Chapter 6: Wireless and Mobile Networks

Background:
- # wireless (mobile) phone subscribers now exceed # wired phone subscribers!
- computer nets: laptops, palmtops, PDAs, Internet-enabled phone 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
- 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

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**
  - 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

- **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

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Characteristics of selected wireless link standards

- **54 Mbps**
  - 802.11(a,g)
- **5-11 Mbps**
  - 802.11b
- **1 Mbps**
  - 802.15

- **384 Kbps**
  - UMTS/WCDMA, CDMA2000
- **56 Kbps**
  - IS-95 CDMA, GSM

- **54 Mbps**
  - 802.11(a,g)
- **56 Kbps**
  - 802.15

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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 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 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 fading:**
  - B, A hear each other
  - B, C hear each other
  - A, C can not 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
- Code
- Slot 1
- Slot 0
- $Z_{in} = d_i c_m$
- Channel output

Receiver

- Received input
- Code
- Slot 1
- Slot 0
- $D_i = \sum_{m=1}^M Z_{in} c_m$

**CDMA: two-sender interference**

Senders

- Data bits
- Code
- Slot 1
- Slot 0
- Channel output

Receiver 1

- Received input
- Code
- Slot 1
- Slot 0
- Channel output

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- 6.5 Principles: addressing and routing to mobile users

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**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 (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

**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 (collision) A (avoidance)

**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
- RTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

Avoid data frame collisions completely using small reservation packets!

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**Collision Avoidance: RTS-CTS exchange**

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**802.11 frame: addressing**

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**802.11 frame: addressing**
**802.11 frame: more**

- 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 mgmt</th>
<th>More data</th>
<th>WEP</th>
<th>Rsvd</th>
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**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

**802.15: 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

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- 6.6 Mobile IP
- 6.7 Handling mobility in cellular networks
- 6.8 Mobility and higher-layer protocols

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)

6.9 Summary
What is mobility?

- Spectrum of mobility, from the network perspective:
  - No mobility
  - High mobility

  - Mobile wireless user, using same access point
  - Mobile user, connecting/disconnecting from network using DHCP
  - Mobile user, passing through multiple access points while maintaining ongoing connections (like cell phone)

Mobility: Vocabulary

- **Home network**: permanent "home" of mobile (e.g., 128.119.40/24)
- **Home agent**: entity that will perform mobility functions on behalf of mobile, when mobile is remote

- **Permanent address**: address in home network, can always be used to reach mobile e.g., 128.119.40.186

- **Visited network**: network in which mobile currently resides (e.g., 79.129.13/24)
- **Care-of-address**: address in visited network (e.g., 79.129.13.2)

- **Home agent**: entity in visited network that performs mobility functions on behalf of mobile

- **Correspondent**: wants to communicate with mobile

Mobility: more vocabulary

- **Permanent address**: remains constant (e.g., 128.119.40.186)
- **Care-of-address**: address in visited network (e.g., 79.129.13.2)

How do you contact a mobile friend?

Consider friend frequently changing addresses, how do you find her?

- Search all phone books?
- Call her parents?
- Expect her to let you know where he/she is?
Mobility: approaches

- Let routing handle it: routers advertise permanent address of mobile-nodes-in-residence via usual routing table exchange.
  - Routing tables indicate where each mobile located
  - No changes to end-systems
- Let end-systems handle it:
  - Indirect routing: communication from correspondent to mobile goes through home agent, then forwarded to remote
  - Direct routing: correspondent gets foreign address of mobile, sends directly to mobile

Mobility: registration

End result:
- Foreign agent knows about mobile
- Home agent knows location of mobile

Mobility via Indirect Routing

- Correspondent addresses packets using home address of mobile
- Home agent intercepts packets, forwards to foreign agent
- Foreign agent receives packets, forwards to mobile
- Mobile replies directly to correspondent
**Indirect Routing: comments**

- Mobile uses two addresses:
  - Permanent address: used by correspondent (hence mobile location is transparent to correspondent)
  - Care-of-address: used by home agent to forward datagrams to mobile
- Foreign agent functions may be done by mobile itself
- Triangle routing: correspondent-home-network-mobile
  - Inefficient when correspondent, mobile are in same network

**Indirect Routing: moving between networks**

- Suppose mobile user moves to another network
  - Registers with new foreign agent
  - New foreign agent registers with home agent
  - Home agent update care-of-address for mobile
  - Packets continue to be forwarded to mobile (but with new care-of-address)
- Mobility, changing foreign networks transparent: ongoing connections can be maintained!

**Mobility via Direct Routing**

- Correspondent forwards to foreign agent
- Foreign agent receives packets, forwards to mobile
- Visited network
- Correspondent requests, receives foreign address of mobile
- Mobile replies directly to correspondent

**Mobility via Direct Routing: comments**

- Overcome triangle routing problem
- Non-transparent to correspondent: correspondent must get care-of-address from home agent
  - What if mobile changes visited network?
Accommodating mobility with direct routing

- anchor foreign agent: FA in first visited network
- data always routed first to anchor FA
- when mobile moves: new FA arranges to have data forwarded from old FA (chaining)

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Mobile IP

- RFC 3220

- has many features we've seen:
  - home agents, foreign agents, foreign-agent registration, care-of-addresses, encapsulation (packet-within-a-packet)

- three components to standard:
  - indirect routing of datagrams
  - agent discovery
  - registration with home agent

Mobile IP: indirect routing

<table>
<thead>
<tr>
<th>Permanent address: 128.119.40.186</th>
</tr>
</thead>
<tbody>
<tr>
<td>Care-of address: 79.129.13.2</td>
</tr>
<tr>
<td>packet sent by correspondent</td>
</tr>
<tr>
<td>dest: 128.119.40.186</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Foreign-agent-to-mobile packet</th>
</tr>
</thead>
<tbody>
<tr>
<td>dest: 128.119.40.186</td>
</tr>
<tr>
<td>packet sent by home agent to foreign agent: a packet within a packet</td>
</tr>
<tr>
<td>dest: 79.129.13.2</td>
</tr>
</tbody>
</table>
**Mobile IP: agent discovery**

- **agent advertisement**: foreign/home agents advertise service by broadcasting ICMP messages (typefield = 9)

```
<table>
<thead>
<tr>
<th>0</th>
<th>8</th>
<th>16</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>type = 9</td>
<td>code = 0</td>
<td>checksum</td>
<td></td>
</tr>
</tbody>
</table>
```

**H,F bits**: home and/or foreign agent

**R bit**: registration required

**0 or more care-of-addresses**

**Mobile IP: registration example**

**Chapter 6 Summary**

**Wireless**

- **wireless links**:
  - capacity, distance
  - channel impairments
  - CDMA

- **IEEE 802.11 ("wi-fi")**
  - CSMA/CA reflects wireless channel characteristics

**Mobility**

- **principles**: addressing, routing to mobile users
  - home, visited networks
  - direct, indirect routing
  - care-of-addresses

- **case studies**
  - mobile IP
  - mobility in GSM

- **impact on higher-layer protocols**