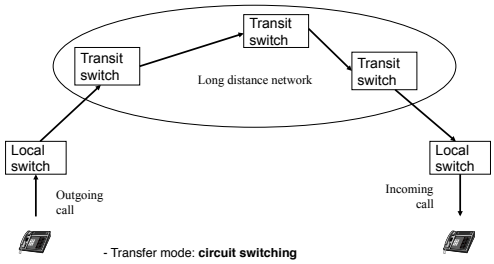
MOBILE COMPUTING

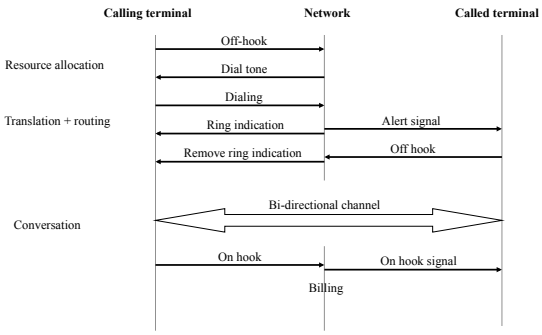
CSE 40814/60814
Spring 2017

Public Switched Telephone Network - PSTN



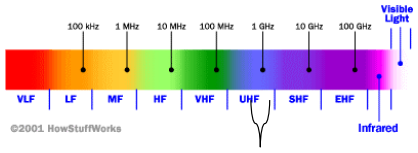
- Transfer mode: **circuit switching**
- All the network (except part of the access network) is digital
- Each voice channel is usually 64kb/s

Basic Call



Cellular Network Basics

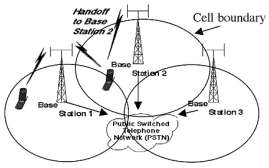
- Cellular network/telephony is a *radio*-based technology; radio waves are electromagnetic waves that *antennas* propagate
- Most signals are in the 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz frequency bands



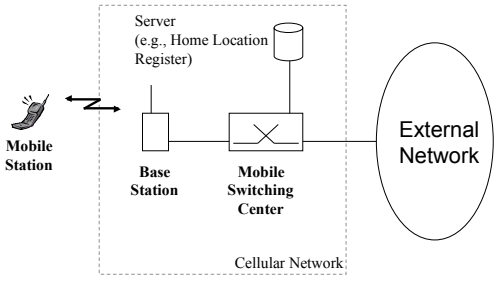
Cell phones operate in this frequency range (note the *logarithmic* scale)

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



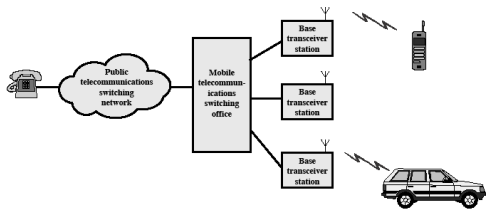
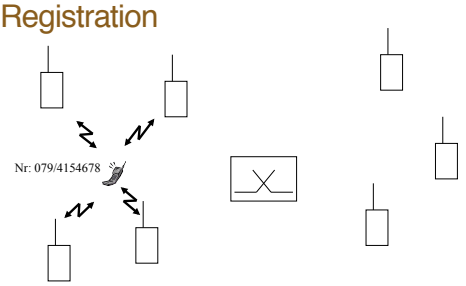


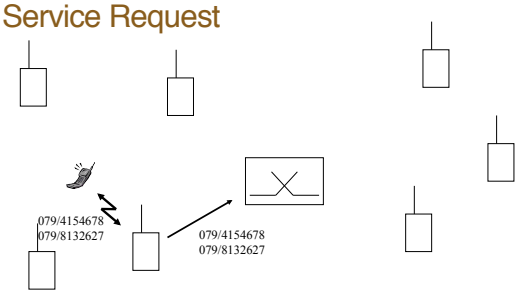
Figure 10.5 Overview of Cellular System

Registration

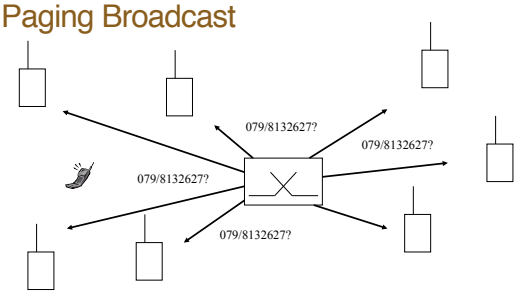


Tune on the strongest signal

Service Request

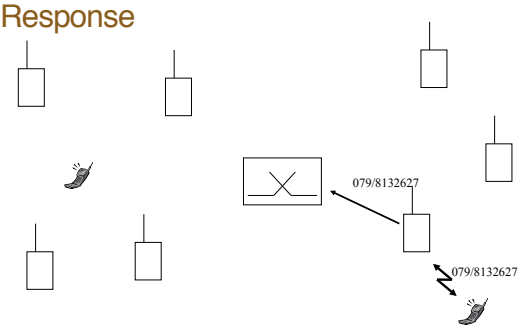


Paging Broadcast

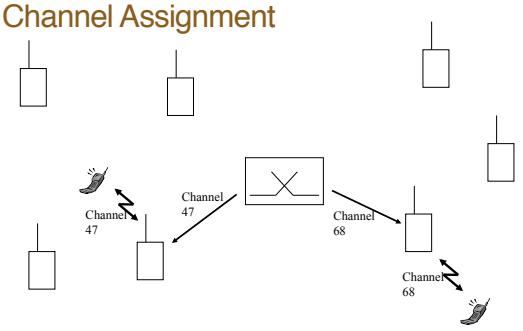


Note: paging makes sense only over a *small* area

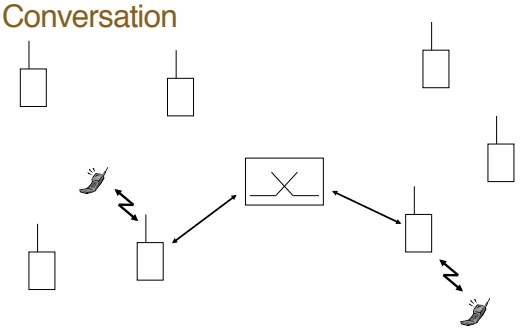
Response



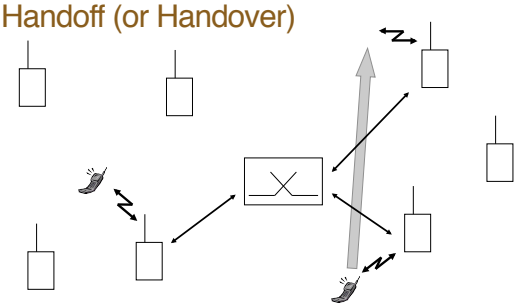
Channel Assignment



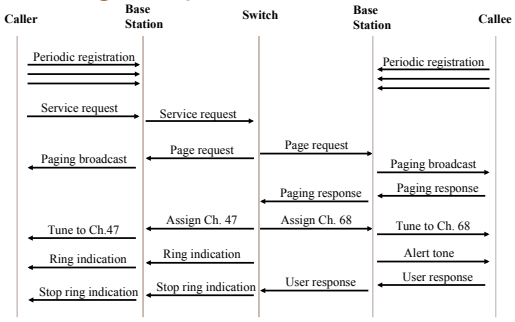
Conversation



Handoff (or Handover)



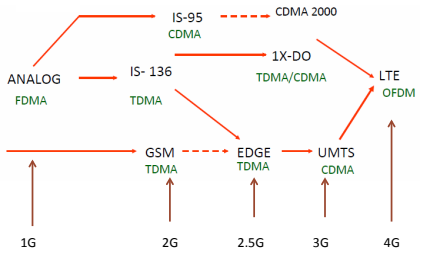
Message Sequence Chart



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)

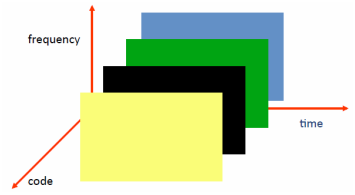
Evolution of Cellular Networks



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**

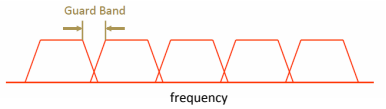
Multiple Access Schemes



3 orthogonal schemes:

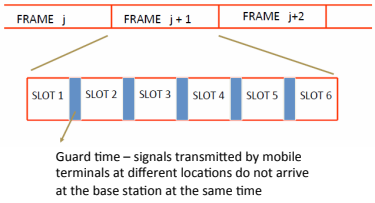
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

Frequency Division Multiple Access



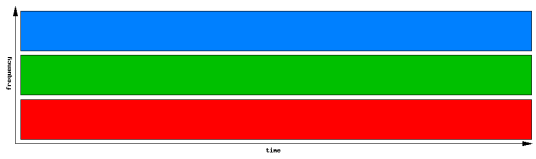
- **Each mobile is assigned a separate frequency channel for the duration of the call**
- Sufficient **guard band** is required to prevent adjacent channel interference
- Usually, mobile terminals will have **one downlink frequency band and one uplink frequency band**
- Different cellular network protocols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

Time Division Multiple Access

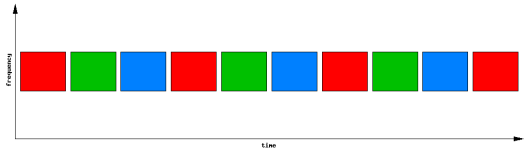


- Time is divided into **slots** and only one mobile terminal transmits during each slot
- Each user is given a specific slot. No competition in cellular network
  - Unlike Carrier Sensing Multiple Access (CSMA) in Wi-Fi

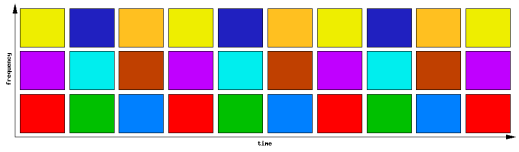
FDMA (1G)



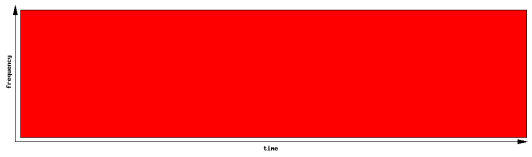
TDMA



F/TDMA (2G)

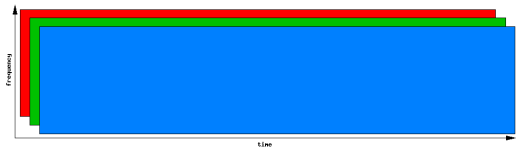


CDMA

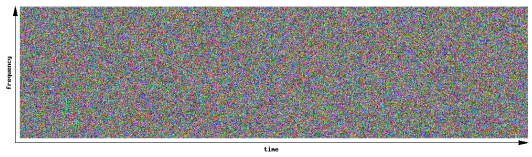


Uses the whole band!

CDMA (sometimes shown like this:)

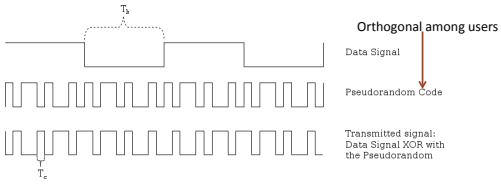


CDMA (3G) (or this:)



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



Basics: Some Math

1	1	-1	-1
x	x	x	x
1	-1	1	-1
=	=	=	=
1	-1	-1	1

CDMA Example

Low-Bandwidth Signal:

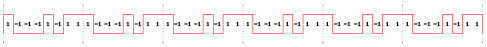
High-Bandwidth Spreading Code:

...repeated...

CDMA Example

Low-Bandwidth Signal:

High-Bandwidth Spreading Code:

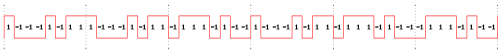


Mix is a simple multiplication

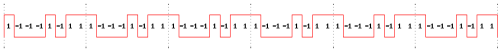
… and then transmit.

CDMA Example

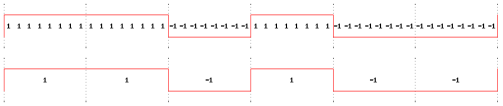
To Decode / Receive, take the signal:



Multiply by the **same** Spreading Code:



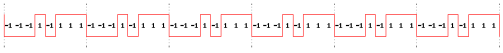
… to get ...



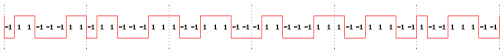
What If We Use Wrong Code?

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

Data	1								-1							
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA																

Another Example

Data	1								-1							
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1															

Another Example

Data	1								-1							
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1														

Another Example

Data	1								-1							
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1	1	-1	-1	1	-1	1								

Another Example

Data	1								-1							
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1	1	-1	-1	1	-1	1	-1							

Another Example

Data	1								-1						
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1	1	-1	-1	1	-1	1	-1							

Another Example

Data	1								-1						
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1	1	-1	-1	1	-1	1	-1	1						

Another Example

Data	1								-1						
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code A	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1

Another Example

Data	1							-1							
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code B	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
CDMA	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1

Another Example

CDMA A	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
CMDA B	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
NOISE	3	2	3	2	5	5	3	2	5	4	5	4	2	4	5	5
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
BAND																

Another Example

CDMA A	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
CMDA B	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
NOISE	3	2	3	2	5	5	3	2	5	4	5	4	2	4	5	5
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
BAND	5	0	3	2	3	7	3	2	3	6	5	4	4	2	5	5

Another Example

BAND	5	0	3	2	3	7	3	2	3	6	5	4	4	2	5	5
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code A	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
Demod	5															
Add these	+									+						
Total																
1 or -1?																

Another Example

BAND	5	0	3	2	3	7	3	2	3	6	5	4	4	2	5	5
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
Demod	5	0	3	-2	-3	7	-3	2	3	-6	5	-4	-4	3	-5	5
Add these	+									+						
Total																
1 or -1?																

Another Example

BAND	5	0	3	2	3	7	3	2	3	6	5	4	4	2	5	5
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
Demod	5	0	3	-2	-3	7	-3	2	3	-6	5	-4	-4	3	-5	5
Add these	+									+						
Total	9									-3						
1 or -1?																

Another Example

BAND	5	0	3	2	3	7	3	2	3	6	5	4	4	2	5	5
x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Spreading Code	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1
=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
Demod	5	0	3	-2	-3	7	-3	2	3	-6	5	-4	-4	3	-5	5
Add these	+							+								
Total	9							-3								
1 or -1?	1							-1								

GSM (2G)

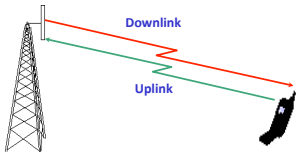
- Abbreviation for Global System for Mobile Communications
- Concurrent development in USA and Europe in the 1980s
- The European system was called GSM and deployed in the early 1990s

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

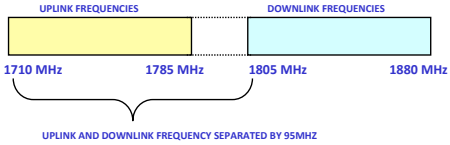
Channels



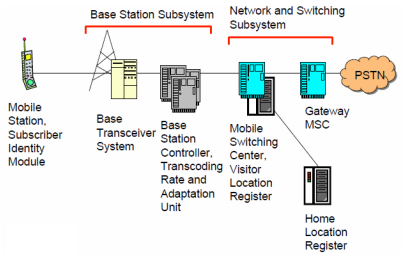
- Physical Channel: Each timeslot on a carrier is referred to as a physical channel
- Logical Channel: Variety of information is transmitted between the MS and BTS. Different types of logical channels:
  - Traffic channel
  - Control Channel

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



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

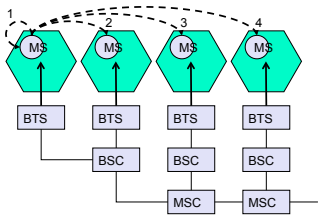
Location Updates

- 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

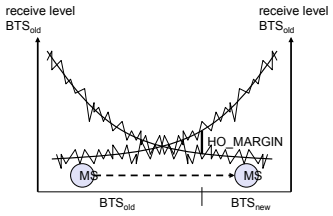
Handoff (Handover)

- 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

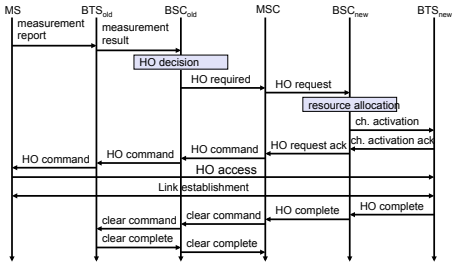
4 types of handover



Handover decision



Handover procedure



Roaming

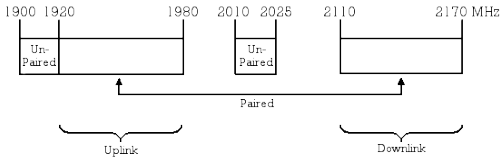
- When a MS enters another operators network, it can be allowed to use the services of this operator
  - Operator to operator agreements and contracts
  - Higher billing
- The MS is identified by the information in the SIM card and the identification request is forwarded to the home operator
  - The home HLR is updated to reflect the MS's current location

UMTS*

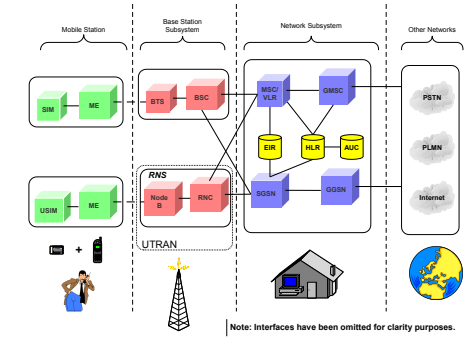
- Universal Mobile Telecommunications System (UMTS)
- UMTS is an upgrade from GSM via GPRS or EDGE
- The standardization work for UMTS is carried out by Third Generation Partnership Project (3GPP)
- Data rates of UMTS are:
  - 144 kbps for rural
  - 384 kbps for urban outdoor
  - 2048 kbps for indoor 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 Architecture*



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

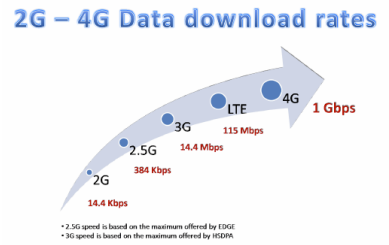
4G (LTE)

- 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

for Network Operators	*for* End Users
High network throughput	Faster data downloads/uploads
Low latency	Improved response for applications
Plug & Play architecture	Improved end-user experience
Low Operating Costs	
All-IP network	
Simplified upgrade path from 3G networks	

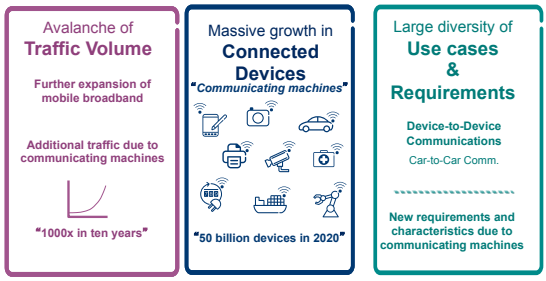
Comparison of LTE Speed

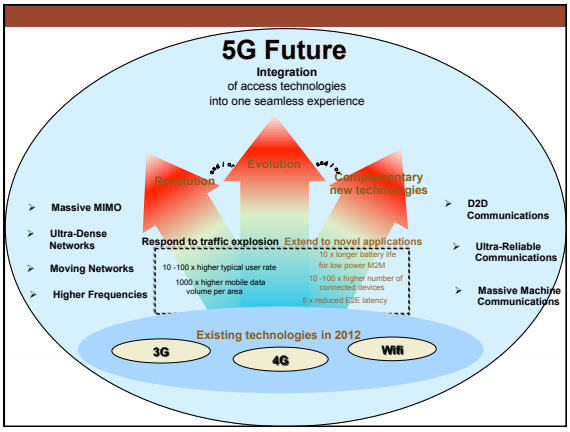


Major LTE Radio Technogies

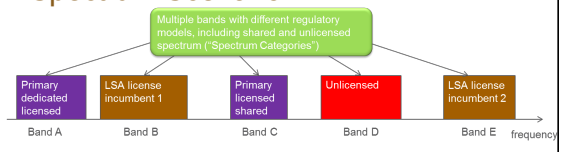
- Uses Orthogonal Frequency Division Multiplexing (OFDM) for downlink
- Uses Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink
- Uses Multi-input Multi-output (MIMO) for enhanced throughput
- Reduced power consumption
- Higher RF power amplifier efficiency (less battery power used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

5G Challenges & Scenarios*





Spectrum Scenario*

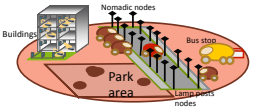


- Dedicated licensed spectrum complemented with various forms of shared spectrum

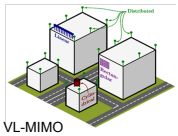
"Toolbox" of different sharing enablers required
In order for 5G system to work under such scenarios

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