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>
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<tbody>
<tr>
<td>Resource allocation</td>
<td>Off-hook</td>
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<td>Dial tone</td>
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<td></td>
<td>Dialing</td>
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<tr>
<td>Translation + routing</td>
<td>Ring indication</td>
<td>Alert signal</td>
</tr>
<tr>
<td></td>
<td>Remove ring indication</td>
<td>Off-hook</td>
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<tr>
<td>Conversation</td>
<td>Bi-directional channel</td>
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<td>On hook signal</td>
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<tr>
<td></td>
<td>Billing</td>
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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.

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

**Architecture of Cellular Networks**

![Diagram of Cellular Network](image)
Registration

Tune on the strongest signal

Figure 10.5 Overview of Cellular System
Service Request

Paging Broadcast

Note: paging makes sense only over a small area
Conversation

Handoff (or Handover)
Message Sequence Chart

Caller          | Base Station          | Switch          | Base Station          | Callee
---             | ---                   | ---             | ---                   | ---
Periodic registration
Service request
Paging broadcast
Tune to Ch. 47
Ring indication
Stop ring indication

Service request
Page request
Assign Ch. 47
Ring indication
Stop ring indication
Page request
Paging response
Assign Ch. 68
User response
Paging broadcast
Alert tone
User response

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)
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.

Guard time – signals transmitted by mobile terminals at different locations do not arrive at the base station at the same time.

FDMA (1G)
CDMA

Uses the whole band!

CDMA (sometimes shown like this:)

[Diagram of CDMA frequency allocation over time]
CDMA (3G) (or this:)

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

Orthogonal among users

Transmitted signal: Data Signal XOR with the Pseudorandom
Basics: Some Math

\[
\begin{array}{cccc}
1 & 1 & -1 & -1 \\
x & x & x & x \\
1 & -1 & 1 & -1 \\
= & = & = & = \\
1 & -1 & -1 & 1 \\
\end{array}
\]

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

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### Another Example

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Another Example

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CDMA 1 -1 1 -1 1 -1 1 -1 1 -1 1

Another Example

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CDMA 1 -1 1 -1 1 -1 1 -1 1 -1 1
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Another Example

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| Total |
| 1 or -1? |
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1 or -1?
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**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

![Uplink and Downlink Frequencies Diagram]

GSM Architecture

![GSM Architecture Diagram]
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)
  • Contain 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 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
UTRAN

- Wide band CDMA technology is selected for UTRAN air interface
  - WCDMA
  - TD-SCDMA
- Base stations are referred to as Node-B and control equipment for Node-B is called as Radio Network Controller (RNC).
  - Functions of Node-B are
    - Air Interface Tx/Rx
    - Modulation/Demodulation
  - Functions of RNC are:
    - Radio Resource Control
    - Channel Allocation
    - Power Control Settings
    - Handover Control
    - Ciphering
    - Segmentation and reassembly

3.5G (HSPA)

High Speed Packet Access (HSPA) is an amalgamation of two mobile telephony protocols, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), that extends and improves the performance of existing WCDMA protocols.

3.5G introduces many new features that will enhance the UMTS technology in future. 1xEV-DV already supports most of the features that will be provided in 3.5G. These include:

- Adaptive Modulation and Coding
- Fast Scheduling
- Backward compatibility with 3G
- Enhanced Air Interface
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

- Faster data downloads/uploads
- Improved response for applications
- Improved end-user experience

*for Network Operators  for End Users*
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)

* 2.5G speed is based on the maximum offered by EDGE
* 3G speed is based on the maximum offered by HSDPA
5G Challenges & Scenarios

- **Avalanche of Traffic Volume**
  - Further expansion of mobile broadband
  - Additional traffic due to communicating machines
  - “1000x in ten years”

- **Massive growth in Connected Devices**
  - “Communicating machines”
  - “50 billion devices in 2020”

- **Large diversity of Use cases & Requirements**
  - Device-to-Device Communications
  - Car-to-Car Comm.
  - New requirements and characteristics due to communicating machines

5G Future
Integration of access technologies into one seamless experience

- **Revolution**
  - Massive MIMO
  - Ultra-Dense Networks
  - Moving Networks
  - Higher Frequencies
  - Respond to traffic explosion
  - 10-100 x higher typical user rate
  - 1000 x higher mobile data volume per area

- **Evolution**
  - Extend to novel applications
  - 10-100 x higher number of connected devices
  - 5 x reduced E2E latency
  - 10 x longer battery life for low power M2M

- **Complementary new technologies**
  - D2D Communications
  - Ultra-Reliable Communications
  - Massive Machine Communications

Existing technologies in 2012
3G  4G  Wifi
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
- Mobile
- Device-to-device
- Context-aware interference and mobility management
- Air interfaces for new applications and reduced signaling