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO</td>
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</tbody>
</table>

- **2G** standards: 802.15, IS-95, CDMA, GSM
- **3G** standards: UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO, UMTS/WCDMA, CDMA2000
- **3G cellular enhanced** standards: 802.16 (WiMAX)
- **4G** standards: 802.11a,g point-to-point

**Indoor** range: 10-30m
**Outdoor** range: 50-200m
**Mid-range outdoor** range: 200m – 4 Km
**Long-range outdoor** range: 5Km – 20 Km
Elements of a wireless network

- **infrastructure mode**
  - base station connects mobiles into wired network
  - handoff: mobile changes base station providing connection into wired network
Elements of a wireless network

Ad hoc mode
- no base stations
- nodes can only transmit to other nodes within link coverage
- nodes organize themselves into a network: route among themselves
## 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>no base station, no connection to larger Internet. May have to relay to reach other a given wireless node MANET, VANET</td>
</tr>
<tr>
<td>no base station, no connection to larger Internet (Bluetooth, ad hoc nets)</td>
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</table>
Wireless Link Characteristics

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 “difficult”
Wireless Link 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)
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 fading:**
- B, A hear each other
- B, C hear each other
- A, C cannot hear each other

interfering at B
Code Division Multiple Access (CDMA)

- used in several wireless broadcast channels (cellular, satellite, etc) standards
- 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
- encoded signal = (original data) \( \times \) (chipping sequence)
- decoding: inner-product of encoded signal and chipping sequence
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)
CDMA Encode/Decode

sender

data bits

\[ d_1 = -1 \]
\[ d_0 = 1 \]

code

channel output \( Z_{i,m} = d_i \cdot c_m \)

slot 1

slot 0

receiver

received input

code

\[ d_1 = -1 \]
\[ d_0 = 1 \]

channel output

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

M

slot 1

slot 0

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CDMA: two-sender interference

senders

```
data bits  | data bits  | channel, $Z^*$
data bits  | data bits  | channel, $Z^*$
  1 1 1 1 1 | 1 1 1 1 1 | 2 2 2 2 2
  -1 -1 -1 -1 | -1 -1 -1 -1 | 2 2
```

receiver 1

```
data bits  | data bits  | slot 1 received input
  1 1 1 1 1 | 1 1 1 1 1 | 2 2 2 2 2
  -1 -1 -1 -1 | -1 -1 -1 -1 | 2 2
```

```
data bits  | slot 0 received input
  1 1 1 1 1 | 1 1 1 1 1
  -1 -1 -1 -1 | -1 -1 -1 -1
```

```
d_1 = \sum_{m=1}^{M} Z_{i,m}^* c_m^1
```

```
d_2 = 1
```

```
d_3 = -1
```

```
d_4 = 1
```
Chapter 6 outline

6.1 Introduction

**Wireless**

- **6.2 Wireless links, characteristics**
  - CDMA
- **6.3 IEEE 802.11 wireless LANs (“wi-fi”)**
- **6.4 Cellular Internet Access**
  - architecture
  - standards (e.g., GSM)

**Mobility**

- **6.5 Principles: addressing and routing to mobile users**
- **6.6 Mobile IP**
- **6.7 Handling mobility in cellular networks**
- **6.8 Mobility and higher-layer protocols**

6.9 Summary
IEEE 802.11 Wireless LAN

- **802.11b**
  - 2.4-5 GHz unlicensed radio spectrum
  - up to 11 Mbps
  - direct sequence spread spectrum (DSSS) in physical layer
    - all hosts use same chipping code
  - widely deployed, using base stations

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

- **802.11g**
  - 2.4-5 GHz range
  - up to 54 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 (service set identifier (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:**
1. Beacon frames sent from APs
2. Association Request frame sent: H1 to selected AP
3. Association Response frame sent: selected AP to H1

**Active Scanning:**
1. Probe Request frame broadcast from H1
2. Probes response frame sent from APs
3. Association Request frame sent: H1 to selected AP
4. Association Response frame sent: 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
  - Short inter-frame space
  - 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
- RTS 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) from A
- RTS(B) from B
- Reservation collision
- CTS(A) from A
- DATA (A)
- ACK(A) from A
- ACK(A) from B
- deferral
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 Frame: Addressing

802.11 frame:
- AP MAC addr
- H1 MAC addr
- R1 MAC addr

802.3 frame:
- R1 MAC addr
- H1 MAC addr

Internet

H1 -> AP -> router -> Internet

AP
R1
router

address 1
address 2
address 3
# 802.11 Frame: More

802.11 Frame: More

<table>
<thead>
<tr>
<th>Frame Control</th>
<th>Duration</th>
<th>Address 1</th>
<th>Address 2</th>
<th>Address 3</th>
<th>Seq Control</th>
<th>Address 4</th>
<th>Payload</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>2</td>
<td>6</td>
<td>0 - 2312</td>
<td>4</td>
</tr>
</tbody>
</table>

- **Duration of reserved transmission time (RTS/CTS)**
- **Frame seq # (for reliable ARQ)**
- **Frame type (RTS, CTS, ACK, data)**

<table>
<thead>
<tr>
<th>Protocol version</th>
<th>Type</th>
<th>Subtype</th>
<th>To AP</th>
<th>From AP</th>
<th>More frag</th>
<th>Retry</th>
<th>Power mgt</th>
<th>More data</th>
<th>WEP</th>
<th>Rsvd</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
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
802.11: 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
802.16: WiMAX

- like 802.11 & cellular: base station model
  - transmissions to/from base station by hosts with omnidirectional antenna
  - base station-to-base station backhaul with point-to-point antenna

- unlike 802.11:
  - range ~ 6 miles ("city rather than coffee shop")
  - ~14 Mbps
802.16: WiMAX: Downlink, Uplink Scheduling

- transmission frame
  - down-link subframe: base station to node
  - uplink subframe: node to base station
- WiMAX standard provide mechanism for scheduling, but not scheduling algorithm

[Diagram: Flowchart showing DL and UL frames with SS #1, SS #2, and SS #k.]

- base station tells nodes who will get to receive (DL map) and who will get to send (UL map), and when
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Components of Cellular Network Architecture

- **cell**
  - covers geographical region
  - **base station (BS)** analogous to 802.11 AP
  - **mobile users** attach to network through BS
  - **air-interface**: physical and link layer protocol between mobile and BS

**MSC**
- connects cells to wide area net
- manages call setup (more later!)
- handles mobility (more later!)

Public telephone network, and Internet

wired network
Cellular networks: the first hop

Two techniques for sharing mobile-to-BS radio spectrum

• **combined FDMA/TDMA:** divide spectrum in frequency channels, divide each channel into time slots

• **CDMA:** code division multiple access
Wireless Standards Evolution to 4G

1G
- Analog AMPS

2G
- IS-95-A/ cdmaOne
- IS-95-B/ cdmaOne

2.5G
- IS-136 TDMA

2.75G
- GSM
- GPRS
- HSCSD

3G
- Existing Spectrum
- 700 MHz
- CDMA2000 1xRTT (1.25 MHz)
- CDMA2000 1xEVDO (1.25 MHz)

4G
- LTE
- WiMAX
- WCDMA
Next Time

- Read Sections 6.5-6.8
  - Mobility