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Public mobile networks

Commercial Generations

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Learning outcomes

- Understand the diversity of situations for mobile networks
- Become aware of celular network architectures

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Wireless networks

- Networks are designed according to the number of users and coverage area
- In wireless networks there are several scales on number of users and coverage area
  - Personal: PANs → Bluetooth
  - Local: LANs → IEEE 802.11
  - Regional: WANs → GSM, UMTS
  - Worldwide : Sattelite → Iridium

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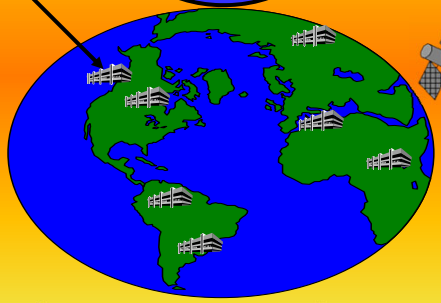
Wireless networks

Wireless LAN
Campus (school, company, airport)

PANs
Personal networks, very limited range
Voice and data with low cost

Sattelite
Worldwide networks
High cost

Cellular
Large geographic coverage



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Types of connections

- Point-to-point networks
  - Communication points need to be in line of sight (LoS) (e.g. sattelite).
- Diffusion networks
  - There is no specific physical relationship between the two communication points (e.g. 802.11)
- Semi-diffusion networks
  - Require some limitations in the relative positioning of the communication points (e.g. Infrared)

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Types of mobility

- User
  - Capacity to access services in different places
- Personal
  - Identifies the user position and allows the reception of information
- Terminal
  - Movement of equipments
    - **Rellocation**
      - Essentially it is a location change
    - **Moving**
      - Accompanying the terminal dynamic movement maintaining the connection
    - **Universality**
      - Capacity of movement in large areas, covering multiple administrative entities

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Cell

- Smallest physical entity that allows the access to mobile entities
- Cell ≠ point-to-point connection
- Associated to the physical mechanism of information transfer (radio technologies or infrared)
- Cell
  - Terminal oriented or
  - Defined by a base station
- There is overlapping of different cells in a wireless network

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Home network

- Network where the user is “known”
- Associated to identification concepts
- Associated to accounting concepts
- Destination network for the others (even if the user is not there)
- Mobility is developed assuming that usually the user is in this network
- There needs to be communication between this network and the one where the user is at each time

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Reacting to location

- Several distinct possibilities
  - "re-addressing" – terminal has a new address, which is communicated to the users requesting communication
  - "tunnel" – information always goes to the home network and is directed to the new location of the user
  - "re-routing" – network modifies the routing tables to route all traffic destined to the terminal to the new access point

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Handover

- Transfer of information flow between access points

Handover ≠ Roaming

- Several handover classifications
  - Scope
  - Technology
  - Connectivity
  - Performance

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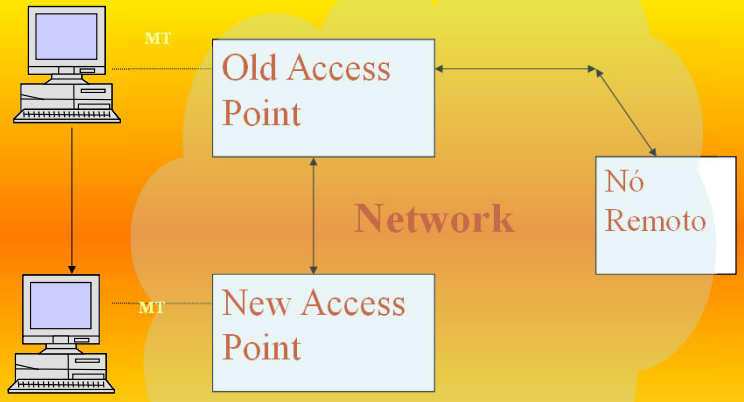
Handover: sequence(s)



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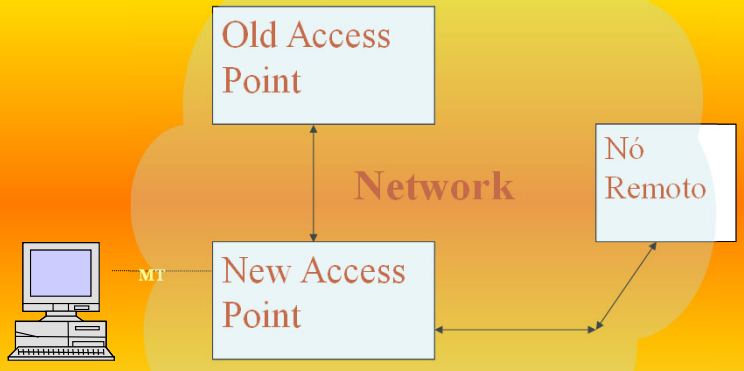
Handover: sequence(s)



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Home Technologies: WiFi, Bluetooth

IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
Year Released	1999	1999	2003	2009	2014	2019
Frequency	5Ghz	2.4GHz	2.4GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz
Maximum Data Rate	54Mbps	11Mbps	54Mbps	600Mbps	1.3Gbps	10-12Gbps

Bluetooth Spec. Evolution

Specifications	1.1	1.2	2.0 + EDR	2.1 + EDR	3.0 +HS	4.0
Adopted	2002	2005	2004	2007	2009	2010
Transmission Rate	723.1 kbps	723.1 kbps	2.1 Mbps	3 Mbps	24 Mbps	25 Mbps
Standard PAN Range	10 m	10 m	10 m	10 m	10 m	50 m
Improved Pairing (without a PIN)				Yes	Yes	Yes
Improved Security		Yes	Yes	Yes	Yes	Yes
NFC Support			Yes	Yes	Yes	Yes

	Speed	Distance	Released Date	Bands	Backward Compatibility	New Hardware Requirement
Version 4.1	24MBs	100 m or 300 feet	4/12/2013	2.4 to 2.485 GHz	Yes	No
Version 4.2	24MBs	100 m or 300 feet	2/12/2014	2.4 to 2.485 GHz	Yes	For some feature
Version 5	48MBs	300 m or 985 feet	16/06/2016	2.4 to 2.485 GHz	No	Yes

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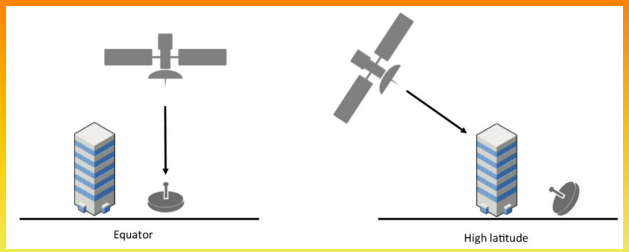
Satellite: LEO and MEO

Abbreviation	Orbit Name	Altitude [km]
LEO	Low Earth Orbit	160 to 2000
MEO	Medium Earth Orbit	2000 to <35786
GSO	Geosynchronous Orbit	35786
GEO	Geostationary Equatorial Orbit	35786

- GEO: 500msec
- LEO: 25msec



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Long Range Technologies for IoT

Network:	Sigfox	LoRa	NB-IoT (Cat NB1)
Type:	PLWAN	PLWAN	DSSS modulation
Low Power:	+++++	++++	++++
Throughput Kbit/s:	0,1	50	100
Bandwidth:	Ultra-narrowband	Narrowband	Narrowband
Latency:	1 – 30s	Based on profile	1.6 – 10s
Standard:	Proprietary	Proprietary	3GPP Rel. 13
Availability world-wide:	++	+++	++
Spectrum:	Unlicensed ISM	Unlicensed ISM	Licensed LTE
Complexity:	Very low	Low	Very low
Coverage / range:	Medium / high	Medium / high	High
Battery life:	Very high	Very high / high	High
Gateway needed:	Yes	Yes	No, but optional
Signal penetration:	High	Medium / high	Medium / high
Security:	+++	+++	+++
Future proof:	+++	+++	+++++

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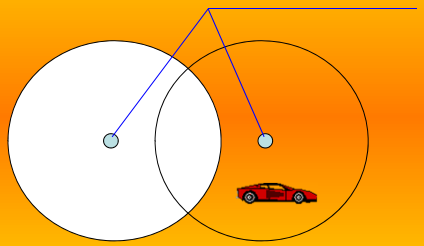
Public cellular network

- Access network with radio link
  - Space is divided in cells with a base station
  - Mobile Node (MN) can work when changing between cells



Cell length is
  - Highly variable
  - Depends on the technology
  - Depends on the number of users

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Cells

Advantages:

> capacity

> # users

< power

> robustness (distributed system)

Each cell locally takes care of interference, coverage area, etc...

- Disadvantages
  - Uses cabled network between cells
  - Many handovers
  - Interference between cells
- Fundamental:

  Cell dimensioning
  - Length of the cell
  - Frequency re-utilization
  - Channel reservation

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Cells

- Length:
  - 100m to 35 km (GSM)
  - Microcells: closed spaces
  - Hat cell: set of cells
    - Avoid frequent handoffs in critical places
- Format:
  - Teoretically analyzed as a hexagon
  - Reality: it depends on the place
- BS positioning:
  - Cell centrally excited
    - BS in the center of the cell, with omni-directional antenna
  - Cell side excited
    - BSs in the vertices (in three)
    - Directional antennas

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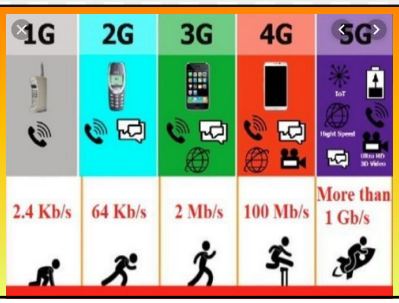
Wide Communication technologies: Cellular

Comparison	2G	3G	4G	5G
Introduced in year	1993	2001	2009	2018
Technology	GSM	WCDMA	LTE, WiMAX	MIMO, mm Waves
Access system	TDMA, CDMA	CDMA	CDMA	OFDM, BDMA
Switching type	Circuit switching for voice and packet switching for data	Packet switching except for air interference	Packet switching	Packet switching
Internet service	Narrowband	Broadband	Ultra broadband	Wireless World Wide Web
Bandwidth	25 MHz	25 MHz	100 MHz	30 GHz to 300 GHz
Advantage	Multimedia features (SMS, MMS), internet access and SIM introduced	High security, international roaming	Speed, high speed handoffs, global mobility	Extremely high speeds, low latency
Applications	Voice calls, short messages	Video conferencing, mobile TV, GPS	High speed applications, mobile TV, wearable devices	High resolution video streaming, remote control of vehicles, robots, and medical procedures



Early cellular systems

- 1G: analog systems (450-900 MHz)
  - Signalling: FSK
  - Share of medium: FDMA
  - NMT (Europe), AMPS (US)
- 2G: digital systems (900, 1800, 1900 MHz)
  - Share of medium : TDMA/CDMA
  - Circuit switching
  - GSM (Europe), IS-136 (US), PDC (Japan)
- 2.5G: extensions for packet switching
  - Digital: GSM → GPRS
  - Analog: AMPS → CDPD
- 3G: networks for data applications
  - High rates, data, Internet
  - Share of medium : TDMA/CDMA/CDMA
  - IMT-2000 (Europe: UMTS)

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GSM: first widespread celular network

- Defined by CEPT/ETSI
- Requirements defined in terms of
  - Services — **Portability =PSTN**
  - QoS — **= PSTN**
  - Security — **Ciphering with low cost**
  - Use of radio frequency — **Efficiency**
  - Network — **Numbering ITU-T, SS-7**
  - Cost — **Low**

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Basic architecture

- Each cell is controlled by a Base Station System (BSS)
- BSS are structured as base station controllers (BSC) + base transceiver station (BTS)
  - BTS comprises the radio transmission and reception devices; manages the signal processing related to the air interface
  - BSC manages the radio interface: allocation, release and handover of radio channels
- BSs are connected to mobile switching center (MSC) through physical lines
- Each MSC is connected to other MSCs
  - ISDN-switch
  - Coordinates and sets up calls to and from Mobile Stations (MS)
- There are MSC connected to the public network (PSTN), the gateway mobile switching center (GMSC).

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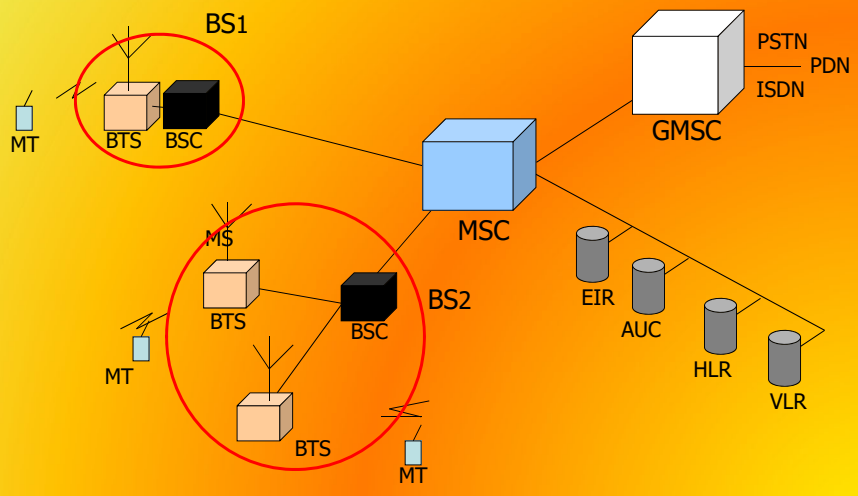
GSM architecture



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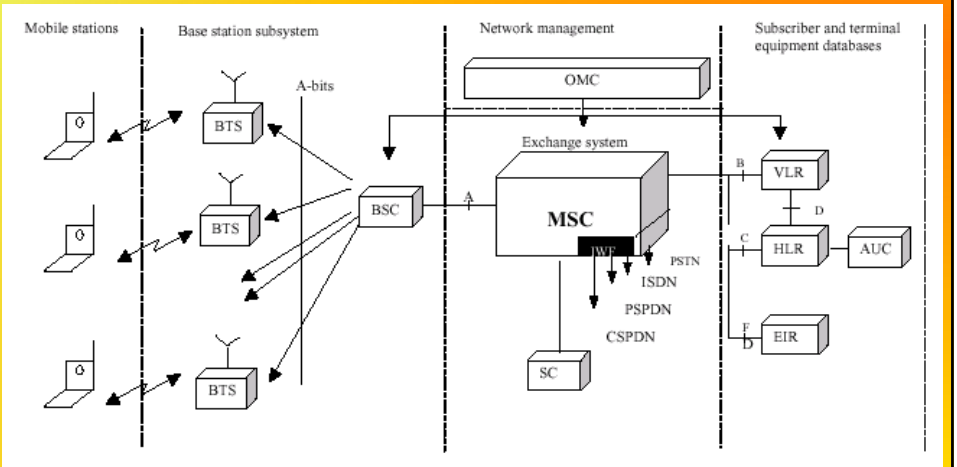
GSM architecture



OMC – Operations and Maintenance Center
SC –Service Center
P/C-SPDN – Packet /Circuit Switched Packet Data Network

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Mobile Switching Center

- MSC = Mobile Switching Center
  Contains:
  - Home Location Register (HLR) - database used to store permanent and semi-permanent subscriber data; it knows in which location area the MS is
  - Visitor Location Register (VLR) - contains all the subscriber data, both permanent and temporary, which are necessary to control a MS in the MSCs coverage area.
  - Autentication Center (Au) - database with subscriber authentication keys and the algorithm required to calculate the authentication parameters to be transferred to the HLR
  - Equipment Identity Registry (EIR) - database contains information on the MS and its capabilities
- Connects to BSS
  (Master of the cell, defines channels and access to them...)
- Contains the registration of its stations
- There is a specific signalling channel
  - MT-BS (MSC): location, call establishment, answer to a received call
  - BS (MSC)-MT: cell identification, location update, establishment of received call

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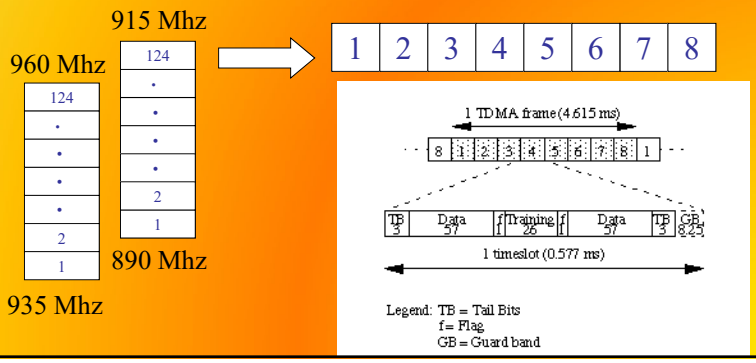
GSM channels

- TDMA structure with 8 timeslots
- Delay of three slots (up and down) → avoids simultaneous rx/tx
- Uplink: 890 - 915 MHz
- Downlink : 935 - 960 MHz
- 124 channels in each band (=> until 8 users per channel)



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Logical channels

- Logical channels are mapped in physical channels. It is a technique to simplify radio resource management.
- A physical channel consists on a specified timeslot in a specified channel
  - GSM distinguishes between *physical channels* (the timeslot) and *logical channels* (the information carried by the physical channels)
- Data channels
  - TCH – Full rate traffic channel
  - TCH/H – Half rate traffic channel
- Signalling channels
  - Synchronizes MN with cell
  - Informs MN about
    - Cell parameters
    - Neighbor cells
    - Channels
  - Performs paging
    - Discovers MN in low-power mode
  - Allows MN to access the network
    - Access in shared mode
    - Fundamental for MN to ask connection
  - BCH – Broadcast channels; CCH – common control channels; DCCH/ACCH – dedicated/associated control channels

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Logical channels

BCH : Broadcast channels
- Broadcast Control Channel (BCCH) - Broadcasts Network information, e.g. for describing the current control channel structure. The BCCH is a point-to-multipoint channel (BSS-to-MS).
- Frequency Correction Channel (FCCH) - MS frequency correction
- Synchronization Channel (SCH) - Synchronisation of the MSs

CCH : common control channels
- Random Access Channel (RACH) - MS access requests, response to call announcement, location update, etc
- Paging Channel (PCH) - MS terminating call announcement

D/ACCH: dedicated/associated control channels
- Stand-alone Dedicated Control Channel (SDCCH) - For signalling exchanges, e.g. during call setup, registration / location updates
- Slow Associated Control Channel (SACCH) - SDCCH in-band signalling, e.g. for link monitoring

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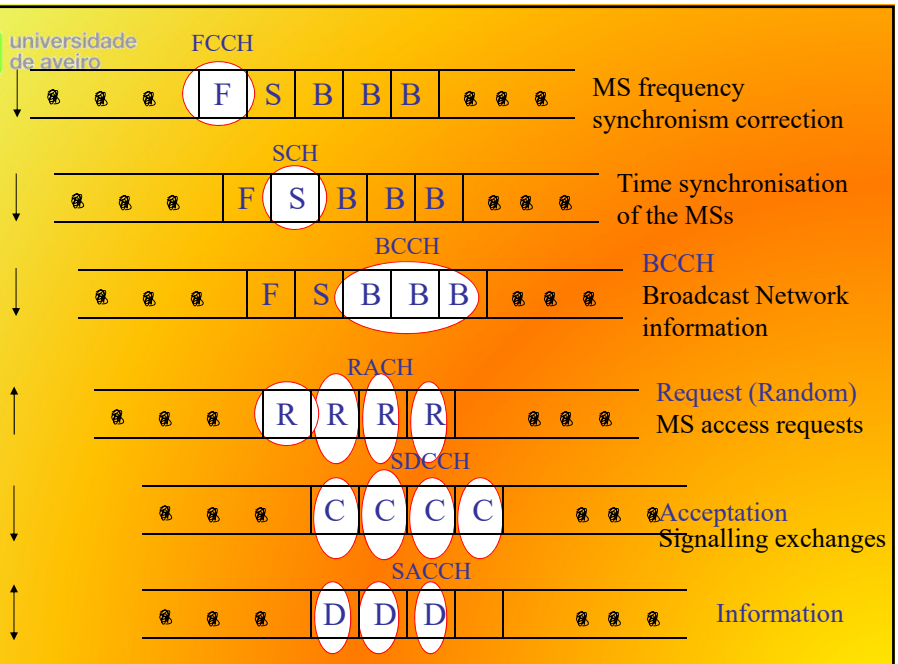

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GPRS

- Transport service dedicated to packet transmission, connecttion oriented to data network (Internet)
  - Better transmission rates (max 150kbps)
  - Allows burst transmissions
  - New network applications
  - New accounting mechanisms (user oriented: per traffic, e.g.)
- **Transmission plane**
  - **Data packets are transmitted by a tunnel mechanism**
- **Control plane**
  - **GTP: a mechanism for tunnel management (create, remove, etc..)**
- **Radio interface**
  - **Logic channels changed, its management changed**
  - **Maintains notion of "master-slave"**
- New security features such as ciphering
- New GPRS-specific signalling

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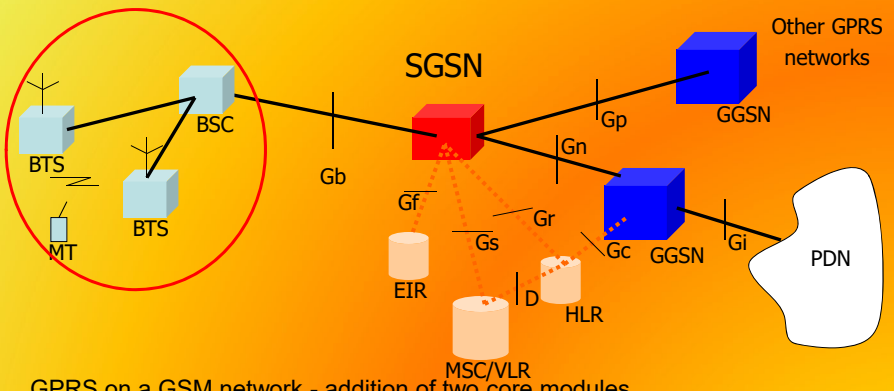
GPRS architecture



GPRS on a GSM network - addition of two core modules

•Gateway GPRS Service Node (GGSN)

Gateway between the GPRS network and public data networks such as IP

Also connects to other GPRS networks to facilitate GPRS roaming

•Serving GPRS Service Node (SGSN)

Provides packet routing to and from the SGSN service area for all users in that service area

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MN registration

There is an explicit registration of MN in the network

- GPRS attach
- GPRS detach – can be initiated by MN or network
- Location packets are periodically sent

- HLR (changed!) maintains information about MN status, including
  - GPRS status (ready, standby, idle)
  - QoS profile (priority 3, delay 4, reliability 5, peak and mean throughput 19 and 9)
  - PDP (packet data protocol) context
    - Is a data structure present on both the SGSN and the GGSN which contains the subscriber's session information when the subscriber has an active session.
    - When a mobile wants to use GPRS, it must first attach and then **activate a PDP context**. This allocates a PDP context data structure in the SGSN that the subscriber is currently visiting and the GGSN serving the subscribers **access point**.
    - Also stored in SGSN and GGSN

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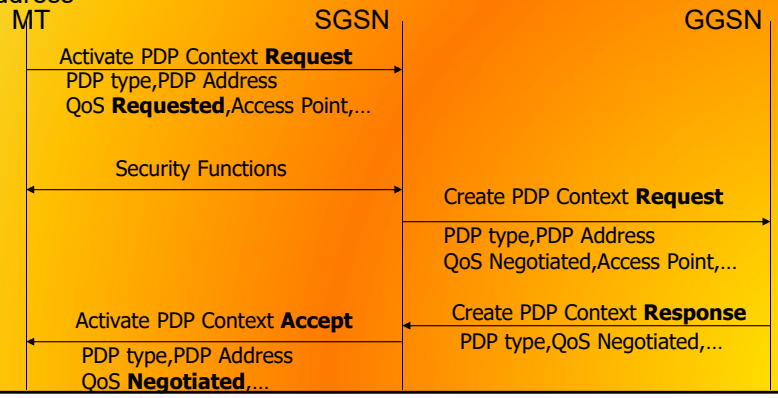
PDP context activation

After attach: MN receives a packet with PDP address

PDP addresses: session specifics

- static: allocated by home network of MN
- dinamic: allocated by GGSN

PDP profile: type, PDP address, QoS requested, correspondent GGSN address



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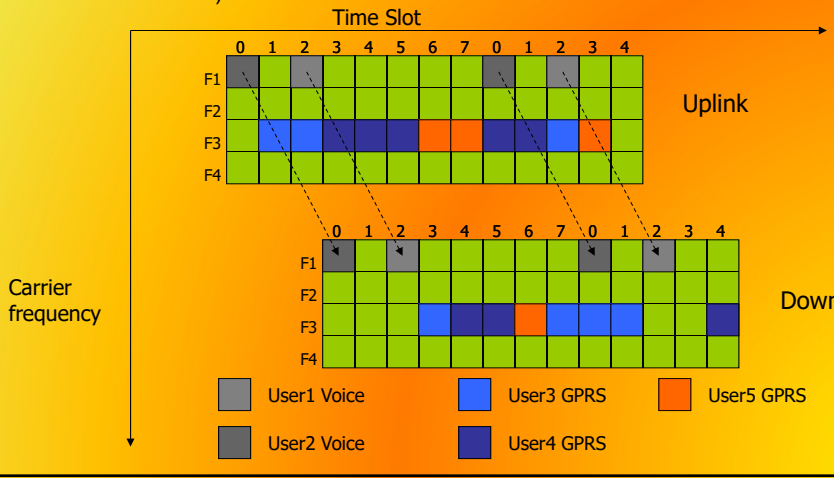
GPRS radio interface

GTP performs tunnelling of user and signalling packets between GPRS nodes
A mobile node can use 8 slots, dinamically allocated
Pointer in the packet indicates where the next packet will come (better for long transmissions)



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Logical channels in GPRS

Group	Channel	Function	Direction
Packet data Traffic channel	PDTCH	Data Traffic	MS ↔ BSS
Packet broadcast control channel	PBCCH	Broadcast Control	MS ← BSS
Packet common Control Channel (PCCCH)	PRACH	Random Access	MS → BSS
	PAGCH	Access Grant	MS ← BSS
	PPCH	Accept/not Paging	MS ← BSS
	PNCH	Notification	MS ← BSS
Packet Dedicated Control Channels	PACCH	Associated Control	MS ↔ BSS
	PTCCH	Timing Advance Control	MS ↔ BSS

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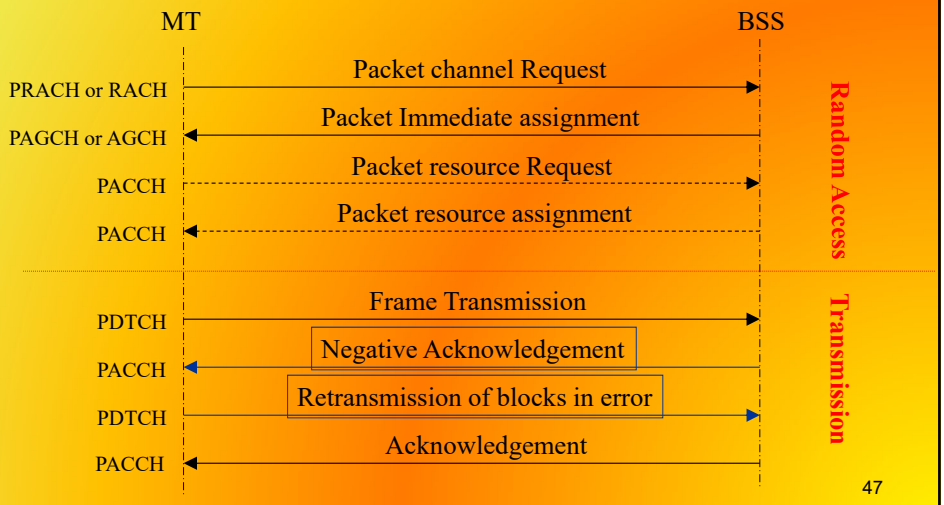
Data transfer (Uplink)



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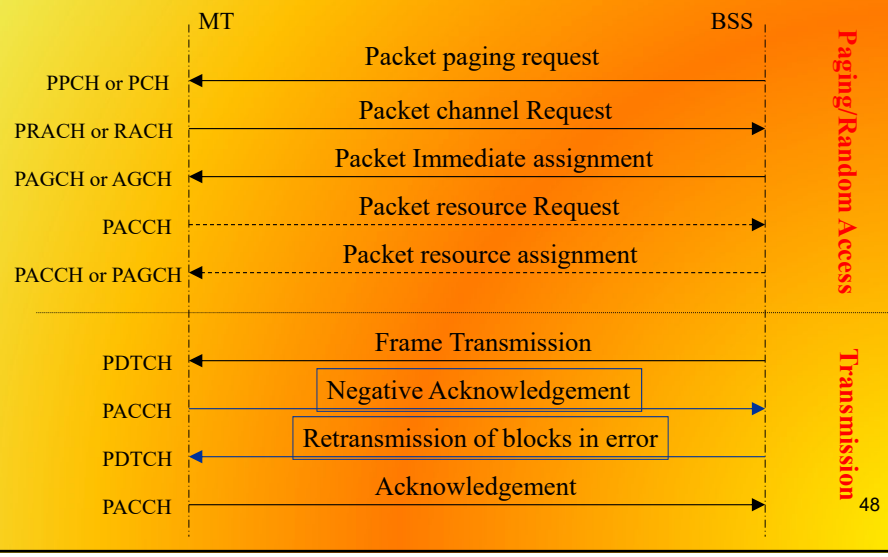
Data transfer (Downlink)



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What is 3GPP?

3rd Generation Partnership Project - partnership of regional SDOs

SDOs take 3GPP specifications and transpose them to regional standards. Addresses:

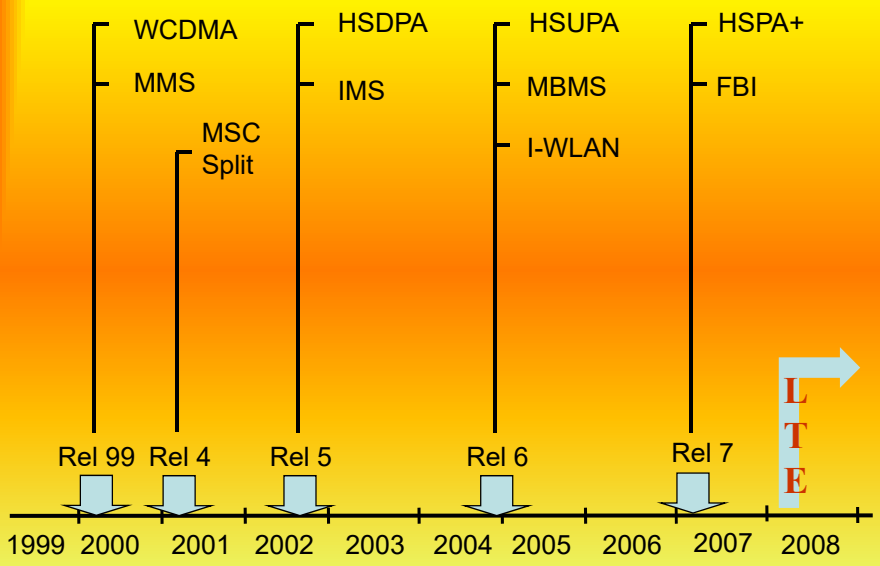
3G (IMT-2000) systems based on the evolved GSM core network and the Universal Terrestrial Radio Access (UTRA), in FDD and TDD modes;

GSM, including GSM evolved radio access technologies (GPRS/EDGE/GERAN)

ITU references the regional standards

GSM
GPRS
EDGE
W-CDMA – FDD (Frequency Division

3GPP Release initial timeline: UMTS is phased



UMTS: first universal celular data system

- 3G system
- Oriented to generalized service diffusion and its future users trends
  - Combines cellular, wireless, paging, etc. functions
- "multimedia everywhere"
- Developed as an evolution path of 2.5G systems
  - Progressive evolution (GPRS-EDGE-UMTS)
- (Initial) Data rates of UMTS were:
  - 144 kbps for rural
  - 384 kbps for urban outdoor
  - 2048 kbps for indoor and low range outdoor
    - Large rates later, progressively increased

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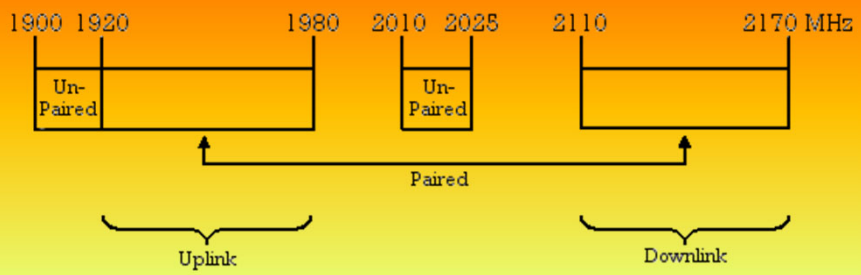
UMTS Frequency Spectrum

- 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.



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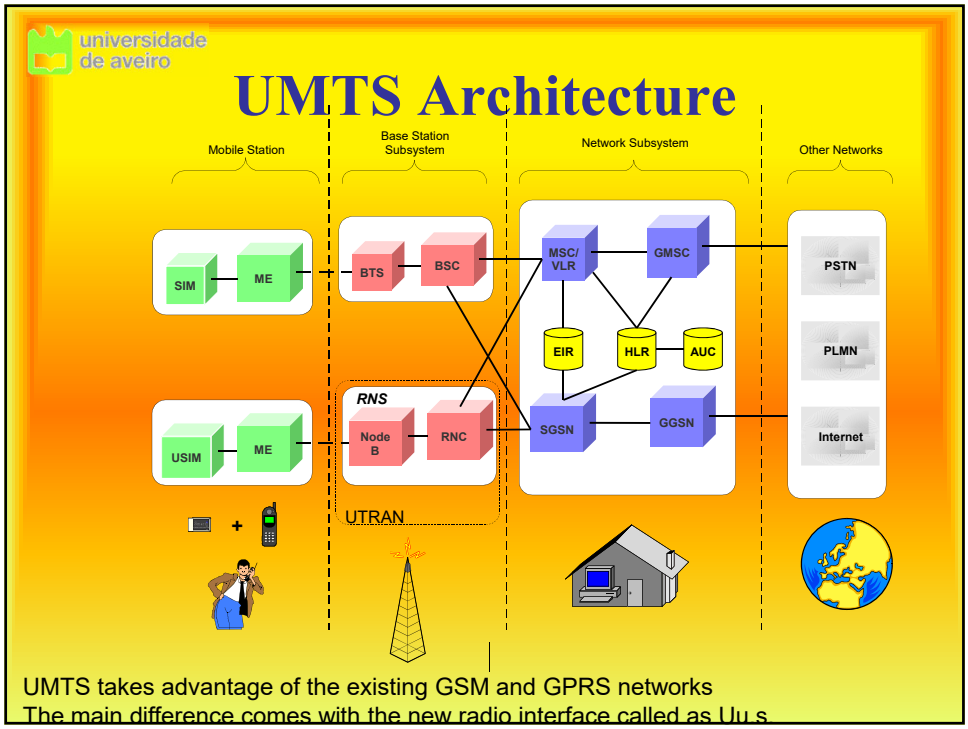
UMTS Network Architecture

- UMTS network architecture consists of three domains
  - Core Network (CN): Provides 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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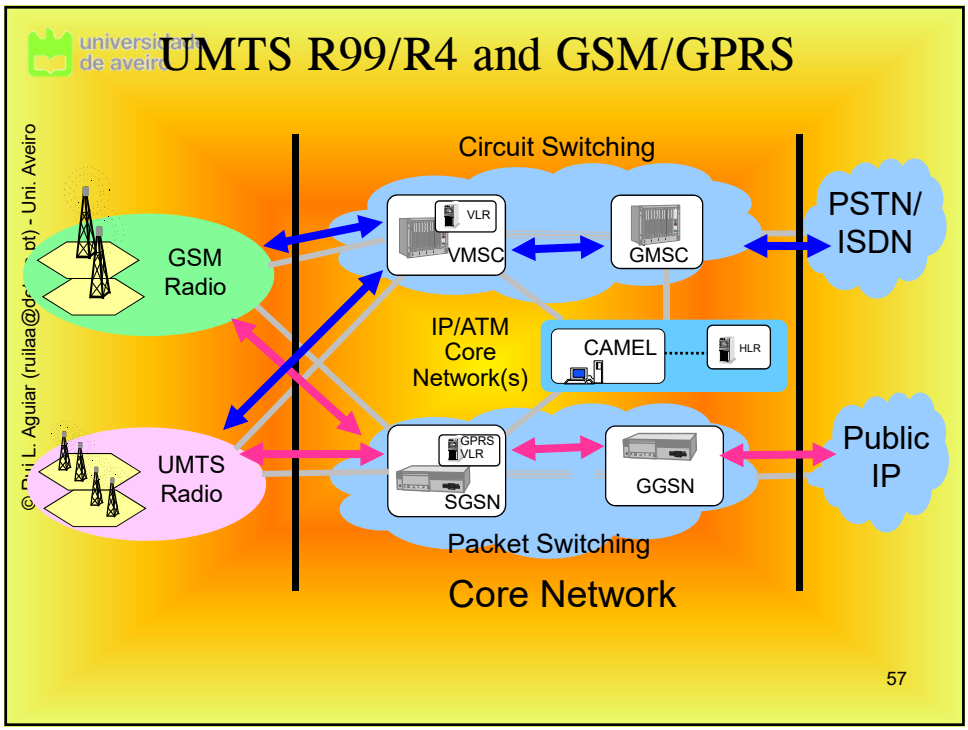
UMTS Architecture
Mobile Station
Base Station Subsystem
Network Subsystem
Other Networks
SIM
ME
USIM
ME
BTS
BSC
RNS
Node B
RNC
UTRAN
MSC/ VLR
GMSC
EIR
HLR
AUC
SGSN
GGSN
PSTN
PLMN
Internet
UMTS takes advantage of the existing GSM and GPRS networks
The main difference comes with the new radio interface called as Uu s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UMTS R99/R4 and GSM/GPRS
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Circuit Switching
GSM Radio
VLR
VMSC
GMSC
PSTN/ ISDN
IP/ATM Core Network(s)
CAMEL
HLR
UMTS Radio
GPRS VLR
SGSN
GGSN
Public IP
Packet Switching
Core Network
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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

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User Call initiation