Chapter 7
Wireless and Mobile Networks

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Background:

- The number of wireless (mobile) phone subscribers now exceeds the number of wired phone subscribers (5-to-1)!
- The number of wireless Internet-connected devices equals the number of 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
6.73 IEEE 802.11 wireless LANs (“Wi-Fi”)
67.4 Cellular Internet Access
  - architecture
  - standards (e.g., 3G, LTE)

**Mobility**
7.5 Principles: addressing and routing to mobile users
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

Wireless and Mobile Networks 7-4
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
Characteristics of selected wireless links

- **Indoor (10-30m)**
  - 802.15
  - 2G: IS-95, CDMA, GSM

- **Outdoor (50-200m)**
  - 802.11a,g
  - 3G: UMTS/WCDMA-HSDPA, CDMA2000-1xEVDO
  - 2.5G: UMTS/WCDMA, CDMA2000
  - 4G: LTE WIMAX

- **Mid-range outdoor (200m – 4 Km)**
  - 802.11a,g point-to-point

- **Long-range outdoor (5Km – 20 Km)**
  - 802.11n
  - 802.11ac
  - 802.11b

Data rate (Mbps):

- 802.15: 1
- 802.11b: 5-11
- 802.11a,g: 54
- 802.11n: 450
- 802.11ac: 1300
- 802.11ac point-to-point: 450

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

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

Wireless and Mobile Networks 7-9
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><em>infrastructure</em></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><em>no infrastructure</em></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>

*MANET, VANET*
Chapter 7 outline

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   • CDMA
7.3 IEEE 802.11 wireless LANs (“Wi-Fi”)
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   • architecture
   • standards (e.g., 3G, LTE)

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7.6 Mobile IP
7.7 Handling mobility in cellular networks
7.8 Mobility and higher-layer protocols
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 \(\rightarrow\) increase SNR \(\rightarrow\) 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

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

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

Channel output \( Z_{i,m} \):
- \( Z_{i,m} = d_i \cdot c_m \)

**Receiver**
- \( D_i = \sum_{m=1}^{M} Z_{i,m} \cdot c_m \)
- \( d_1 = -1 \)
- \( d_0 = 1 \)

**Sender**
- Channel output:
  - Slot 1: 1 1 1 1 -1 -1 -1 -1
  - Slot 0: 1 1 1 1 -1 -1 -1 -1

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CDMA: two-sender interference

**Senders**

**Sender 1**
- Data bits: $d_1 = -1$
- Code: $11111111-1-1-1$

**Sender 2**
- Data bits: $d_2^1 = 1$, $d_2^2 = 1$
- Code: $11111111111$

**Channel, $Z_{i,m}^*$**

$Z_{i,m}^1 = d_1^1 c_m^1$

$Z_{i,m}^2 = d_2^2 c_m^2$

**Receiver 1**
- Data bits $d_1 = -1$
- Code: $11111111-1-1-1$

**Channel sums together transmissions by sender 1 and 2**

$Z_{i,m} = Z_{i,m}^1 + Z_{i,m}^2$

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

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

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: $2^+ \text{ nodes transmitting at same time}$
- 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
   a. Start random backoff time
   b. Timer counts down while channel idle
   c. Transmit when timer expires
   d. 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

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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 router

H1

802.11 frame: addressing
### 802.11 frame: more

- **Frame Control**: Contains information about the frame type, protocol version, and duration.

- **Duration of reserved transmission time (RTS/CTS)**: Indicates the time required for the RTS/CTS packet.

- **Frame seq # (for RDT)**: Sequence number for RDT frames.

- **Frame Type**: Includes RTS, CTS, ACK, and data types.

- **Address 1-4**: Source and destination addresses.

- **Sequence Control**: Sequence number for the frame.

- **Payload**: Data payload of the frame.

- **CRC**: Cyclic Redundancy Check for error detection.

<table>
<thead>
<tr>
<th>Field</th>
<th>Length</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame Control</td>
<td>2</td>
<td>Contains frame type, protocol version, and duration.</td>
</tr>
<tr>
<td>Duration</td>
<td>2</td>
<td>Duration of reserved transmission time (RTS/CTS).</td>
</tr>
<tr>
<td>Address 1</td>
<td>6</td>
<td>Source address.</td>
</tr>
<tr>
<td>Address 2</td>
<td>6</td>
<td>Destination address.</td>
</tr>
<tr>
<td>Address 3</td>
<td>6</td>
<td>Source address.</td>
</tr>
<tr>
<td>Address 4</td>
<td>6</td>
<td>Destination address.</td>
</tr>
<tr>
<td>Sequence Control</td>
<td>2</td>
<td>Sequence number for the frame.</td>
</tr>
<tr>
<td>Address 4</td>
<td>6</td>
<td>Source address.</td>
</tr>
<tr>
<td>Payload</td>
<td>0 - 2312</td>
<td>Data payload.</td>
</tr>
<tr>
<td>CRC</td>
<td>4</td>
<td>Cyclic Redundancy Check.</td>
</tr>
<tr>
<td>Type</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>Subtype</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>To AP</td>
<td>1</td>
<td>Destination address.</td>
</tr>
<tr>
<td>From AP</td>
<td>1</td>
<td>Source address.</td>
</tr>
<tr>
<td>More frag</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>Retry</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>Power mgt</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>More data</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>WEP</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</td>
</tr>
<tr>
<td>Rsvd</td>
<td>1</td>
<td>Frame type: RTS, CTS, ACK, data.</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

![Graph showing BER vs SNR]

- QAM256 (8 Mbps)
- QAM16 (4 Mbps)
- BPSK (1 Mbps)
- Operating point
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
What haven’t we talked about yet?

- Other sources of interference/bit errors
  - e.g. interference, reflection, WiFi channels, etc.
- 802.11 operating modes
  - master and managed (collectively, infrastructure), ad hoc, mesh, repeater, promiscuous, and monitor
- Security
  - e.g. the difference between WEP and WPA?
  - Open WiFi?
- Anything else?
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  • architecture
  • standards (e.g., 3G, LTE)

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7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols
Components of cellular network architecture

- **MSC**
  - connects cells to wired tel. net.
  - manages call setup (more later!)
  - handles mobility (more later!)

**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

**Public telephone network**

**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
2G (voice) network architecture

Base station system (BSS)

Base transceiver station (BTS)

Base station controller (BSC)

Mobile Switching Center (MSC)

Mobile subscribers

Legend

Base transceiver station (BTS)
Base station controller (BSC)
Mobile Switching Center (MSC)

Public telephone network

Gateway MSC

Legend

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3G (voice+data) network architecture

Key insight: new cellular data network operates in parallel (except at edge) with existing cellular voice network

- voice network unchanged in core
- data network operates in parallel

MSC

SGSN

GGSN

Gateway MSC

Public telephone network

Public Internet

Serving GPRS Support Node (SGSN)

Gateway GPRS Support Node (GGSN)
3G (voice+data) network architecture

- Radio access network (WCDMA, HSPA)
- Universal Terrestrial Radio Access Network (UTRAN)
- Core network: General Packet Radio Service (GPRS) Core Network
- Public Internet
- Gateway MSC
- Public telephone network
- GGSN

Diagram: 3G network architecture with MSC, SGSN, and GGSN connected to radio network controller.
3G versus 4G LTE network architecture

**3G**
- Radio network controller
- MSC
- SGSN

**4G-LTE**
- MSC
- Gateway MSC
- SGSN
- GGSN
- MME
- HSS
- S-GW
- P-GW

3G Universal Terrestrial Radio Access Network (UTRAN)
4G-LTE Evolved Packet Core (EPC)

Public telephone network
Public Internet

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4G: differences from 3G

- all IP core: IP packets tunneled (through core IP network) from base station to gateway
- no separation between voice and data – all traffic carried over IP core to gateway
Functional split of major LTE components

- eNodeB
  - Inter-cell RRM
  - RB control
  - Connection Mobility Control
  - Radio Admission Control
  - eNB measurement configuration and provision
  - Dynamic resource allocation (scheduler)
- RRC
- PDCP
- RLC
- MAC
- PHY

- MME
  - NAS security
  - Idle state mobility handling
  - EPS Bearer Control
- S-GW
  - Mobile anchoring
- P-GW
  - UE IP address allocation
  - Packet filtering

- E-UTRAN
- S1
- EPC
- Internet

Handles idle/active UE transitions
Pages UE
Sets up eNodeB-PGW tunnel (aka bearer)

Holds idle UE info
QoS enforcement
Radio+Tunneling: UE – eNodeB – PGW

IP packet from UE encapsulated in GPRS Tunneling Protocol (GTP) message at eNodeB

GTP message encapsulated in UDP, then encapsulated in IP. Large IP packet addressed to S-GW

Link-layer radio net
Quality of Service in LTE

- QoS from eNodeB to SGW: min and max guaranteed bit rate
- QoS in radio access network: one of 12 QCI values

<table>
<thead>
<tr>
<th>QCI</th>
<th>RESOURCE TYPE</th>
<th>PRIORITY</th>
<th>PACKET DELAY BUDGET (MS)</th>
<th>PACKET ERROR LOSS RATE</th>
<th>EXAMPLE SERVICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GBR</td>
<td>2</td>
<td>100</td>
<td>$10^2$</td>
<td>Conversational voice</td>
</tr>
<tr>
<td>2</td>
<td>GBR</td>
<td>4</td>
<td>150</td>
<td>$10^3$</td>
<td>Conversational video (live streaming)</td>
</tr>
<tr>
<td>3</td>
<td>GBR</td>
<td>5</td>
<td>300</td>
<td>$10^6$</td>
<td>Non-conversational video (buffered streaming)</td>
</tr>
<tr>
<td>4</td>
<td>GBR</td>
<td>3</td>
<td>50</td>
<td>$10^3$</td>
<td>Real-time gaming</td>
</tr>
<tr>
<td>5</td>
<td>Non-GBR</td>
<td>1</td>
<td>100</td>
<td>$10^6$</td>
<td>IMS signaling</td>
</tr>
<tr>
<td>6</td>
<td>Non-GBR</td>
<td>7</td>
<td>100</td>
<td>$10^3$</td>
<td>Voice, video (live streaming), interactive gaming</td>
</tr>
<tr>
<td>7</td>
<td>Non-GBR</td>
<td>6</td>
<td>300</td>
<td>$10^6$</td>
<td>Video (buffered streaming)</td>
</tr>
<tr>
<td>8</td>
<td>Non-GBR</td>
<td>8</td>
<td>300</td>
<td>$10^6$</td>
<td>TCP-based (for example, WWW, e-mail), chat, FTP, p2p file sharing, progressive video and others</td>
</tr>
<tr>
<td>9</td>
<td>Non-GBR</td>
<td>9</td>
<td>300</td>
<td>$10^6$</td>
<td></td>
</tr>
</tbody>
</table>
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What is mobility?

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

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

*Wireless and Mobile Networks* 7-49
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!
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
**Mobility: registration**

**end result:**
- foreign agent knows about mobile
- home agent knows location of mobile

![Diagram showing mobility registration process](image)
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 update 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, receives foreign address of mobile
2. Correspondent forwards to foreign agent
3. Foreign agent receives packets, forwards to mobile
4. Mobile replies directly to correspondent

Wireless and Mobile Networks 7-58
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 outline

7.1 Introduction

Wireless

7.2 Wireless links, characteristics
   • CDMA

7.3 IEEE 802.11 wireless LANs (“Wi-Fi”)

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

Mobility

7.5 Principles: addressing and routing to mobile users

7.6 Mobile IP

7.7 Handling mobility in cellular networks

7.8 Mobility and higher-layer protocols
Mobile IP

- RFC 3344
- 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

- Permanent address: 128.119.40.186
- Care-of address: 79.129.13.2

- Packet sent by home agent to foreign agent: a *packet within a packet*
- Packet sent by correspondent: dest: 128.119.40.186
- Foreign-agent-to-mobile packet: dest: 128.119.40.186
- Wireless and Mobile Networks 7-63
Mobile IP: agent discovery

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

```
+-------------------+-------------------+-------------------+
| 0 | 8 | 16 | 24 |
+-------------------+-------------------+-------------------+
| type = 9          | code = 0          | checksum          |
|                    | router address    |                   |
| type = 16         | length            | sequence #        |
| registration lifetime | RBHFMGV bits | reserved |
+-------------------+-------------------+-------------------+
```

- H,F bits: home and/or foreign agent
- R bit: registration required

Wireless and Mobile Networks 7-64
Mobile IP: registration example

visited network: 79.129.13/24

home agent
HA: 128.119.40.7

foreign agent
COA: 79.129.13.2

mobile agent
MA: 128.119.40.186

registration req.
COA: 79.129.13.2
HA: 128.119.40.7
MA: 128.119.40.186
Lifetime: 9999
Identification: 714
encapsulation format
....

registration reply
HA: 128.119.40.7
MA: 128.119.40.186
Lifetime: 4999
Identification: 714
encapsulation format
....

registration req.
COA: 79.129.13.2
HA: 128.119.40.7
MA: 128.119.40.186
Lifetime: 9999
Identification: 714
encapsulation format
....

registration reply
HA: 128.119.40.7
MA: 128.119.40.186
Lifetime: 4999
Identification: 714
encapsulation format
....

ICMP agent adv.
COA: 79.129.13.2
....

Wireless and Mobile Networks 7-65
Components of cellular network architecture

recall:

- wired public telephone network
- correspondent

different cellular networks, operated by different providers
Handling mobility in cellular networks

- **home network**: network of cellular provider you subscribe to (e.g., Sprint PCS, Verizon)
  - **home location register (HLR)**: database in home network containing permanent cell phone #, profile information (services, preferences, billing), information about current location (could be in another network)

- **visited network**: network in which mobile currently resides
  - **visitor location register (VLR)**: database with entry for each user currently in network
  - could be home network
GSM: indirect routing to mobile

1. Call routed to home network
2. Home MSC consults HLR, gets roaming number of mobile in visited network
3. Home MSC sets up 2nd leg of call to MSC in visited network
4. MSC in visited network completes call through base station to mobile

Mobile Switching Center (MSC), Home Location Register (HLR), Visitor Location Register (VLR)

GSM: indirect routing to mobile

1. Call routed to home network
2. Home MSC consults HLR, gets roaming number of mobile in visited network
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Wireless and Mobile Networks 7-68
GSM: handoff with common MSC

- **handoff goal:** route call via new base station (without interruption)
- reasons for handoff:
  - stronger signal to/from new BSS (continuing connectivity, less battery drain)
  - load balance: free up channel in current BSS
  - GSM doesn't mandate why to perform handoff (policy), only how (mechanism)
- handoff initiated by old BSS
GSM: handoff with common MSC

1. old BSS informs MSC of impending handoff, provides list of 1+ new BSSs
2. MSC sets up path (allocates resources) to new BSS
3. new BSS allocates radio channel for use by mobile
4. new BSS signals MSC, old BSS: ready
5. old BSS tells mobile: perform handoff to new BSS
6. mobile, new BSS signal to activate new channel
7. mobile signals via new BSS to MSC: handoff complete. MSC reroutes call
8. MSC-old-BSS resources released
GSM: handoff between MSCs

- **anchor MSC**: first MSC visited during call
  - call remains routed through anchor MSC
- new MSCs add on to end of MSC chain as mobile moves to new MSC
- optional path minimization step to shorten multi-MSC chain

(a) before handoff
GSM: handoff between MSCs

- **anchor MSC**: first MSC visited during call
  - call remains routed through anchor MSC
- new MSCs add on to end of MSC chain as mobile moves to new MSC
- optional path minimization step to shorten multi-MSC chain

(b) after handoff
Handling Mobility in LTE

- Paging: idle UE may move from cell to cell: network does not know where the idle UE is resident
  - paging message from MME broadcast by all eNodeB to locate UE

- Handoff: similar to 3G:
  - preparation phase
  - execution phase
  - completion phase
# Mobility: cellular versus Mobile IP

<table>
<thead>
<tr>
<th>cellular element</th>
<th>Comment on cellular element</th>
<th>Mobile IP element</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home system</td>
<td>Network to which mobile user’s permanent phone number belongs</td>
<td>Home network</td>
</tr>
<tr>
<td>Gateway Mobile Switching Center, or “home MSC”. Home Location Register (HLR)</td>
<td>Home MSC: point of contact to obtain routable address of mobile user. HLR: database in home system containing permanent phone number, profile information, current location of mobile user, subscription information</td>
<td>Home agent</td>
</tr>
<tr>
<td>Visited System</td>
<td>Network other than home system where mobile user is currently residing</td>
<td>Visited network</td>
</tr>
<tr>
<td>Visited Mobile services Switching Center. Visitor Location Record (VLR)</td>
<td>Visited MSC: responsible for setting up calls to/from mobile nodes in cells associated with MSC. VLR: temporary database entry in visited system, containing subscription information for each visiting mobile user</td>
<td>Foreign agent</td>
</tr>
<tr>
<td>Mobile Station Roaming Number (MSRN), or “roaming number”</td>
<td>Routable address for telephone call segment between home MSC and visited MSC, visible to neither the mobile nor the correspondent.</td>
<td>Care-of-address</td>
</tr>
</tbody>
</table>
Wireless, mobility: impact on higher layer protocols

- logically, impact *should* be minimal ...
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile

- ... but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily
  - delay impairments for real-time traffic
  - limited bandwidth of wireless links
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