First Generation Cellular

David Tipper
Associate Professor
Graduate Telecommunications and Networking Program
University of Pittsburgh
Telcom 2700
Slides 5
http://www.sis.pitt.edu/~dtipper/tipper.html

First Generation Systems

• Goal: Provide basic voice service to mobile users over large area
• 1G Systems developed late 70's early 80's, deployed in 80's
  – Advanced Mobile Phone System (AMPS) - USA
  – Total Access Communications Systems (TACS) - UK
  – Nordic Mobile Telephone (NMT) System – Scandinavian PTTs
  – C450 - W. Germany
  – NTT System - Nippon Telephone & Telegraph (NTT) – Japan
• Incompatible systems using different frequencies!
  – Have similar characteristics though

First Generation Systems

• Characteristics of 1G systems
  – Use Cellular Concept to provide service to a geographic area (i.e. number of small adjacent cells to provide coverage)
    • Frequency Reuse
    • Handoff/Handover
  – FDMA/FDD systems
  – Common Air Interface (CAI) standards only
    • Analog Voice communications using FM
    • Digital Control channels for signalling
  – Adjustable Mobile Power levels
  – Macro Cells : 1-40 km radius
• Focus on AMPS system
AMPS

- Advanced Mobile Phone System is first generation wireless in US
  - Earlier systems used line of sight radio (eg, AT&T’s Improved Mobile Telephone Service in 1960s)
  - AT&T developed cellular concept in 1940s
  - 1971 proposed High Capacity Mobile Phone Service to FCC
  - 1979 FCC standardized it as AMPS in 800-900 MHz range
  - 1983 launched in Chicago
- Licenses for geographic service areas (similar to radio station model) – areas based on commercial trading zones
  - MSA: metro service area, RSA: rural service area

AMPS

FCC allocated 2 licenses for each MSA, RSA
One license to local phone company: wireline common carrier (WCC)
Other license given out by lottery: radio common carrier (RCC)
Speculation and fraud in RCC lottery!

AMPS

- Originally 40 MHz of spectrum separated into two bands of 20 MHz each (A and B band), Later expanded to 25 MHz each
  - A band lower spectrum went to RCC, B band to WCC
- FDD used with 45 MHz separation in uplink and downlink – prevents self interference.
- AMPS uses 30 kHz radio channels between mobile station and base stations (EIA/TIA-533 radio interface)
- Two service providers in area are each allocated 25 MHz => 12.5 MHz for each direction => 416 pairs of channels: split into 395 voice channels + 21 control channels for signaling
- Channels numbered consecutively 1-666, when expanded kept same numbering assuming 30 KHz channels even in places were no spectrum allowed
  - \[ f(c)_{\text{uplink}} = 825,000 + 30 \times (c) \text{ KHz} \quad 1 \leq c \leq 799 \]
  - \[ f(c)_{\text{uplink}} = 825,000 + 30 \times (c-1023) \text{ KHz} \quad 991 \leq c \leq 1023 \]
  - \[ f(c)_{\text{downlink}} = f(c)_{\text{uplink}} + 45,000 \text{ KHz} \]
AMPS Frequency Allocation and Channels

- Original spectrum (666 channels)
- Expanded spectrum (832 channels)

FDD/FDMA - AMPS (B block)

- Frequency allocation and channels
- AMPS Frequency Allocation and Channels

Initial AMPS System Operators

- Switching Equipment
- No. of Cells
- System Operator
- Area
- Market No.
AMPS operators typically used either clusters of size 21 with no sectoring or clusters of 7 in cell frequency reuse pattern with 3 sectors per cell. To plan cells, use a Frequency Chart to group frequencies into 21 categories: Cells 1-7 and sectors A, B, C in each cell.

Notice 21 control channels for each provider in the center of AMPS band: A provider has 312-333, B provider has 334-354.

For AMPS equipment, usually requires C/I = 18 dB => frequency reuse cluster size K = 21 or K = 7 (usually having 3 sectors per cell). For K=7 case and 395 traffic channels, 4 cells in a cluster with 56 channels, 3 cell with 57.

Traffic load in Erlangs:

<table>
<thead>
<tr>
<th>Cell</th>
<th>Channel</th>
<th>Erlangs (2% blocking)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>56</td>
<td>47.7</td>
</tr>
<tr>
<td>B</td>
<td>56</td>
<td>47.7</td>
</tr>
<tr>
<td>C</td>
<td>56</td>
<td>47.7</td>
</tr>
<tr>
<td>D</td>
<td>56</td>
<td>47.7</td>
</tr>
<tr>
<td>E</td>
<td>57</td>
<td>49.7</td>
</tr>
<tr>
<td>F</td>
<td>57</td>
<td>49.7</td>
</tr>
<tr>
<td>G</td>
<td>57</td>
<td>49.7</td>
</tr>
</tbody>
</table>
First Generation Systems

- Basic Architecture: AMPS, NMT, etc., similar
- Mobile telephone switching office (MisTO) connects base stations to PSTN; location and equipment databases were local to each geographical service area

![Diagram of First Generation Systems](image)

AMPS (cont)

- Identification numbers:
  - Mobile station’s 32-bit binary ESN (electronic serial number) stored in ROM at time of manufacture
    - 8-bit manufacturer code + 6-bit reserved (unused) + 18-bit manufacturer assigned serial number
  - Service provider’s 15-bit binary SID (system identification number) assigned by FCC license – one for each service provider in an area
    - Transmitted to identify service provider’s system
  - Mobile station’s 34-bit MIN (mobile identification number) = 10-digit telephone number
    - Station Class Mark (SCM): type of mobile, e.g., 1 – vehicle mount, 4 handheld
    - Supervisory Auditory Tone (SAT): tone to identify base station assigned to a call: pure tone at 5970, 6000, or 6030 Hz. Transmitted by both mobile and base station to distinguish between frequency reuse clusters
    - Signaling Tone (ST): 10 KHz tone for on/off hook signalling

<table>
<thead>
<tr>
<th>Notation</th>
<th>Name</th>
<th>Size (bits)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIN</td>
<td>Mobile identifier</td>
<td>34</td>
<td>Directory number assigned by operating company to a subscriber</td>
</tr>
<tr>
<td>ESN</td>
<td>Electronic serial number</td>
<td>32</td>
<td>Assigned by manufacturer to a mobile station</td>
</tr>
<tr>
<td>SID</td>
<td>System identifier</td>
<td>15</td>
<td>Assigned by regulators to a geographical service area</td>
</tr>
<tr>
<td>SCC</td>
<td>Station class mark</td>
<td>4</td>
<td>Indicates capabilities of a mobile station</td>
</tr>
<tr>
<td>SAT</td>
<td>Supervisory audible tone</td>
<td>1</td>
<td>One of three sine wave signals</td>
</tr>
<tr>
<td>DCC</td>
<td>Digital color code</td>
<td>2</td>
<td>Assigned by operating company to each base station</td>
</tr>
</tbody>
</table>
### AMPS Logical Channels

<table>
<thead>
<tr>
<th>Name</th>
<th>Notation</th>
<th>Use</th>
<th>Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Control Channel (1 per sector per cell)</td>
<td>RECC</td>
<td>Signalling</td>
<td>(Random Access) Many-to-one</td>
</tr>
<tr>
<td>Reverse Voice Channel (Associated Control Channel)</td>
<td>RVC</td>
<td>Traffic (Signalling)</td>
<td>Dedicated One-to-One</td>
</tr>
<tr>
<td>Forward Control Channel</td>
<td>FOCC</td>
<td>Signalling</td>
<td>Broadcast One-to-Many</td>
</tr>
<tr>
<td>Forward Voice Channel (Associated Control Channel)</td>
<td>FVC</td>
<td>Traffic (Signalling)</td>
<td>Dedicated One-to-One</td>
</tr>
</tbody>
</table>

### AMPS FM modulator

- **Audio input**
- **Compress**
- **Pre-emphasize**
- **Limit**
- **Low Pass Filter**
- **Frequency Modulator**
- **Amplify & Transmit**
- **μ-law compandor**
- Supervisory audio tone

### Companding

- Analog Componder emphasizes small values, de-emphasizes large values
- Reverse the mapping at the receiver with an expander

\[
P(a) = \text{sgn}(a) \frac{\ln(1 + \mu|a|)}{\ln(1 + \mu)}
\]
Modulation Techniques

- Frequency Modulation for voice: change frequency with information \( s(t) \)
  \[
  m(t) = V \cos(\phi(t)) \quad \text{where} \\
  \frac{d\phi(t)}{dt} = \omega + \kappa s(t)
  \]
  Bandwidth of FM signal is approximately \( 2(Mi + 1) \text{ fmax} = 2(3+1)4 \text{ KHz} = 32 \text{ KHz} \)

- For digital control info use same modulator in Frequency Shift Keying (FSK) mode:
  - change frequency with each symbol
  - Manchester format for digital data feed to modulator
  - 10 Kbps channel rate

Channel Coding in AMPS

\((n, k; d_{\text{min}})\) code
- BCH
- Repeat \( m \) times
- Majority Logic
- BCH Decode

<table>
<thead>
<tr>
<th>Channel</th>
<th>Channel Bits, k Information Bits, d_{\text{min}} Minimum Distance</th>
<th>Code Rate ( r = k/n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>RVC</td>
<td>48, 36, 5</td>
<td>662-703</td>
</tr>
<tr>
<td>FVC</td>
<td>40, 28, 11</td>
<td>271</td>
</tr>
<tr>
<td>RECC</td>
<td>48, 36, 5</td>
<td>1,250-1,442</td>
</tr>
<tr>
<td>FOCC</td>
<td>40, 28, 5</td>
<td>1,215</td>
</tr>
</tbody>
</table>

AMPS FOCC: Structure

Word A(1), wordA(2), ..., wordA(5) are identical with 28 bits information in a \((40,28,5)\) BCH code

Word B(i) has same format as Word A(i)

Word B bit rate = \(28/463 \times 10 \text{kbps} = 604.75 \text{ bps} \)

(463 = (40x10)+10+11+42 busy/idle bits)
**AMPS: RECC Structure**

<table>
<thead>
<tr>
<th>Bit</th>
<th>Data(1)</th>
<th>Data(2)</th>
<th>Data(3)</th>
<th>Data(4)</th>
<th>Data(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>11 1</td>
<td>7 48</td>
<td>48 48</td>
<td>48 48</td>
<td>48 48</td>
</tr>
</tbody>
</table>

- Digital Color Code
- Word sync 11000010010
- Bit sync 101010...

Data(1)...Data(5) are identical with 36 information bits encoded with BCH (48,36,5) block code.

With 1 word per frame \(5 \times 48 = 30 + 11 + 7 = 288\) bits => data rate \(= \frac{36}{288} \times 10\text{kbps} = 1250\text{bps}\)

With 5 words per frame = 1248 bits => data rate \(= 5 \times \frac{36}{1248} \times 10\text{kbps} = 1442\text{bps}\)

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**Reverse control channel access protocol**

- **Begin**
- **NSZTR = 0**
- **NBUSY = 1**
- **busy/idle = 0?**
- **NBUSY++**
- **NBUSY = 0**
- **NBUSY < MAXBUSY?**
- **Send message**
- **busy/idle = 1**
- **before 5.6 ms?**
- **NSZTR++**
- **NSZTR++**
- **busy/idle = 0**
- **before 10.4 ms?**
- **NSZTR < MAXSZTR?**
  - **Random delay 0-200 ms**
  - **NSZTR < MAXSZTR?**

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**AMPS - Initialization**

- **Base station**
  - Power up and tune to provider A or B
- **Mobile station**
  - Scan and tune to strongest control channel
- **Control channels**
  - Update operating parameters and SID
- **System parameter message**
  - Control message
- **Receive MIN, ESN, SID, registers user**
- **Control message**
  - Verify initialization parameters; idle state
**Associated Signalling FVC: Structure**

- Word sync 11 bits 1110001010
- Bit sync 101010...
- Data(1)...Data(11) identical with BCH (40,28,5) block code
- Bit rate = 28/1032 x 10kbps = 27 bps

Permits signalling while a call is in progress
Uses blank and burst mode – interrupts voice and replaces it with control information
For example, increase/decrease power level of mobile.
Handoff order

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**Associated Signalling RVC Structure**

- Word sync 11 bits 110001010
- Bit sync 101010...
- Data(1)...Data(11) identical with BCH (40,36,5) block code
- One per frame: 544 bits, with 2 per frame 1024 bits

As in FVC works in blank and burst mode
Effective bit rate is 652 bps or 712 bps at 10 kbps channel speed

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**AMPS Transmission Formatting**

Network Control Message: 16 Codewords

- 26 Bit Words: FOCC and FVC
- 12 Parity Bits: BCH Code

Active User Signal: 1 bit + SAT + 31

- 26 Bit Words: RECC and RVC
- 12 Parity Bits: BCH Code

Repeat 8 times FVC

- 8 Times: FOCC

Fake 8 kbps Manchester Code

Aligns on 8 kHz Frequency Modulation
Max. Deviation 12 kHz

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### AMPS Messages

<table>
<thead>
<tr>
<th>Message</th>
<th>Network Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward Control Channel Messages</strong></td>
<td></td>
</tr>
<tr>
<td>SYSTEM PARAMETER</td>
<td>Call/Radio Resources Management</td>
</tr>
<tr>
<td>GLOBAL ACTION</td>
<td>Radio Resources Management</td>
</tr>
<tr>
<td>REGISTRATION IDENTITY</td>
<td>Mobility Management</td>
</tr>
<tr>
<td>CONTROL-FILLER</td>
<td>Radio Resources Management</td>
</tr>
<tr>
<td>PAGE</td>
<td>Call Management</td>
</tr>
<tr>
<td>INITIAL VOICE CHANNEL</td>
<td>Radio Resources Management</td>
</tr>
<tr>
<td>REDIRECT</td>
<td>Call Management</td>
</tr>
<tr>
<td>INTERCEPT</td>
<td>Call Management</td>
</tr>
<tr>
<td>SEND CALLED-ADDRESS</td>
<td>Call Management</td>
</tr>
<tr>
<td>DIREC TED-PERY</td>
<td>Radio Resources Management</td>
</tr>
<tr>
<td>RELEASE</td>
<td>Call Management</td>
</tr>
<tr>
<td>CONFIRM REGISTRATION</td>
<td>Mobility Management</td>
</tr>
</tbody>
</table>

| **Forward Voice Channel Messages**   |                                    |
| ALERT                               | Call Management                     |
| SIDF ALERT                           | Call Management                     |
| MAINTENANCE                          | Operations admin. and maintenance   |
| RELEASE                              | Call Management                     |
| SEND CALLED-ADDRESS                 | Call Management                     |
| HANDOFF                              | Radio Resources Management          |
| CHANGE POWER LEVEL                  | Radio Resources Management          |

### Sample AMPS Messages

**HANDOFF** message on FVC

**Bit Position**

<table>
<thead>
<tr>
<th>Bit Position</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>10 a preamble indicates start of message</td>
</tr>
<tr>
<td>3-4</td>
<td>SAT of new channel (00, 01 or 10)</td>
</tr>
<tr>
<td>5-6</td>
<td>SAT of present channel (00, 01 or 10)</td>
</tr>
<tr>
<td>7-14</td>
<td>Not Used</td>
</tr>
<tr>
<td>15-17</td>
<td>Power level of new AMPS frequency channel</td>
</tr>
<tr>
<td>18-28</td>
<td>New AMPS channel number</td>
</tr>
</tbody>
</table>

**CHANGE POWER LEVEL** message on FVC

**Bit Position**

<table>
<thead>
<tr>
<th>Bit Position</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>10 a preamble indicates start of message</td>
</tr>
<tr>
<td>3-4</td>
<td>11 indicates not a handoff message</td>
</tr>
<tr>
<td>5-6</td>
<td>SAT of present channel (00, 01 or 10)</td>
</tr>
<tr>
<td>7-14</td>
<td>Not Used</td>
</tr>
<tr>
<td>15-17</td>
<td>New power level</td>
</tr>
<tr>
<td>18-28</td>
<td>01011 indicates power control message</td>
</tr>
</tbody>
</table>
**AMPS Messages**

<table>
<thead>
<tr>
<th>Message</th>
<th>Network Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reverse Control Channel Messages</td>
<td></td>
</tr>
<tr>
<td>ORIGINATION</td>
<td>Call Management, Authentication</td>
</tr>
<tr>
<td>PAGE RESPONSE</td>
<td>Call Management, Authentication</td>
</tr>
<tr>
<td>REGISTRATION</td>
<td>Mobility Management</td>
</tr>
<tr>
<td>Reverse Voice Channel Messages</td>
<td>Call Management</td>
</tr>
<tr>
<td>CALLED-STATION ADDRESS</td>
<td></td>
</tr>
<tr>
<td>ORDER CONFIRMATION</td>
<td></td>
</tr>
</tbody>
</table>

---

**AMPS - Mobile Originates Call**

Base station

- Pass to PSTN
- Control message
- Send supervisory signal to confirm forward channel
- Answers and starts conversation

Mobile station

- Origination message (MIN, ESN, called party)
- Tune to voice channel
- Send supervisory signal to confirm reverse channel

---

**AMPS - Mobile Originates Call**

<table>
<thead>
<tr>
<th>MITNO</th>
<th>Base Station</th>
<th>Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initiate FOCC</td>
<td>overhead message train</td>
<td>scan control channels, lock on FOCC, record system parameters, display roaming status</td>
</tr>
<tr>
<td>Idle FOCC</td>
<td>access channel info</td>
<td>record access channel info</td>
</tr>
<tr>
<td>access FOCC</td>
<td>service request</td>
<td>press SEND button</td>
</tr>
<tr>
<td>select voice channel</td>
<td>PAGING messages</td>
<td>ORIGINATE</td>
</tr>
<tr>
<td>Voice channel indication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>INITIAL VOICE CHANNEL</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
AMPS - Mobile Originates Call continued

<table>
<thead>
<tr>
<th>MTSO</th>
<th>Base Station</th>
<th>Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>conversation</strong>&lt;br&gt;PVC and PVC&lt;br&gt; <strong>Detect SAT</strong>&lt;br&gt;Confirm voice channel connection&lt;br&gt;Complete call through network&lt;br&gt;<strong>Press END button</strong>&lt;br&gt;Transmit ST (10 kHz)&lt;br&gt;Call release indication&lt;br&gt;Release call in network&lt;br&gt;<strong>Turn off transmitter</strong>&lt;br&gt;<strong>ends when the user presses the END button</strong></td>
<td>Tune to voice channel, detect SAT&lt;br&gt;Transmit SAT&lt;br&gt;Detected SAT&lt;br&gt;Confirm voice channel connection&lt;br&gt;Complete call through network&lt;br&gt;<strong>Press END button</strong>&lt;br&gt;Transmit ST (10 kHz)&lt;br&gt;Call release indication&lt;br&gt;Release call in network&lt;br&gt;<strong>Turn off transmitter</strong>&lt;br&gt;<strong>ends when the user presses the END button</strong></td>
<td><strong>detect SAT</strong>&lt;br&gt;Transmit SAT&lt;br&gt;Detected SAT&lt;br&gt;Confirm voice channel connection&lt;br&gt;Complete call through network&lt;br&gt;<strong>Press END button</strong>&lt;br&gt;Transmit ST (10 kHz)&lt;br&gt;Call release indication&lt;br&gt;Release call in network&lt;br&gt;<strong>Turn off transmitter</strong>&lt;br&gt;<strong>ends when the user presses the END button</strong></td>
</tr>
</tbody>
</table>

AMPS - Mobile Receives Call

Base station Mobile station

Mobile ID from PSTN, page control message Receives page Page response message (MIN, ESN)

Control message, tune to voice channel Tune to voice channel

Send supervisory signal to confirm forward channel Send supervisory signal to confirm reverse channel

AMPS - Mobile Terminated Call

<table>
<thead>
<tr>
<th>MTSO</th>
<th>Base Station</th>
<th>Terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>initiate FOCC</strong></td>
<td>Access channel info Record access channel info&lt;br&gt;Call arrives from network Send ringing tone to caller page commands to calls&lt;br&gt;<strong>PAGE</strong>&lt;br&gt;<strong>Detect users MIN</strong>&lt;br&gt;<strong>PAGE RESPONSE</strong>&lt;br&gt;Service request&lt;br&gt;Select voice channel&lt;br&gt;Voice channel indication&lt;br&gt;INTERNAL VOICE CHANNEL&lt;br&gt;Transmit SAT</td>
<td><strong>FOCC</strong>&lt;br&gt;Access channel info Record access channel info&lt;br&gt;Call arrives from network Send ringing tone to caller page commands to calls&lt;br&gt;<strong>PAGE</strong>&lt;br&gt;<strong>Detect users MIN</strong>&lt;br&gt;<strong>PAGE RESPONSE</strong>&lt;br&gt;Service request&lt;br&gt;Select voice channel&lt;br&gt;Voice channel indication&lt;br&gt;INTERNAL VOICE CHANNEL&lt;br&gt;Transmit SAT</td>
</tr>
</tbody>
</table>
**AMPS - Handoff**

- **Handoff initiation:**
  - Base station 1 notices mobile station's signal is weakening (when the received signal strength goes below a certain threshold value)
  - Base station 1 sends a handoff measurement request message to its MSC
  - MSC requests neighbor base stations to report their reception of mobile's signal strength
  - MSC picks neighbor base station with highest received signal strength

**Handoff decision**

<table>
<thead>
<tr>
<th>BS1</th>
<th>BS2</th>
<th>BS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak signal level</td>
<td>Receiver sensitivity</td>
<td>NO-MARGIN</td>
</tr>
</tbody>
</table>

distance

<table>
<thead>
<tr>
<th>BS1</th>
<th>BS2</th>
<th>BS3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS1</td>
<td>BS2</td>
<td>BS3</td>
</tr>
</tbody>
</table>
AMPS Handoff

MTSO    Original Base Station    New Base Station    Terminal

Conversation
RVC and PVC

Handoff request

Measurement request

Measurement request at many cells

Measurement report

Measurement report

Handoff command

Handoff indication

First Generation Systems (cont)

<table>
<thead>
<tr>
<th>System</th>
<th>Japan</th>
<th>North America</th>
<th>England</th>
<th>Scandinavia</th>
<th>Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission Freq: (MHz)</td>
<td>NTT</td>
<td>AMPS</td>
<td>TACS</td>
<td>NMT</td>
<td>C450</td>
</tr>
<tr>
<td>Base station</td>
<td>870-885</td>
<td>869.894</td>
<td>917-950</td>
<td>463-467.5</td>
<td>461.3-465.74</td>
</tr>
<tr>
<td>Mobile station</td>
<td>925-940</td>
<td>824.849</td>
<td>872-905</td>
<td>453-457.5</td>
<td>451.3-455.74</td>
</tr>
<tr>
<td>Spacing Between Tc and Fc Freq: (MHz)</td>
<td>55</td>
<td>45</td>
<td>45</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Spacing Between Channels (kHz)</td>
<td>25, 12.5</td>
<td>30</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>No. channels</td>
<td>600</td>
<td>832 (control ch.2x2)</td>
<td>1320 (control ch.2x2)</td>
<td>180</td>
<td>222</td>
</tr>
</tbody>
</table>
Generations of mobile communications

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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First Generation Systems (cont)

- First generation systems targeted to few subscribers with car phones
  - Rapid growth in demand for cellular services
  - Availability of low cost, lightweight, portable handsets
  - Growing demand for system capacity
- Capacity can be increased by smaller cells but:
  - More difficult to place base stations at locations necessary for radio coverage
- Increased signaling for handoffs, and more frequent handoffs
  - Base stations handle more access requests and registrations
  - Analog technology has limited options to combat interference effects from smaller cells
- Demand for second generation, digital cellular
  - Also, incompatible first generation (analog) standards in Europe motivated new pan-European digital standard

First Generation Systems (cont)

- Covered with omni or directional antennas
- Slow data rates
- Cellular radio signaling
- Bandwidth used for communications
- Covered by reuse of channels

Data Tx. Rate (kb/s)

Message sent again when an error is detected.

Receiving steps predetermined according to the message content.

Transmitted signal is checked when sent back to the transmitter by the receiver.

Message Protection

- Control signal:
  - ±4
  - ±5
  - ±4.5

- Frequency deviation (kHz):
  - ±4
  - ±5
  - ±9.5
  - ±12
  - ±4.5

- Frequency deviation (kHz):
  - ±4
  - ±5
  - ±9.5
  - ±12
  - ±4.5

- Modulation:
  - FSK

- Data Tx. Rate (kb/s):
  - ±4
  - ±5
  - ±6.4
  - ±8
  - ±12

First Generation Systems (cont)

Telcom 2700

- System: NMT
- Coverage radius (km):
  - Urban: 10
  - Suburban: 30

Audio signal:

- Modulation: FM
- Frequency deviation (kHz):
  - ±5
  - ±12
  - ±9.5
  - ±5
  - ±4

Control signal:

- Modulation: FSK
- Frequency deviation (kHz):
  - ±4.5
  - ±8
  - ±10
  - ±12
  - ±6.4

- Data Tx. Rate (kb/s):
  - ±5
  - ±10
  - ±12
  - ±3.5
  - ±2.5

- Message Protection:
  - Transmitted signal checked when sent back to the transmitter by the receiver.
  - Principle of majority decision:
    - Principle of majority decision:
      - Received signal checked according to the message content.
      - Message sent again when an error is detected.