Cellular Phone Systems

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Why Cellular Mobile Telephone Systems?

• Operational limitations of conventional mobile telephone systems
  – limited service capability
  – poor service performance
  – inefficient frequency spectrum utilization

Mobility Management

• Mobility management enables telecommunications networks to
  – locate roaming mobile terminals (MTs) for call delivery (location management)
  – maintain connections with MTs that change their point of attachment (handoff/handover management)
Location Management

• MT periodically performs location registration (i.e., location update)
  – explicitly notify the network of its new access point and store changes to its user location profile
• when incoming calls arrive, the network performs call delivery
  – querying the user profile to deliver the calls to the current cell location of the MT

GSM Registration Procedure

1: old TMSI + old VLR id
2: TMSI⇒IMSI
3: location update
4: new TMSI
5: registration cancellation
Call Delivery for Mobile Terminated Call

Registration Area Planning

- Registration/Location Area (RA/LA)
  - consists of one or more cells
  - the basic unit of registration/paging
Hand-off (Hand-over)

Handoff Management

- Ongoing calls are modified under two conditions: signal strength deterioration and user mobility
- *intra-cell* and *inter-cell* handoffs
  - within and between cells
- *soft* handoff and *hard* handoff
  - without and with interruptions in radio links
Who Initiates the Handoff?

• **NCHO** (Network-controlled handoff) or **MAHO** (Mobile-assisted Handoff)
  – the networks generates a new connection, finding new resources for the handoff and performing any additional routing operations

• **MCHO** (Mobile-controlled handoff)
  – the MT finds the new resources and the network approves

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Three Classes of Handoffs in GSM

1. different BTS, same BSC
2. different BSC, same MSC
3. different MSC, same PLMN
   (old MSC=anchor MSC
   new MSC=relay MSC)
Technical Terms

• Call drop rate
  – The probability that an ongoing call is dropped due to handoff

• Call blocking rate
  – The probability that a new call is denied due to lack of available channel

• Usually call drop rate is more important than call blocking rate

Handoff Management: Channel Reservation Scheme

• Reserve some channels for handoff calls
• Trade call blocking rate for call drop rate
Channel Assignment Problem

• Allocate channels to cells
• should consider
  – QoS (Quality of Service)
    • co-channel interference
    • adjacent channel interference
  – spectrum utilization
• Goal: maximize both QoS and spectrum utilization

Co-Channel and Adjacent-Channel Interference

• Co-channel interference
  – Radio signals assigned to the same channel will interfere with each other
• Adjacent channel interference
  – Two frequencies of wavelength close to each other will interfere with each other and should not be assigned to neighboring cells
A channel assigned to A should not be assigned to B nor C at the same time. However, it can be assigned to D without co-channel interference.

Adjacent channel interference
Classification of Channel Assignment Schemes

• **Fixed Channel Assignment**
  – Each cell is assigned a fixed subset of frequencies
  – low response time with low utilization

• **Dynamic Channel Assignment**
  – Does not give any frequency to any cell a priori
  – high response time with high utilization

A Typical Fixed Channel Assignment Scheme

• All channels are divided into 7 disjoint sets
Generations of Cellular Systems

• The first generation
  – AMPS
  – Analog system, circuit-switched service
• The second generation
  – GSM, IS-136, PDC, IS-95
  – Digital system, circuit-switched service
• 2.5 G
  – GPRS
  – Digital system, packet-switched service
• 3 G
  – IMT-2000
  – Digital system, multimedia service

Advanced Mobile Phone Service (AMPS)

• Analog cellular system (1983)
• Frequency Division Multiple Access (FDMA)
• 50 channels per cell
### AMPS (1/2)

- The first cellular system
- Developed during 1970s in Bell Lab.
- 10 years to generate the AMPS specification
- 1974—1978 field trial in Chicago
- Commercial service has been available since 1983
- FDMA (Frequency Division multiple Access) / FDD (Frequency Division Duplex) technology

### AMPS (2/2)

- Channel spacing: 30 KHz
- Frequency bands
  - Forward link (BS → MS): 869 MHz – 894 MHz
  - Reverse link (MS → BS): 824 MHz – 849 MHz
  - Total 832 full-duplex channels
- Roaming management standard: EIA/TIA IS-41
- Service area: North America, Taiwan
### Digital Cellular Phone Systems

<table>
<thead>
<tr>
<th>Standard</th>
<th>GSM 900</th>
<th>GSM 1800</th>
<th>IS-54/-136</th>
<th>IS-95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency band</td>
<td>down 935-960 up 880-915</td>
<td>down 1805-1880 up 1710-1785</td>
<td>down 869-894 up 824-849</td>
<td>down 869-894 up 824-849</td>
</tr>
<tr>
<td>Multiple access</td>
<td>TDMA/FDMA</td>
<td>TDMA/FDMA</td>
<td>TDMA/FDMA</td>
<td>CDMA/FDMA</td>
</tr>
<tr>
<td>Duplex method</td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
<td>FDD</td>
</tr>
<tr>
<td>No. of channels</td>
<td>124 8 users/channel</td>
<td>374 8 users/channel</td>
<td>832 3 users/channel</td>
<td>20 798 users/channel</td>
</tr>
<tr>
<td>Channel spacing</td>
<td>200 kHz</td>
<td>200 kHz</td>
<td>30 kHz</td>
<td>1250 kHz</td>
</tr>
<tr>
<td>Modulation</td>
<td>GMSK</td>
<td>GMSK</td>
<td>p/4 DQPSK</td>
<td>QPSK/DQPSK</td>
</tr>
<tr>
<td>Channel bit rate</td>
<td>270.83 kb/s</td>
<td>270.83 kb/s</td>
<td>48.6 kb/s</td>
<td>1.2288 Mb/s</td>
</tr>
</tbody>
</table>

### Digital Cellular Phone Systems (Cont.)

<table>
<thead>
<tr>
<th>System</th>
<th>IS-54</th>
<th>IS-95/DS</th>
<th>GSM 900/1800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portable txmit power</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max/avg.</td>
<td>600 mW/200mW</td>
<td>600 mW/600 mW</td>
<td>1W/125 mW</td>
</tr>
<tr>
<td>Speech coding</td>
<td>VSELP</td>
<td>QCELP</td>
<td>RPE-LTP</td>
</tr>
<tr>
<td>Speech rate (Kbps)</td>
<td>7.95</td>
<td>8 (var.)</td>
<td>13</td>
</tr>
<tr>
<td>Ch. coding</td>
<td>1/2 rate conv.</td>
<td>1/2 rate fwd</td>
<td>1/2 rate conv.</td>
</tr>
<tr>
<td>Frame (ms)</td>
<td>40</td>
<td>20</td>
<td>4.615</td>
</tr>
</tbody>
</table>
IS-136 DAMPS (1/2)

- Also referred to as digital AMPS (DAMPS), American Digital Cellular (ADC), North American TDMA (NA-TDMA), or even TDMA.
- The successor of IS-54 (IS-54c == IS-136)
- About four months to create the IS-54 specifications.
- The same frequency spectrum as AMPS.
- Also defined for 1850 – 1990 PCS spectrum.

IS-136 DAMPS (2/2)

- FDMA – TDMA (Time Division multiple Access) / FDD (Frequency Division Duplex) technology
- Carrier spacing = 30kHz.
- 3 channels (time slots) per frequency carrier
- Speech coding rate: 7.95 kbps
- Capacity: about 3 times that of AMPS
- Roaming management standard: EIA/TIA IS-41
- Service area: North America
IS-95 cdmaOne (1/2)

- Developed by Qualcomm
- DS-CDMA (Direct Sequence Code Division multiple Access) / FDD (Frequency Division Duplex) technology
- About two years to create the IS-95 specifications.
- Frequency bands
  - AMPS (824 – 894 MHz)
  - PCS (1850 – 1990 MHz)

IS-95 cdmaOne (2/2)

- Carrier Spacing: 1.25 MHz
- Capacity: 3 – 6 times than that of TDMA, 10 times than that of AMPS. (4 – 5 times than that of GSM, 8 – 10 times than that of AMPS).
- Speech coding rate: 13 or 8 kbps
- Roaming management standard: EIA/TIA IS-41
- Service area: North America, South Korea, China
Cordless Phone Systems

<table>
<thead>
<tr>
<th>System</th>
<th>CT2</th>
<th>CT2+</th>
<th>DECT</th>
<th>PHS</th>
<th>PACS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplexing</td>
<td>TDD</td>
<td>TDD</td>
<td>TDD</td>
<td>FDD</td>
<td>FDD</td>
</tr>
<tr>
<td>Frequency band (MHz)</td>
<td>864-868</td>
<td>944-948</td>
<td>1880-1900</td>
<td>1850-1910/1930-1990</td>
<td>1895-1918</td>
</tr>
<tr>
<td>Carrier spacing (kHz)</td>
<td>100</td>
<td>1728</td>
<td>300</td>
<td>300/300</td>
<td></td>
</tr>
<tr>
<td>Number of carriers</td>
<td>40</td>
<td>10</td>
<td>77</td>
<td>16 pairs/10 MHz</td>
<td></td>
</tr>
<tr>
<td>Bearer channel/carrier</td>
<td>1</td>
<td>12</td>
<td>4</td>
<td>8/pair</td>
<td></td>
</tr>
<tr>
<td>Channel bit rate (kbps)</td>
<td>72</td>
<td>1152</td>
<td>384</td>
<td>384</td>
<td></td>
</tr>
<tr>
<td>Modulation</td>
<td>GFSK</td>
<td>GFSK</td>
<td>π/4 QPSK</td>
<td>π/4 QPSK</td>
<td></td>
</tr>
<tr>
<td>Speech coding</td>
<td>32 kbps</td>
<td>32 kbps</td>
<td>32 kbps</td>
<td>32 kbps</td>
<td></td>
</tr>
<tr>
<td>Average handset TX power (mW)</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Peak handset TX power (mW)</td>
<td>10</td>
<td>250</td>
<td>80</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Frame duration (ms)</td>
<td>2</td>
<td>10</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

CT2

- Developed in Europe
- Available since 1989
- FDMA / TDD (Time Division Duplexing) technology
- Speech coding rate: 32kbps
- Data rate: 2.4 – 4.8 kbps
- Max Tx power: 10mW.
- Do not support handoff
- Do not support call-delivery (call-termination)
- CT2+ supports call-delivery
DECT (1/2)

- DECT specifications were published in 1992
- Pico-cell design
- Digital system; TDMA/TDD technology
- 12 frequency channels/frequency carrier
- Sleep mode is employed to conserve the power of MSs.
- Time slot transfer: DECT may move a conversation from one time slot to another to avoid interference

DECT (2/2)

- Supports seamless handoff
- Speech coding rate: 32 kbps
- Supports dynamic channel allocation
- Typically implemented as a wireless-PBX connected to the PSTN
- Can interwork with GSM to allow users mobility, where the GSM handsets provide DECT connection capability.
PHS (1/2)

- Developed by the Research and Development Center for Radio System (RCR) in Japan
- Digital system
- Offer services for homes, offices (1895 – 1906.1 MHz), and outdoor (1906.1– 1918.1 MHz) environments
- TDMA / TDD technology
- Carrier spacing: 300 kHz
- 4 time slots/frequency carrier

PHS (2/2)

- Supports sleep mode
- Supports dynamic channel allocation
- PHS utilizes dedicated control channels to carry system and signaling information
- Speech coding rate: 32 kbps
- User mobility: up to 100 km/hr
- Data rate
  - Current stage: up to 64 kbps (大衆電信, Taiwan)
  - Future: 128 kbps → 512 kbps → 3G
PACS

- Developed at Telcordia (formerly Bellcore)
- Designed for Wireless Local Loop (WLL) and PCS
- TDMA/FDD or TDMA/TDD technology
- 8 voice channels/frequency carrier
- Speech coding rate: 32 kbps
- Mobile-controlled handoff (MCHO)
- Roaming management: IS-41-like protocol
- Supports both circuit-based and packet-based access protocol
- User mobility: up to 38 miles/hr

Data Services in DECT

- DECT data link layer is designed for circuit and packet mode services
  - in the packet mode, it is possible to allocate multiple time slots to SUs
Mobile Data Systems

- DataTAC/Ardis: IBM, Motorola - 1983
- MobiTex/RAM: Ericsson, Bellsouth - 1989
- CDPD: Open System (IBM, AT&T) - 1993
- GPRS: ETSI

Mobile Data Systems (cont.)

<table>
<thead>
<tr>
<th>System</th>
<th>DataTAC</th>
<th>MobiTex</th>
<th>CDPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq. Band (MHz)</td>
<td>800</td>
<td>900, 400</td>
<td>800</td>
</tr>
<tr>
<td>Channel spacing (KHz)</td>
<td>12.5/25</td>
<td>12.5/25</td>
<td>30</td>
</tr>
<tr>
<td>Protocol</td>
<td>RD-LAP</td>
<td>MPAKS</td>
<td>TCP/IP</td>
</tr>
<tr>
<td>Data rate (Kbps)</td>
<td>4.8/19.2</td>
<td>8/16</td>
<td>19.2</td>
</tr>
<tr>
<td>Throughput (Kbps)</td>
<td>2.2/12.0</td>
<td>4-5</td>
<td>9.6-14.4</td>
</tr>
<tr>
<td>Specification</td>
<td>Closed</td>
<td>Closed</td>
<td>Open</td>
</tr>
</tbody>
</table>
GPRS (1/2)

- GSM data services
  - Short Message Services (SMS)
  - Bearer Services: 9.6 kbps (14.4 kbps for Phase 2+, 1996) circuit-switched data
  - High Speed Circuit-Switched Data (HSCSD): 9.6 - 115.2 kbps (Phase 2+, 1997)
  - GPRS
- GSM Phase 2+ for GPRS was completed in 1998.
- Provides best-effort packet-switched service
- External Network: X.25, Internet (TCP/IP)

GPRS (2/2)

- Up to 8 time slots can be assigned to a single user
- Coding schemes:
  - CS-1: 9.06 kbps
  - CS-2: 13.4 kbps
  - CS-3: 13.6 kbps
  - CS-4: 21.4 kbps (no channel coding)
- Data rate: (9.06, 13.4, 15.6, 21.4, depends on channel coding) x (1 to 8) => 171.2 kbps (max)
- Additional equipments are introduced in GPRS
  - Gateway GPRS Support Node (GGSN)
  - Serving GPRS Support Node (SGSN)
  - Packet Control Unit (PCU)
GPRS Architecture

<table>
<thead>
<tr>
<th>MH</th>
<th>Mobile Host</th>
<th>MSC</th>
<th>Mobile Switching Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTS</td>
<td>Base Transceiver Station</td>
<td>VLR</td>
<td>Visitor Location Register</td>
</tr>
<tr>
<td>BSC</td>
<td>Base Station Controller</td>
<td>HLR</td>
<td>Home Location Register/GPRS Registry</td>
</tr>
<tr>
<td>SGSN</td>
<td>Serving GPRS Support Node</td>
<td>PSTN</td>
<td>Public Switched Telephone Network</td>
</tr>
<tr>
<td>GGSN</td>
<td>Gateway GPRS Support Node</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>