Chapter 7
Wireless and Mobile Networks

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Ch. 6: 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
Chapter 7 outline

7.1 Introduction

Wireless
7.2 Wireless links, characteristics
   • CDMA
7.3 IEEE 802.11 wireless LANs (“Wi-Fi”)

Skipping
7.4 Cellular Internet Access
   • architecture
   • standards (e.g., 3G, LTE)

Mobility
7.5 Principles: addressing and routing to mobile users

Skipping:
7.6 Mobile IP
7.7 Handling mobility in cellular networks
7.8 Mobility and higher-layer protocols
Elements of a wireless network

network infrastructure
Elements of a wireless network

- Wireless hosts
  - laptop, smartphone
  - run applications
  - may be stationary (non-mobile) or mobile
    - wireless does not always mean mobility

Network infrastructure
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

- 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

Network infrastructure
Characteristics of selected wireless links

Indoor
- 10-30m

Outdoor
- 50-200m

Mid-range outdoor
- 200m – 4 Km

Long-range outdoor
- 5Km – 20 Km

Data rates (Mbps):
- 802.15: 1
- 802.11b: 5-11
- 802.11a,g: 54
- 802.11n: 450
- 802.11 ac: 1300

Wireless technologies:
- 2G: IS-95, CDMA, GSM
- 2.5G: UMTS/WCDMA, CDMA2000
- 3G: UMTS/WCDMA-HSPDA, CDMA2000-1xEVDO
- 4G: LTWE WIMAX
- 802.11a,g point-to-point

Wireless and Mobile Networks 7-8
Elements of a wireless network

- **Infrastructure mode**
  - Base station connects mobiles into a wired network.
  - Handoff: Mobile changes base station providing connection into wired network.

Network infrastructure
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
<table>
<thead>
<tr>
<th>wireless network taxonomy</th>
<th>single hop</th>
<th>multiple hops</th>
</tr>
</thead>
<tbody>
<tr>
<td>infrastructure (e.g., APs)</td>
<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>
</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 other a given wireless node MANET, VANET</td>
</tr>
</tbody>
</table>
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7.6 Mobile IP
7.7 Handling mobility in cellular networks
7.8 Mobility and higher-layer protocols
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 “difficult”
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
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**
  - $d_1 = -1$
  - $d_0 = 1$
- **code**
  - Slot 1: 1 1 1 1 -1 -1 -1 -1
  - Slot 0: 1 1 1 1 -1 -1 -1 -1

**channel output $Z_{i,m} = d_i \cdot c_m$**
- Slot 1 output: 1 1 1 1 -1 -1 -1 -1
- Slot 0 output: 1 1 1 1 -1 -1 -1 -1

**receiver**
- **received input**
  - Code: 1 1 1 1 -1 -1 -1 -1
- **M**

**$D_i = \sum_{m=1}^{M} Z_{i,m} \cdot c_m$**

**output**
- Slot 1: $d_1 = -1$
- Slot 0: $d_0 = 1$
CDMA: two-sender interference

Sender 1

Sender 2

channel sums together transmissions by sender 1 and 2

receiver 1

using same code as sender 1, receiver recovers sender 1’s original data from summed channel data!
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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:**
1. beacon frames sent from APs
2. association Request frame sent: H1 to selected AP
3. association Response frame sent from selected AP to H1

**active scanning:**
1. Probe Request frame broadcast from H1
2. Probe Response frames sent from APs
3. Association Request frame sent: H1 to selected AP
4. 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)
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) from A
- RTS(B) from B
- Reservation collision
- CTS(A) from the AP
- DATA (A)
- ACK(A)
- defer
# 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 |

<table>
<thead>
<tr>
<th>Frame</th>
<th>Duration</th>
<th>Address 1</th>
<th>Address 2</th>
<th>Address 3</th>
<th>Sequence 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>
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- Address 1: MAC address of wireless host or AP transmitting this frame
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802.11 frame: addressing

802.11 frame

AP MAC addr | H1 MAC addr | R1 MAC addr
address 1    | address 2   | address 3

802.3 frame

Internet

R1 router

dest. address | source address
R1 MAC addr   | H1 MAC addr
802.11 frame: more

frame type (RTS, CTS, ACK, data)

duration of reserved transmission time (RTS/CTS)

frame seq # (for RDT)

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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
**802.11: 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

Master device
Slave device
Parked device (inactive)
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Mobility

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7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols
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 wired tel. net.
  - manages call setup (more later!)
  - handles mobility (more later!)

*Public telephone network*

*Mobile Switching Center*

*Mobile Switching Center*
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
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What is mobility?

- spectrum of mobility, from the *network* perspective:

  - no mobility
  - mobile wireless user, using same access point
  - mobile user, connecting/disconnecting from network using DHCP.
  - mobile user, passing through multiple access point while maintaining ongoing connections (like cell phone)
  - high mobility
**Mobility: vocabulary**

- **home network**: permanent "home" of mobile (e.g., 128.119.40/24)
- **permanent address**: address in home network, *can always* be used to reach mobile (e.g., 128.119.40.186)
- **home agent**: entity that will perform mobility functions on behalf of mobile, when mobile is remote

**Diagram:**
- **Wide area network**
- **Home network**
- **Home agent**
- **Mobile device**

*Wireless and Mobile Networks 7-40*
Mobility: more vocabulary

**permanent address**: remains constant (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)

**foreign agent**: entity in visited network that performs mobility functions on behalf of mobile.

**correspondent**: wants to communicate with mobile

**wide area network**
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?
- Facebook!

I wonder where Alice moved to?
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: 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

*not scalable to millions of mobiles*
Mobility: registration

end result:
- foreign agent knows about mobile
- home agent knows location of mobile
Mobility via indirect routing

1. Correspondent addresses packets using home address of mobile.
2. Home agent intercepts packets, forwards to foreign agent.
3. Foreign agent receives packets, forwards to mobile.
4. Mobile replies directly to correspondent.

- Home network
- Wide area network
- Visited network
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 updates care-of-address for mobile
  - packets continue to be forwarded to mobile (but with new care-of-address)

- mobility, changing foreign networks transparent: on going connections can be maintained!
Mobility via direct routing

1. Correspondent requests to send packets to a mobile device.
2. Correspondent forwards the request to a foreign agent.
3. Foreign agent receives the packets and forwards them to the mobile device.
4. Mobile device replies directly to the correspondent.

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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)
Chapter 7 summary

Wireless

- wireless links:
  - capacity, distance
  - channel impairments
  - CDMA
- IEEE 802.11 (“Wi-Fi”)
  - CSMA/CA reflects wireless channel characteristics
- cellular access
  - architecture
  - standards (e.g., 3G, 4G LTE)

Mobility

- principles: addressing, routing to mobile users
  - home, visited networks
  - direct, indirect routing
  - care-of-addresses
- case studies
  - mobile IP
  - mobility in GSM, LTE
- impact on higher-layer protocols