Public Switched Telephone Network - PSTN

- Transfer mode: circuit switching
- All the network (except part of the access network) is digital
- Each voice channel is usually 64kb/s

Basic Call

<table>
<thead>
<tr>
<th>Calling terminal</th>
<th>Network</th>
<th>Called terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Off-hook</td>
<td>Alert signal</td>
</tr>
<tr>
<td></td>
<td>Dial tone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dialog</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ring indication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Remove ring indication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>On hook</td>
<td>Off-hook</td>
</tr>
<tr>
<td></td>
<td>Bi-directional channel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>On hook</td>
<td>On hook</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Billing</td>
</tr>
</tbody>
</table>
Cellular Network Basics

- Cellular network/telephony is a radio-based technology; radio waves are electromagnetic waves that antennas propagate.
- Most signals are in the 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz frequency bands.

![Frequency Bands Diagram](image)

Cell phones operate in this frequency range (note the logarithmic scale).

Cellular Network

- **Base stations** transmit to and receive from mobile devices at the assigned spectrum.
  - Multiple base stations use the same spectrum (spectral reuse).
- The service area of each base station is called a **cell**.
  - Each mobile terminal is typically served by the ‘closest’ base stations.
  - **Handoff** when terminals move.

![Cellular Network Diagram](image)

Architecture of Cellular Networks

- **Mobile Station**
  - **Base Station**
  - **Mobile Switching Center**
  - **Server** (e.g., Home Location Register)
  - **External Network**
  - **Cellular Network**
Figure 10.5 Overview of Cellular System

Registration

Service Request

Time on the strongest signal

Nr: 079/4154678

079/4154678

079/8132627

079/8132627
Note: paging makes sense only over a small area
Conversation

Handoff (or Handover)

Message Sequence Chart

<table>
<thead>
<tr>
<th>Caller</th>
<th>Base Station</th>
<th>Switch</th>
<th>Base Station</th>
<th>Caller</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Periodic registration</td>
<td>Service request</td>
<td>Page request</td>
<td>Periodic registration</td>
</tr>
<tr>
<td></td>
<td>Service request</td>
<td></td>
<td>Page request</td>
<td>Service request</td>
</tr>
<tr>
<td></td>
<td>Paging broadcast</td>
<td></td>
<td>Paging broadcast</td>
<td>Paging broadcast</td>
</tr>
<tr>
<td></td>
<td>Tune to Ch 47</td>
<td></td>
<td>Tune to Ch 47</td>
<td>Tune to Ch 47</td>
</tr>
<tr>
<td></td>
<td>Ring indication</td>
<td></td>
<td>Assign Ch 47</td>
<td>Assign Ch 68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Paging response</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Assign Ch 68</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tune to Ch 48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Alert tone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Stop ring indication</td>
</tr>
</tbody>
</table>
Cellular Network Generations

It is useful to think of a cellular network in terms of generations:

- **0G**: Briefcase-size mobile radio telephones
- **1G**: Analog cellular telephony
- **2G**: Digital cellular telephony
- **3G**: High-speed digital cellular telephony (including video telephony)
- **4G**: IP-based “anytime, anywhere” voice, data, and multimedia telephony at faster data rates than 3G (being deployed now)

Evolution of Cellular Networks

The Multiple Access Problem

The base stations need to serve many mobile terminals at the same time (both downlink and uplink)
- All mobiles in the cell need to transmit to the base station
- Interference among different senders and receivers
- So we need multiple access scheme
Multiple Access Schemes

3 orthogonal schemes:
• Frequency Division Multiple Access (FDMA)
• Time Division Multiple Access (TDMA)
• Code Division Multiple Access (CDMA)

Frequency Division Multiple Access

- Each mobile is assigned a separate frequency channel for the duration of the call
- Sufficient guard band is required to prevent adjacent channel interference
- Usually, mobile terminals will have one downlink frequency band and one uplink frequency band
- Different cellular network protocols use different frequencies
- Frequency is a precious and scarce resource
  - Cognitive radio research

Time Division Multiple Access

- Time is divided into slots and only one mobile terminal transmits during each slot
- Each user is given a specific slot. No competition in cellular network
  - Unlike Carrier Sensing Multiple Access (CSMA) in Wi-Fi
CDMA

Uses the whole band!

CDMA (sometimes shown like this:)

CDMA (3G) (or this:)

9
Code Division Multiple Access

- Use of orthogonal codes to separate different transmissions
- Each symbol of bit is transmitted as a larger number of bits using a user-specific code – spreading
- Bandwidth occupied by the signal is much larger than the information transmission rate
- But all users use the same frequency band together

Basics: Some Math

\[
\begin{align*}
1 & \quad 1 & \quad -1 & \quad -1 \\
X & \quad X & \quad X & \quad X \\
1 & \quad -1 & \quad 1 & \quad -1 \\
= & \quad = & \quad = & \quad = \\
1 & \quad -1 & \quad -1 & \quad 1
\end{align*}
\]

CDMA Example

Low-Bandwidth Signal:

High-Bandwidth Spreading Code:

...repeated...
CDMA Example

Low-Bandwidth Signal:

High-Bandwidth Spreading Code:

Mix is a simple multiplication

... and then transmit.

CDMA Example

To Decode / Receive, take the signal:

Multiply by the same Spreading Code:

... to get ...

What If We Use Wrong Code?

Take the same signal:

Multiply by the wrong Spreading Code:

... you get ...

... which clearly hasn't recovered the original signal. Using wrong code is like being off-frequency.
CDMA
- Requires right code AND accurate timing!

Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>
Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>
Another Example

<table>
<thead>
<tr>
<th>Data</th>
<th>1</th>
<th>-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>Spreading Code B</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>=</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>CDMA</td>
<td>1</td>
<td>-1</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>CDMA A</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>-1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMDA B</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOISE</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>=</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAND</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Another Example

<table>
<thead>
<tr>
<th>CDMA A</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>-1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CMDA B</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOISE</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>=</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAND</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
### Another Example

<table>
<thead>
<tr>
<th>BAND</th>
<th>5 2 3 2 3 2 3 5 4 4 2 5 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x x x x x x x x x x x x x</td>
</tr>
<tr>
<td>Spreading Code A</td>
<td>1 1 -1 -1 1 1 -1 1 1 1 1 1</td>
</tr>
<tr>
<td>=</td>
<td>-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1</td>
</tr>
<tr>
<td>Demod</td>
<td>5</td>
</tr>
<tr>
<td>Add these</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
</tr>
<tr>
<td>1 or -1?</td>
<td></td>
</tr>
</tbody>
</table>

**Spreading Code**

<table>
<thead>
<tr>
<th>1 1 -1 -1 1 1 -1 1 1 1 1 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demod</td>
</tr>
<tr>
<td>Add these</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>1 or -1?</td>
</tr>
</tbody>
</table>

### Another Example

<table>
<thead>
<tr>
<th>BAND</th>
<th>5 2 3 2 3 2 3 5 4 4 2 5 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x x x x x x x x x x x x x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1 1 -1 -1 1 1 -1 1 1 1 1 1</td>
</tr>
<tr>
<td>=</td>
<td>-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1</td>
</tr>
<tr>
<td>Demod</td>
<td>5</td>
</tr>
<tr>
<td>Add these</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
</tr>
<tr>
<td>1 or -1?</td>
<td></td>
</tr>
</tbody>
</table>

### Another Example

<table>
<thead>
<tr>
<th>BAND</th>
<th>5 2 3 2 3 2 3 5 4 4 2 5 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x x x x x x x x x x x x x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1 1 -1 -1 1 1 -1 1 1 1 1 1</td>
</tr>
<tr>
<td>=</td>
<td>-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1</td>
</tr>
<tr>
<td>Demod</td>
<td>5</td>
</tr>
<tr>
<td>Add these</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
</tr>
<tr>
<td>1 or -1?</td>
<td></td>
</tr>
</tbody>
</table>

### Another Example

<table>
<thead>
<tr>
<th>BAND</th>
<th>5 2 3 2 3 2 3 5 4 4 2 5 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>x x x x x x x x x x x x x</td>
</tr>
<tr>
<td>Spreading Code</td>
<td>1 1 -1 -1 1 1 -1 1 1 1 1 1</td>
</tr>
<tr>
<td>=</td>
<td>-1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1</td>
</tr>
<tr>
<td>Demod</td>
<td>5</td>
</tr>
<tr>
<td>Add these</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1</td>
</tr>
<tr>
<td>1 or -1?</td>
<td></td>
</tr>
</tbody>
</table>
GSM (2G)

- Abbreviation for Global System for Mobile Communications
- Concurrent development in USA and Europe in the 1980s
- The European system was called GSM and deployed in the early 1990s

GSM Services

- Voice, 3.1 kHz
- Short Message Service (SMS)
  - 1985 GSM standard that allows messages of at most 160 chars. (incl. spaces) to be sent between handsets and other stations
  - Multi-billion $ industry
- General Packet Radio Service (GPRS)
  - GSM upgrade that provides IP-based packet data transmission up to 114 kbps
  - Users can “simultaneously” make calls and send data
  - GPRS provides “always on” Internet access and the Multimedia Messaging Service (MMS) whereby users can send rich text, audio, video messages to each other
  - Performance degrades as number of users increase
  - GPRS is an example of 2.5G telephony – 2G service similar to 3G
**GSM Channels**

- Physical Channel: Each timeslot on a carrier is referred to as a physical channel
- Logical Channel: Variety of information is transmitted between the MS and BTS. Different types of logical channels:
  - Traffic channel
  - Control Channel

**GSM Frequencies**

- Originally designed on 900MHz range, now also available on 800MHz, 1800MHz and 1900 MHz ranges.
- Separate uplink and downlink frequencies
  - One example channel on the 1800 MHz frequency band, where RF carriers are spaced every 200 kHz

**GSM Architecture**

- Diagram showing the architecture of a GSM network, including Base Station Subsystem, Network and Switching Subsystem, PSTN, Mobile Switching Center, etc.
Mobile Station (MS)

- MS is the user’s handset and has two parts
  - Mobile Equipment
    - Radio equipment
    - User interface
    - Processing capability and memory required for various tasks
      - Call signalling
      - Encryption
      - SMS
    - Equipment IMEI (Intl. Mobile Equipment Identity) number (like serial number)
  - Subscriber Identity Module (SIM)

Subscriber Identity Module

- A small smart card
- Encryption codes needed to identify the subscriber
- Subscriber IMSI (Intl. Mobile Subscriber Identity) number
  - 64-bit number; includes:
    - MCC (Mobile Country Code): 3 decimal places, Intl. standardized
    - MNC (Mobile Network Code): 2 decimal places, network within country
    - MSIN (Mobile Subscriber Identification Number): max. 10 decimal places
- Subscriber’s own information (telephone directory)
- Third party applications (banking, etc.)
- Can also be used in other systems besides GSM, e.g., some WLAN access points accept SIM based user authentication

Base Station Subsystem

- Transcoding Rate and Adaptation Unit (TRAU)
  - Performs coding between the 64kbps PCM coding used in the backbone network and the 13kbps coding used for the Mobile Station (MS)
- Base Station Controller (BSC)
  - Controls the channel (time slot) allocation implemented by the BTSes
  - Manages the handovers within BSS area
  - Knows which mobile stations are within the cell and informs the MSC/VLR about this
- Base Transceiver System (BTS)
  - Controls several transmitters
    - Each transmitter has 8 time slots, some used for signaling, on a specific frequency
Network and Switching Subsystem

- The backbone of a GSM network is a telephone network with additional cellular network capabilities
- Mobile Switching Center (MSC)
  - A typical telephony exchange (ISDN exchange) which supports mobile communications
- Visitor Location Register (VLR)
  - A database, part of the MSC
  - Contains the location of the active Mobile Stations
- Gateway Mobile Switching Center (GMSC)
  - Links the system to PSTN and other operators
- Home Location Register (HLR)
  - Contains subscriber information, including authentication information in Authentication Center (AuC)
  - Equipment Identity Register (EIR)
    - International Mobile Station Equipment Identity (IMEI) codes for e.g., blacklisting stolen phones

Home Location Register

- One database per operator
- Contains all the permanent subscriber information
  - MSISDN (Mobile Subscriber ISDN number) is the telephone number of the subscriber
  - International Mobile Subscriber Identity (IMSI) is a 15 digit code used to identify the subscriber
  - IMSI code is used to link the MSISDN number to the subscriber’s SIM (Subscriber Identity Module)
  - Charging information
  - Services available to the customer
  - Also the subscriber’s present Location Area Code, which refers to the MSC, which can connect to the MS.

Other Systems

- Operations Support System
  - The management network for the whole GSM network
  - Usually vendor dependent
  - Very loosely specified in the GSM standards
- Value added services
  - Voice mail
  - Call forwarding
  - Group calls
- Short Message Service Center
  - Stores and forwards the SMS messages
  - Like an E-mail server
  - Required to operate the SMS services
Location Updates

- The cells overlap and usually a mobile station can 'see' several transceivers (BTSes)
- The MS monitors the identifier for the BSC controlling the cells
- When the mobile station reaches a new BSC's area, it requests a location update
- The update is forwarded to the MSC, entered into the VLR, the old BSC is notified and an acknowledgement is passed back

Handoff (Handover)

- When a call is in process, the changes in location need special processing
- Within a BSS, the BSC, which knows the current radio link configuration (including feedbacks from the MS), prepares an available channel in the new BTS
- The MS is told to switch over to the new BTS
- This is called a **hard handoff**
  - In a **soft handoff**, the MS is connected to two BTSes simultaneously

4 types of handover
Handover decision

Handover procedure

Roaming
• When a MS enters another operators network, it can be allowed to use the services of this operator
  • Operator to operator agreements and contracts
  • Higher billing
• The MS is identified by the information in the SIM card and the identification request is forwarded to the home operator
  • The home HLR is updated to reflect the MS's current location
**UMTS**
- Universal Mobile Telecommunications System (UMTS)
- UMTS is an upgrade from GSM via GPRS or EDGE
- The standardization work for UMTS is carried out by Third Generation Partnership Project (3GPP)
- Data rates of UMTS are:
  - 144 kbps for rural
  - 384 kbps for urban outdoor
  - 2048 kbps for indoor and low range outdoor
- Virtual Home Environment (VHE)

**UMTS Frequency Spectrum**
- UMTS Band
  - 1900-2025 MHz and 2110-2200 MHz for 3G transmission
  - In the US, 1710–1755 MHz and 2110–2155 MHz will be used instead, as the 1900 MHz band was already used.

**UMTS Architecture**

---

Note: Interfaces have been omitted for clarity purposes.
UMTS Network Architecture*

- UMTS network architecture consists of three domains
  - Core Network (CN): Provide switching, routing and transit for user traffic
  - UMTS Terrestrial Radio Access Network (UTRAN): Provides the air interface access method for user equipment.
  - User Equipment (UE): Terminals work as air interface counterpart for base stations. The various identities are: IMSI, TMSI, P-TMSI, TLLI, MSISDN, IMEI, IMEISV

4G (LTE)

- LTE stands for Long Term Evolution
- Next Generation mobile broadband technology
- Promises data transfer rates of 100 Mbps
- Based on UMTS 3G technology
- Optimized for All-IP traffic

Advantages of LTE

- High network throughput
- Low latency
- Plug & Play architecture
- Low Operating Costs
- All-IP network
- Simplified upgrade path from 3G networks

*for Network Operators *for End Users

Faster data downloads/uploads
Improved response for applications
Improved end-user experience
Comparison of LTE Speed

2G – 4G Data download rates

Major LTE Radio Technologies
- Uses Orthogonal Frequency Division Multiplexing (OFDM) for downlink
- Uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink
- Uses Multi-input Multi-output (MIMO) for enhanced throughput
- Reduced power consumption
- Higher RF power amplifier efficiency (less battery power used by handsets)

5G Challenges & Scenarios*

Avalanche of Traffic Volume
Further expansion of mobile broadband
Additional traffic due to communicating machines
*”100x in ten years”

Massive growth in Connected Devices
*Communicating machines*

Large diversity of Use cases & Requirements
Device-to-Device Communications
Car-to-Car Comm.

New requirements and characteristics due to communicating machines

*50 billion devices in 2020*
5G Future
Integration of access technologies into one seamless experience

- Massive MIMO
- Ultra-Dense Networks
- Moving Networks
- Higher Frequencies

Existing technologies in 2012

D2D Communications
Massive MIMO Communications

Respond to traffic explosion
- 10-100 x higher typical user rate
- 10-100 x higher number of connected devices
- 10 x longer battery life for low power M2M

Evolution
- Higher Frequencies
- Massive MIMO
- Ultra-Dense Networks
- Moving Networks

1000 x higher mobile data volume per area
10-100 x higher number of connected devices
5 x reduced E2E latency
10 x longer battery life for low power M2M

Revolution
Existing technologies in 2012
3G
4G
Wifi

Extend to novel applications

Spectrum Scenario*
- Dedicated licensed spectrum complemented with various forms of shared spectrum

"Toolbox" of different sharing enablers required
In order for 5G system to work under such scenarios

Technology Components*
- New spectrum bands and access methods
- Dense and moving networks
- Multi-hop wireless backhaul
- VL-MIMO Massive multi-antenna systems
- Context-aware interference and mobility management
- Air interfaces for new applications and reduced signaling
- Mobile Device-to-device

* Spectral Scenario and Technology Components are subject to change.