Chapter I

Cellular Concepts, standards and architectures of radio networks

Introduction

The distribution of users in a given area poses a delicate problem for mobile networks. Without corded phones, subscribers can be virtually anywhere and the network must provide a connection for those subscribers during their displacement. To increase the quality of service of the mobile network, good coverage area must be done. Precious site planning for a mobile network is therefore an essential aspect of the implementation of this network. Network planning is a task to select and place base stations (BTS). Planning is a process that requires inputs from many domains of cellular technology, such as transmission, multiple access systems, data communications, mobile beamforming, smart arrays, cell site dimensioning, etc.

The main goal of mobile network planning is to offer these networks a rentable solution in terms of coverage, capacity, and quality. Depending on whether capacity or coverage is the primary criterion, different regions have different design criteria for planning processes. A mobile network's design typically involves a number of network planning procedures, particularly in the transmission area.

For each cell site, planning engineers should attempt to do very realistic/accurate dimensioning. Many inputs are needed for the dimensioning exercise such as:

- Cost of construction
- The geographical area to be covered and cell site localization
- Estimated traffic in each region and allowable congestion rate
- Frequency band to be used and frequency re-use
- Development of cellular technology (2G towards new technologies)

Several factors must be taken into account to improve the quality of services, such as the number of populations in a given area, the geographical distribution of the population and vehicles, population income and cell phone usage statistics.

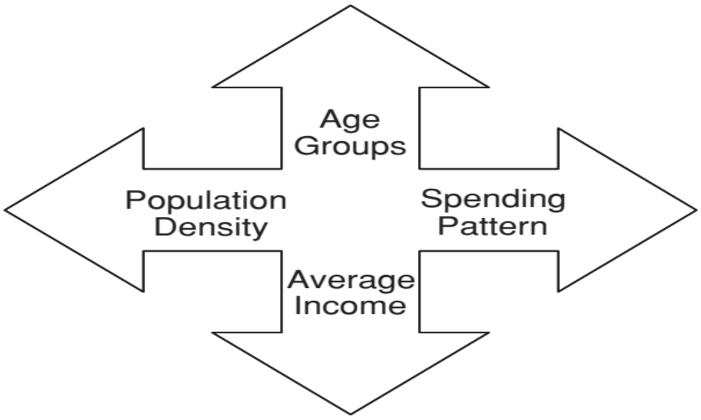

Figure 1-1: Factors to identify a geographic area.

I.1. Some mobile network standards

I.1.1. GSM standard

The GSM (Global System for Mobile Communication) network is considered as the first digital cellular telecommunications system. This system allows the users to exchange information (SMS, voice) between them with good quality.

There are two standards of GSM: GSM 900 and DCS 1800. These two standards are classified depending on the corresponding frequency band reserved for each standard by the World Administrative Radio Conference.

In 1982, the European conference defined GSM 900:

- The frequency band used for the uplink is 890 MHz to 915 MHz (from MS to BTS).
- The frequency band used for the downlink is 935 MHz to 960 MHz (from BTS to MS).

For DCS (Digital Cellular System), the uplink and downlink bands are defined as:

- The frequency band used for the uplink is 1710 MHz to 1785 MHz
- The frequency band used for the downlink is 1805 MHz to 1880 MHz

I.1.1.1 GSM architecture

A GSM network offers many services to its subscribers which are classified into three categories:

- Teleservices (emergency calls, voice messaging, telephony with fixed telephone subscribers)
- Bearer services (data services, short message service SMS, cell broadcast, local features)

- Supplementary services (add-ons: call forwarding, advice of charge, call waiting, conference call, …)

Basically, A GSM system is designed as a combination of three major subsystems: the network subsystem (NSS), the radio subsystem (BSS), and the operation and support subsystem (OSS) in some cases, this last subsystem is known by operation and maintenance center (OMC):

- Base Station Subsystem (BSS, radio subsystem) which provides radio transmissions and manages the radio interface.
- Network Switching subsystem (NSS, Network Subsystem) is the link between the GSM radio part and the PSTN switched network which performs the call set-up and mobility functions
- Operating and maintenance subsystem (OSS, Operation and Support System) which allows the operator to administer and manage the network

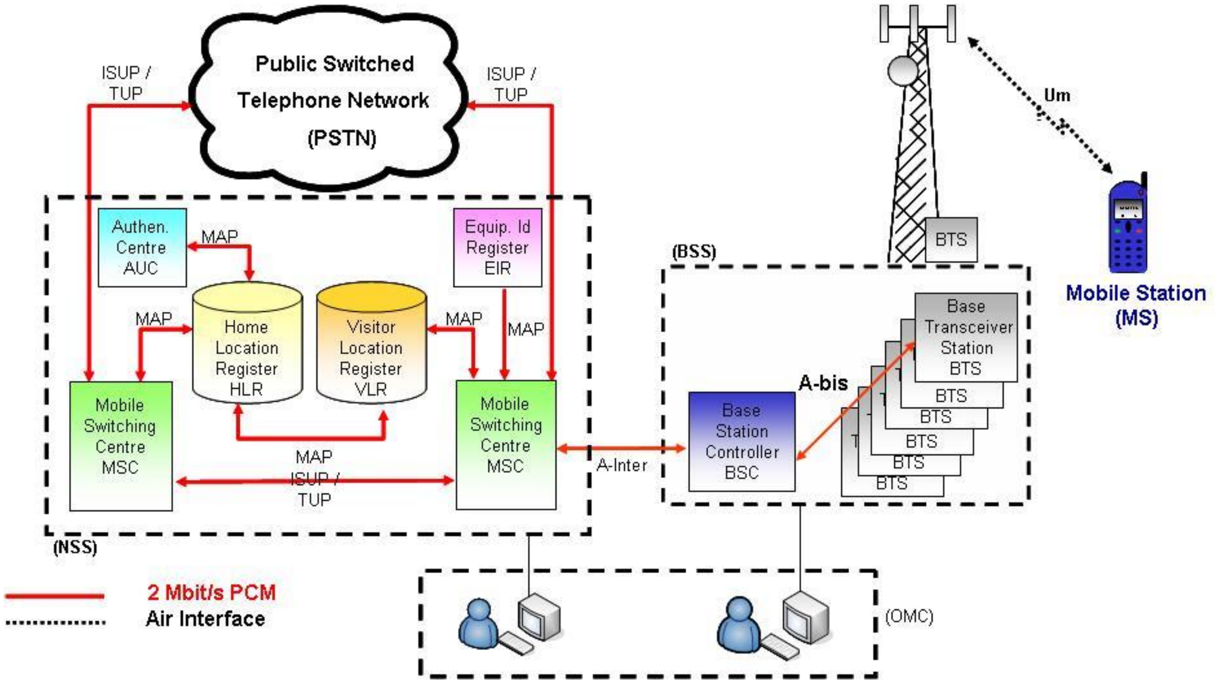

Figure 1-2 : GSM network architecture

A. *Base Station Subsystem (BSS)*

A radio subsystem is the assembly consisting of one or more base stations (BTS), mobile stations (MS), and the base station controller (BSC). This set manages all the radiocommunication part (radio channels, mobile stations, management of Handovers, …).

B. Network Switching Subsystem (NSS)

A network switching subsystem is the part which includes several devices, their connections, functions related to end-to-end calls, management of subscribers, mobility, and interface with the fixed PSTN. Among these equipment, one can cite

- *Mobile Switching Center* (MSC): The MSC enables many functions such as call setup, routing, and handover between BSCs in its propre region and to or from other MSC, and other functions such as billing for all subscribers based in its own area;
- Home Location Register (HLR): The HLR is defined as a centralized database of all subscribers registered in a given PLMN. We can find more than one HLR in a PLMN,
- Visitor Location Register (VLR).
- AUthentication Center (AUC).
- Equipment Identity Register (EIR).

In GSM, the signaling between all these devices is ensured by the CCITT signaling network (CCITT Signaling System No. 7, SS7 protocols).

C. Operation and Support System or Operation and maintenance center

This subsystem includes all activities that allow memorizing and controlling the performance of GSM equipment and allow to use resources in order to provide a certain level of quality to users. Among these tasks, we can cite

- Administrative functions (declaration of subscribers, billing, …)
- Security management (against intrusion for example)
- Operation and performance management (traffic and quality observation, network load, etc.)
- Control and configuration of the system (updating of upgrade software and new functionalities, introduce new equipment into the network)
- Network maintenance (equipment test from time to time to minimize loss of service due to failure).

The OSS part has two levels: OMC (Operations & Maintenance Center) and NMC (Network Management Center).

I.1.1.2 Frequency allocation in GSM network

The GSM network has been deployed in several frequency bands, including the 900 MHz band, the 1800 MHz band and the 1900 MHz band (in North America). Table I.1 shows the allocated frequencies for these three bands. The entire spectrum of a given band is made available in a given country, it is likely to be shared between several operators (three in Algeria: ATM Mobilis, Djezzy and Ooredoo).

Table 1-1: Frequency allocation for GSM standards.

	GSM900	GSM1800	GSM1900
Frequency band used for Up-Link (from MS to BTS)	**890-915 MHz**	**1710-1785MHz**	**1850-1910MHz**
Frequency band used for Down-Link (from BTS to MS)	**935-960 MHz**	**1805-1880MHz**	**1930-1990MHz**
Available frequency bands	**25+25 MHz**	**75+75MHz**	**60+60MHz**
Access technique	**AMRT/AMRF**	**AMRT/AMRF**	**AMRT/AMRF**
Radio channel bandwidth	**200 KHz**	**200 KHz**	**200 KHz**
Frequency duplex (FDD)	**45 MHz**	**95MHz**	**80MHz**
Number of radio channels in UL/DL	**124**	**375**	**300**
Number of Time slots	**8**	**8**	**8**
Transmission type	**digital**	**digital**	**digital**
Aggregate data rate	**270 Kbit/s**	**270 Kbit/s**	**270 Kbit/s**
Gross Rate (full rate speech)	**22.8 Kbit/s**	**22.8 Kbit/s**	**22.8 Kbit/s**
speech codec transmission rate (full rate)	**13 Kbit/s**	**13 Kbit/s**	**13 Kbit/s**
Modulation type	**GMSK**	**GMSK**	**GMSK**
Coding type	**RPE-LTP**	**RPE-LTP**	**RPE-LTP**

Each RF carrier (124 for GSM 900) is divided into eight time slots (Ts), numbered from 0 to 7, and these time slots are transmitted in a frame structure.

I.1.1.3 Geographical structure of the GSM network

The GSM network is structured, hierarchically, in zones. Each zone having an identifier. The following diagram presents the geographical structure with the codes associated with each zone.

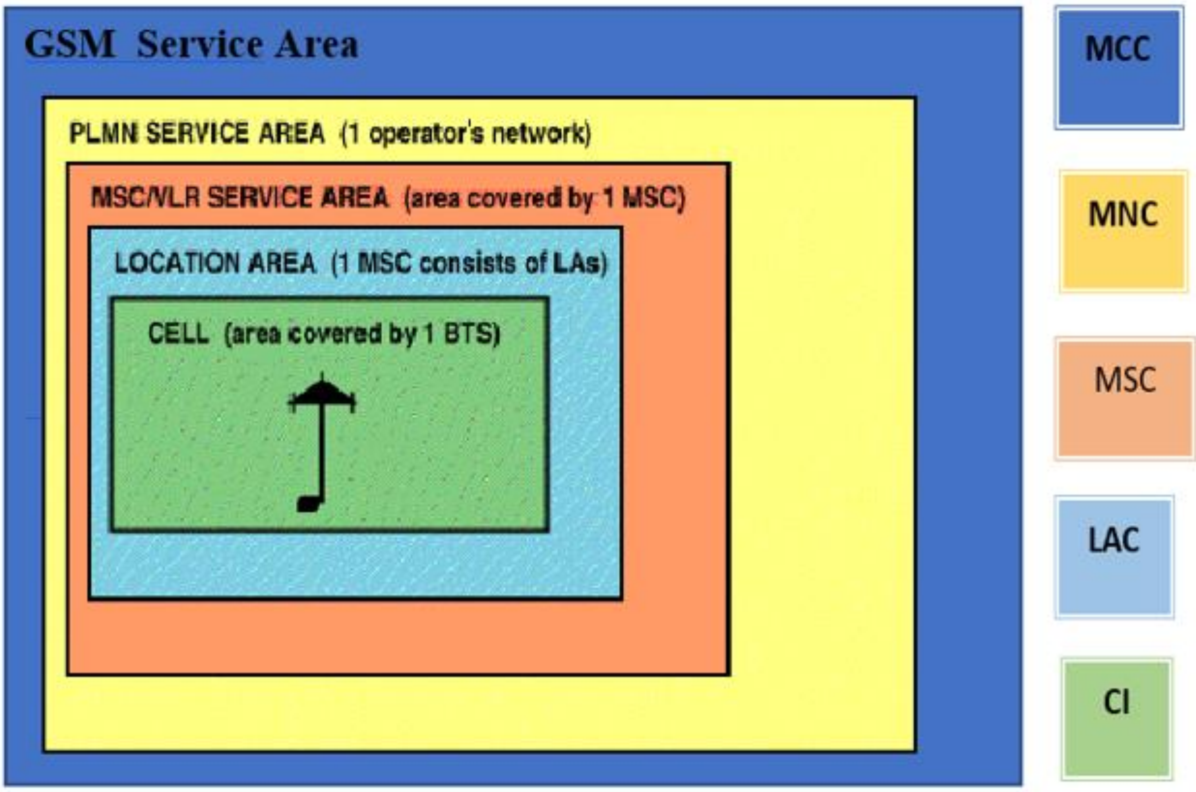

Figure 1-3: Geographic Structure of GSM network

I.1.1.3 .1 GSM service Area

This area is the entire geographical area in which a subscriber can access a GSM network. It is identified by Mobile Country Code (MCC) and Mobile network code (MNC).

For example, Algeria mobile country code MCC is 603. And the Mobile Network code MNC is 01 for Mobilis, 02 for Djezzy, and 03 for Ooreedo.

I.1.1.3 .2 PLMN service Area (Public Land Mobile Network)

PLMN is considered as a group of cells of a GSM network which are administered by an operator in a given geographical area. It is identified by MNC (Mobile Network Code) and NDC (National Destination Code). For GSM applications, an NDC is allocated to each GSM PLMN. In some countries more than one NDC may be required for each GSM PLMN.

I.1.1.3 .3 MSC service Area

MSC area is a set of location areas (LAs) which represent the geographical area of GSM network. This area is controlled by one MSC.

I.1.1.3 .4 Location Area

The location area is the geographical area used by GSM network, in particular used by the MSC/VLR during paging, which makes it possible to locate subscribers in idle mode and thus facilitate the search procedure. This area includes a number of cells controlled by one or more BSCs. LA is identified by LAI (Location Area Identity), as follow

$$LAI = MCC+MNC+LAC.$$

I.1.1.3 .5 Cell

The cell is the basic unit of a cellular network system. It is defined as an area covered by one BTS or one sector of a BTS. Generally, it is identified by CGI (Cell Global Identity) or CI (Cell Identity).

I.1.1.4 Standardized interfaces in GSM network

In this section, we will briefly present the different interfaces in the GSM network, as well as their main functions. The interfaces ensure the communication between the different parts of the GSM network and allow their interoperation as shown in the following Figure.

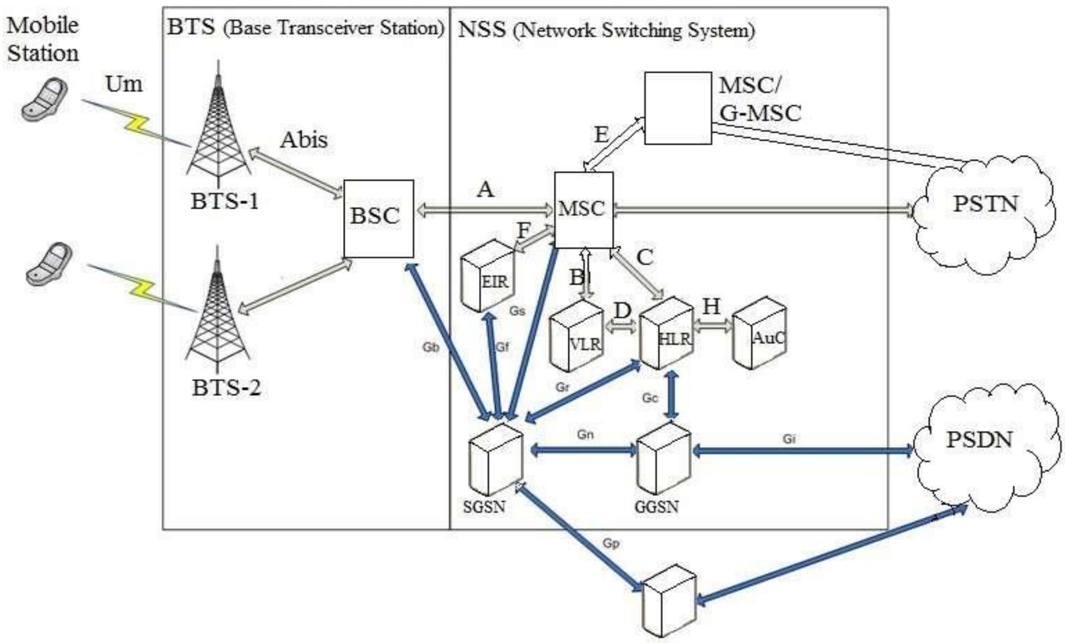

Figure 1-4: Interfaces in GSM network

The main standardized interfaces of the GSM network are as follows;

- The U_m radio interface (between mobile and BTS)
- The interfaces between the access network and the GSM circuit and GPRS core network

- The MAP-E and Gn interfaces

The A-bis interface between BTS and BSC. The A-bis interfaces of the access network are not standardized, forcing the operator to combine BSC and BTS equipment from the same manufacturer.

Table 1-2: Some GSM network interfaces.

Interface	Equipements	Function
Um	BTS-Mobile	Radio interface
A-bis	BSC-BTS	Supervision of the BTS, activation of radio resources
A-BSSMAP	BSC-MSC	Resource allocation, Handover management
H	HLR-AuC	Exchange of information with encryption and authentication
E	MSC-GMSC	Transport of SMS
D	VLR-HLR	The VLR informs the HLR about the location of the mobile
C	GMSC-HLR	Interrogation of the HLR to reach a mobile subscriber.
B	MSC-VLR	User information exchange and location area update

Note: As radio engineers, we are interested in the radio interface (Um). This interface is located between the Mobile Ms and the BTS.

I.1.1.5 GSM radio interface protocols

We will present an overview of the signaling protocols of the GSM network. Protocol layers have some equivalence for low-level layers

- Level 1, or physical layer
- Level 2, or data link layer
- Level 3, or routing layer

Level 1 is based on GMSK modulation with mixed access mode (TFDMA).

Level 2 aims to provide reliable transport of information between the mobile and the GSM network. The protocol layers of this level are based on the LAPDm (modified LAPD) protocol.

Level 3 contains mobility management protocols (MM protocol: Mobility management) and call setup (CM/SM: Connection/Session Management).

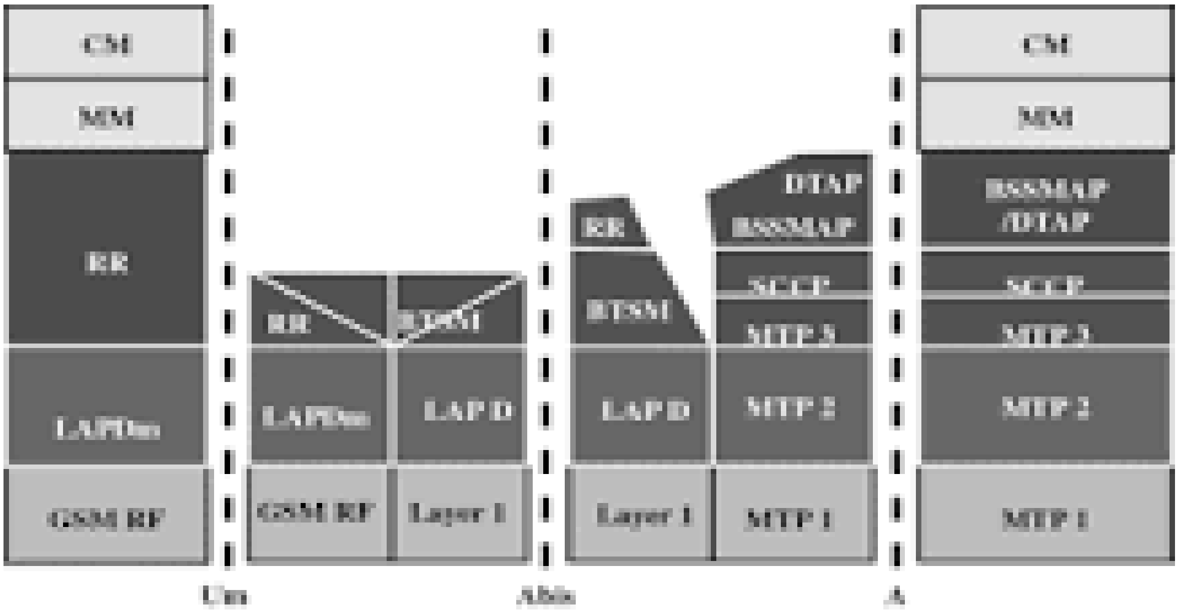

Figure I.5: *GSM signaling architecture*

I.1.1.6 Gaussian Minimum Shift Keying modulation (GMSK)

The modulation used in the GSM network is the Gaussian minimum shift modulation (GMSK). It consists of an MSK modulation followed by Gaussian-type low-pass filter in order to minimize the spectral band of the modulated signal. This modulation technique is widely used due to its reduced power spectral density and error performance.

The transfer function of the Gaussian filter is given by

$$H(f) = exp\left\{-\left(\frac{f}{B_b}\right)^2 \frac{Ln\ 2}{2}\right\}$$

where B_b is the passband of the filter at -3dB.

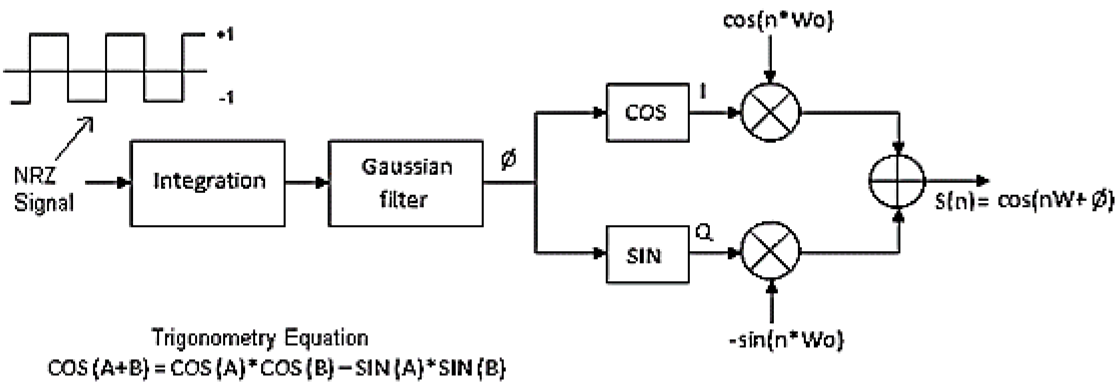

Figure 1-6: Block diagram of GMSK modulator.

Note: In GSM network, the Gaussian filter used in GMSK modulation, is generally characterized by the product $B.T_b$=0.3 where, T_b represents the duration of a bit and B the cut-off frequency at -3 dB of the filter.

I.1.1.7 Radio resource sharing (multiplexing techniques)

The field of wireless telecommunications had rapid and continuous expansion for the last years. It detects various restrictions as a result of radio spectrum saturation, which decrease system capacity and service quality. To overcome these limitations (increase the capacity of systems), many techniques have been used. These techniques are known by multiplexing techniques.

Among these techniques, we can cite temporal multiple access technique (Time Division Multiple Access: TDMA), frequential (Frequency Division Multiple Access: FDMA), and in coding (Code Division Multiple Access: CDMA). GSM network (2G) uses digital transmissions based on a combination of two techniques (TFDMA). For the third-generation network (UMTS: Universal Mobile Telecommunications System), the access technique used is WCDMA (Wideband Code Division Multiple Access). In this last system (3G), the used frequency bands have a bandwidth of 60 MHz (1920-1980 MHz and 2110-2170 MHz) for FDD systems (Frequency Duplex Division) and a bandwidth of 15 MHz (2010-2025 MHz) for TDD (Time Duplex Division) which use the same frequency band in both directions (up and down link).

- Frequency Division Multiple Access (FDMA)

In GSM system, the dedicated bands are divided into 124 frequency channels with a width of 200 kHz. On a frequency band, modulated signals are emitted around a carrier frequency which sits in the center of the band.

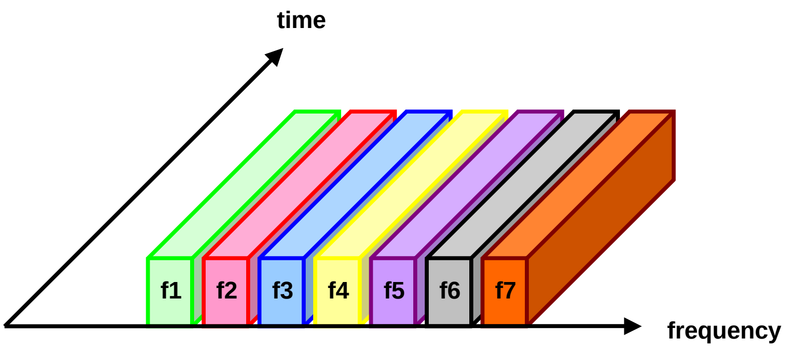

Figure 1-6 : *FDMA Frequency Division Multiple Access*

➢ Time Division Multiple Access (TDMA)

Principle: Each carrier is divided into time intervals called Time slots (Ts). The elementary duration of a slot has been fixed for the GSM standard on a 13 MHz clock and is equal to:

$$T_{slot} = (75/130) \times 10^{-3} s \text{ or around } 0.5769 \text{ ms.}$$

In GSM, a slot hosts a radio signal element called burst which is defined as the information format during one timeslot on the TDMA channel using the same frequency carrier. There are eight bursts during a frame cycle (T_{TDMA}).

$$T_{TDMA} = 8 \times T_{slot} = 4.6152 \text{ ms.}$$

Each user use only one timeslot per frame cycle. The slots are numbered by a TN index which varies from 0 to 7. A “physical channel” is therefore constituted by the periodic repetition of a slot in the TDMA frame on a particular frequency.

GSM designers have provided for the possibility of allocating to a user only one slot every 2 TDMA frames. This allocation constitutes a half-rate physical channel as opposed to the full-rate channel defined previously.

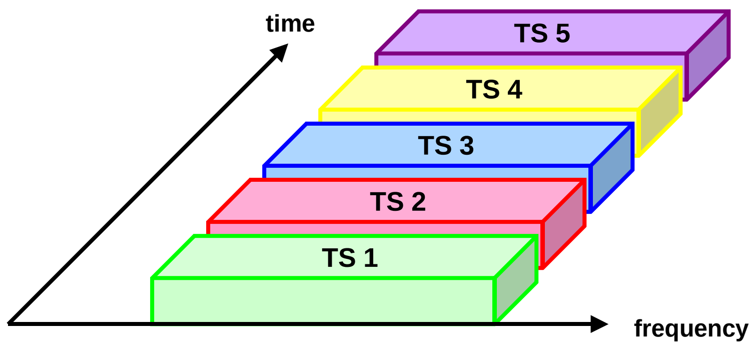

Figure 1-7 : *TDMA Time Division Multiple Access*

➢ **Code division multiple Access (CDMA)**

The CDMA combines FDMA and TDMA techniques. For CDMA based on spread spectrum, each user is assigned a unique pseudorandom user code and thus can access the frequency-time domain uniquely (using the same frequency at the same instant).

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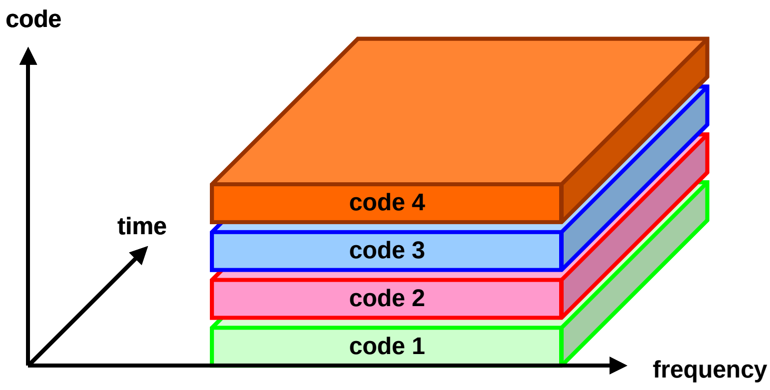

Figure 1-8 : *CDMA Code Division Multiple Access*

- Frequency division duplex (FDD)

FDD is the first separation method, which involves the transmission separation between the two directions spectrally by assigning a separate frequency for each direction. The signals do not interfere with each other because there is a certain duplex distance between these two frequencies. This FDD system is used by second generation and third generation cellular systems (GSM and UMTS).

- Time division duplex (TDD)

In the case of Time Division Duplex TDD, transmissions in both directions are implemented on the same frequency carrier. The frequency channel is divided into time periods. Each time period can be used by the radio equipment only for reception or for transmission. Many systems use TDD such as UMTS and DECT as an example.

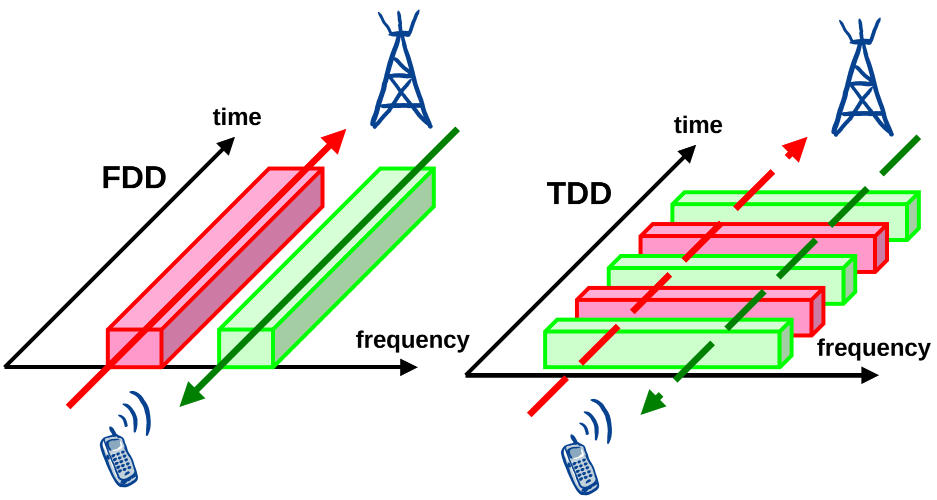

Figure 1-9 : *FDD et TDD*

I.1.1.8 Radio channels

The GSM channels are classified on two types: physical channels and logical channels. The logical channels are classified on two subtypes: traffic channels and control channels. The GSM radio interface is based on splitting the GSM spectrum into 124 carriers spaced of 200 KHz each (FDMA principle). Each carrier is split into 8 timeslots (TDMA principle).

I.1.1.8.1 Physical channels

A simplex physical channel is the repetition of a slot in each TDMA frame. A duplex physical channel is formed by a pair of simplex physical channels (both channels are separated by the duplex separation). The uplink is shifted by three timeslots from the downlink. It means that the transmission of the uplink (mobile) and the downlink (BTS) are delayed by an offset of three timeslots at the air interface, which is called timing advance. Physical channels provide a physical transmission medium for one or more logical channel.

If the carrier supporting the downlink is on f_d, the uplink must be at the frequency f_M, so we have:

$$f_M = f_d - \Delta\psi \qquad \text{where } \Delta\psi \text{ is the duplex separation}$$

The TDMA timeslots (ARFCN number + timeslot number) can be considered as physical channels when, they are used to move the information, physically, from a given place to another.

I.1.1.8.2 Logical channels

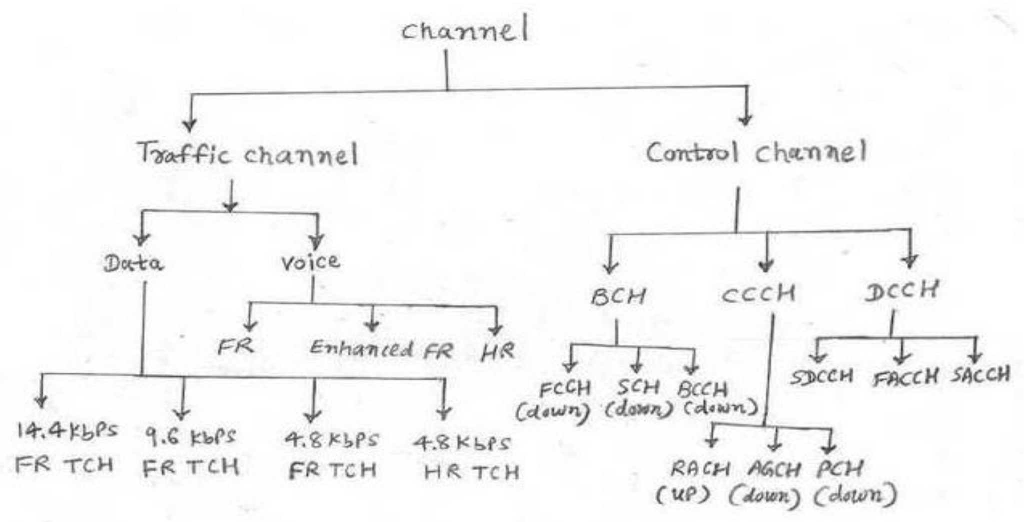

Figure 1-10 : *Logical channels in GSM*

❖ Control channels

A. *Broadcast channels BCH*

A.1 Frequency Correction Channel (FCCH)

On the FCCH, information about correction of the transmission frequency is broadcast to the MSs; (frequency correction burst)

A.2 Synchronization Channel (SCH)

The SCH broadcasts information to identify a BTS, i.e. BSIC. The SCH also broadcasts data for the frame synchronization of a MS, i.e. Reduced Frame Number (RFN) of the TDMA frame.

A.3 Broadcast Control Channel (BCCH)

On this channel, a series of information elements is broadcast to the MSs which characterize the organization of the radio network, such as radio channel configurations (of the currently used cell as well as of the neighboring cells), synchronization information (frequencies as well as frame numbering) and registration identifiers (LAI, CI, BSIC). In particular, this includes information about the structural organization (formats) of the CCCH of the local BTS. The BCCH is broadcast on the first frequency assigned to the cell (the so-called BCCH carrier)

B. *Common Control Channels CCCH :*

B.1 Paging Channel (PCH)

The PCH is also part of the downlink of the CCCH. It is used for paging to find specific MSs.

B.2 Random Access Channel (RACH)

The RACH is the uplink portion of the CCCH. It is accessed from the mobile stations in a cell without reservation in a competitive multiple-access mode using the principle of slotted Aloha, to ask for a dedicated signaling channel for exclusive use by one MS for one signaling transaction.

B.3 Access Grant Channel (AGCH)

The AGCH is the downlink part of the CCCH. It is used to assign an SDCCH or a TCH to a MS.

C. *Dedicated Control Channel (DCCH)*

C.1 Stand-alone dedicated channel (SDCCH)

The SDCCH is a dedicated point-to-point signaling channel (DCCH) which is not tied to the existence of a TCH ('standalone'), i.e. it is used for signaling between a MS and the BSS when there is no active connection. The SDCCH is requested from the MS via the RACH and assigned via the AGCH. After the completion of the signaling transaction, the SDCCH is released and can be reassigned to another MS. Examples of signaling transactions which use an SDCCH are the updating of location information or parts of the connection setup until the connection is switched through.

C.2 Slow associated control Channel (SACCH)

An SACCH is always assigned and used with a TCH or an SDCCH. The SACCH carries information for the optimal radio operation, e.g., commands for synchronization and transmitter power control and reports on channel measurements.

C.3 Fast associated control Channel (FACCH)

By using dynamic preemptive multiplexing on a TCH, additional bandwidth can be made available for signaling. The signaling channel created this way is called FACCH. It is only assigned in connection with a TCH, and its short-time usage goes at the expense of the user data transport.

I.1.1.8.3 Traffic Channel (TCH)

A 26 multi-frame carries 24 traffic frames, one for signaling frame and the last frame is not used. Traffic channels carry either voice or data and are divided into two families: full-rate channels and half-rate channels.

I.1.1.8.4 Signaling Channels

The signaling channels are divided into four branches which are

- Broadcast channels
- Common control channels
- Dedicated channels
- Associated channels.

Table 1-3: Classification of logical channels in GSM.

Group		Channel	Function	Direction
Traffic channel	TCH	TCH/F, Bm	Full-rate TCH	MS ↔ BSS
		TCH/H, Lm	Half-rate TCH	MS ↔ BSS
Signaling channels (Dm)	BCH	BCCH	Broadcast control	MS ← BSS
		FCCH	Frequency correction	MS ← BSS
		SCH	Synchronization	MS ← BSS
	CCCH	RACH	Random access	MS → BSS
		AGCH	Access grant	MS ← BSS
		PCH	Paging	MS ← BSS
		NCH	Notification	MS ← BSS
	DCCH	SDCCH	Stand-alone dedicated control	MS ↔ BSS
		SACCH	Slow associated control	MS ↔ BSS
		FACCH	Fast associated control	MS ↔ BSS

I.1.1.9 GSM frame structure

The GSM frame structure is designated as hyperframe, superframe, multiframe and frame.

The minimum unit being frame (or TDMA frame) is made of 8 timeslots.

One GSM hyperframe composed of 2048 superframes.

Each GSM superframe composed of multiframes (either 26 or 51 as described below).

Each GSM multiframe composed of frames (either 51 or 26 based on multiframe type).

Each frame composed of 8 time slots.

Hence there will be total of 2715648 TDMA frames available in GSM and the same cycle continues.

As shown in the following figure, there are two types of multiframe structure.

- 26 frame multiframe - Called traffic multiframe, composed of 26 bursts in a duration of 120ms, out of these 24 are used for traffic, one for SACCH and one is not used.
- 51 frame multiframe- Called control multiframe,composed of 51 bursts in a duration of 235.4 ms.

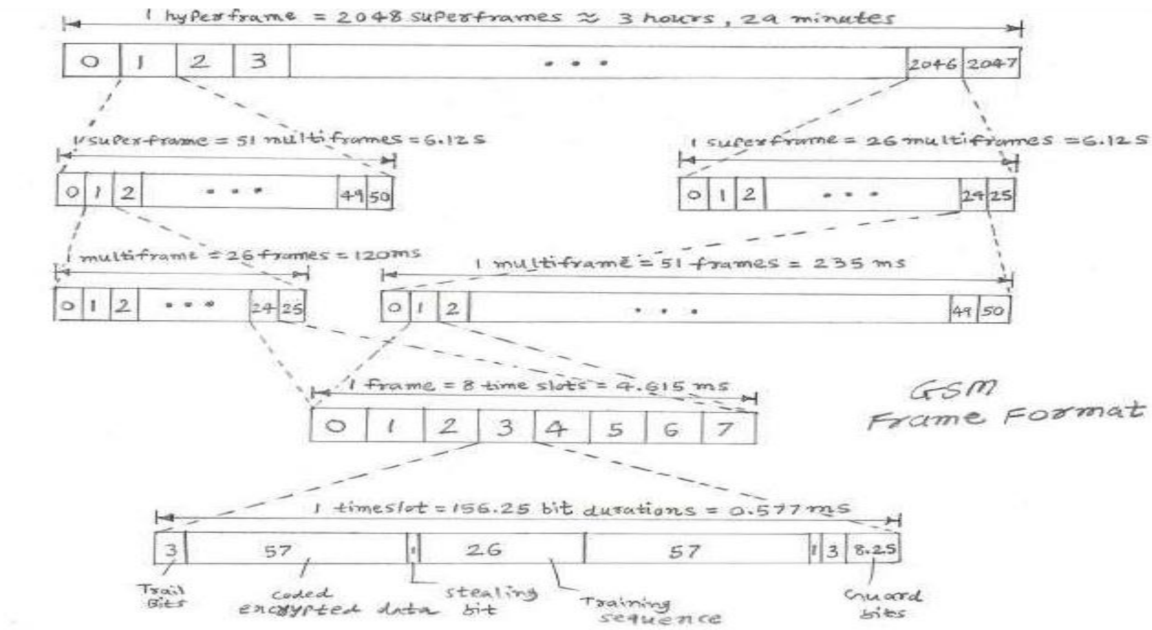

Figure 1-11: *GSM frame structure*

I.1.2 General Packet Radio Service *norm (GPRS)*

It is important to note that the GPRS network is integrated into the architecture of the GSM network. In particular, both networks use the same frequency bands. So, the resources of the GSM operator previously planning only for voice traffic are now shared between voice traffic (GSM) and data traffic (GPRS). GSM and GPRS networks operate in parallel, which requires to add new nodes called GSN (GPRS Support Nodes) located on a backbone network (back one). The GPRS service makes it possible to consider the GSM network as a packet data transmission network.

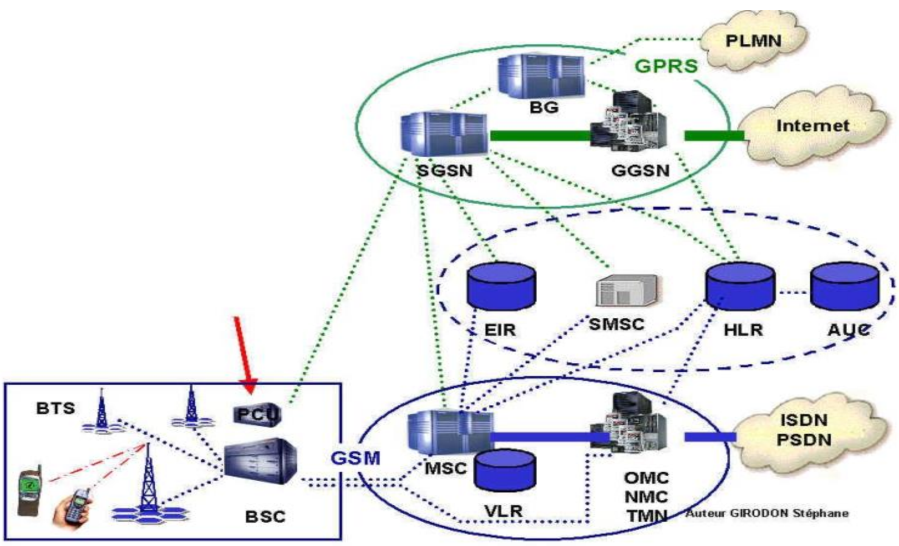

Figure 1-12 : *GPRS Architecture*

In addition, there is another advanced version known as EDGE (Enhanced Data Rate for GSM Evolution). EDGE was created to increase the speeds offered by using a new modulation known by 8PSK, which makes it possible to multiply the speeds by three compared to GPRS (which uses the same two-state GMSK modulation as GSM).

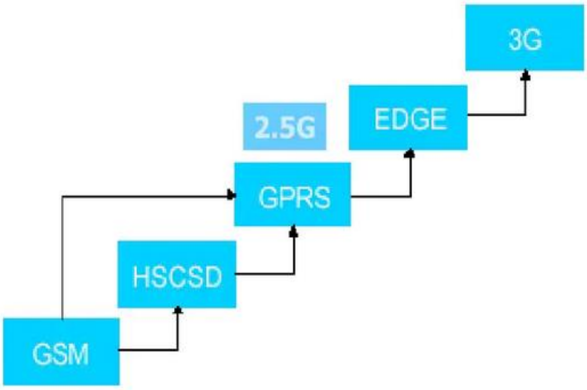

Figure 1-13: *Evolution of GSM network towards 3G*

I.1.3 Universal Mobile for Telecommunication System *norm (UMTS)*

There are several forms of 3G in the world, CDMA2000 in the United States, UMTS based on the foundations of GSM in Europe and another from China: TD-SCDMA. UMTS is based on the W-CDMA multiple access technique, a so-called spread spectrum technique, while multiple access for GSM is done by a mixed combination of TFDMA time and frequency division.

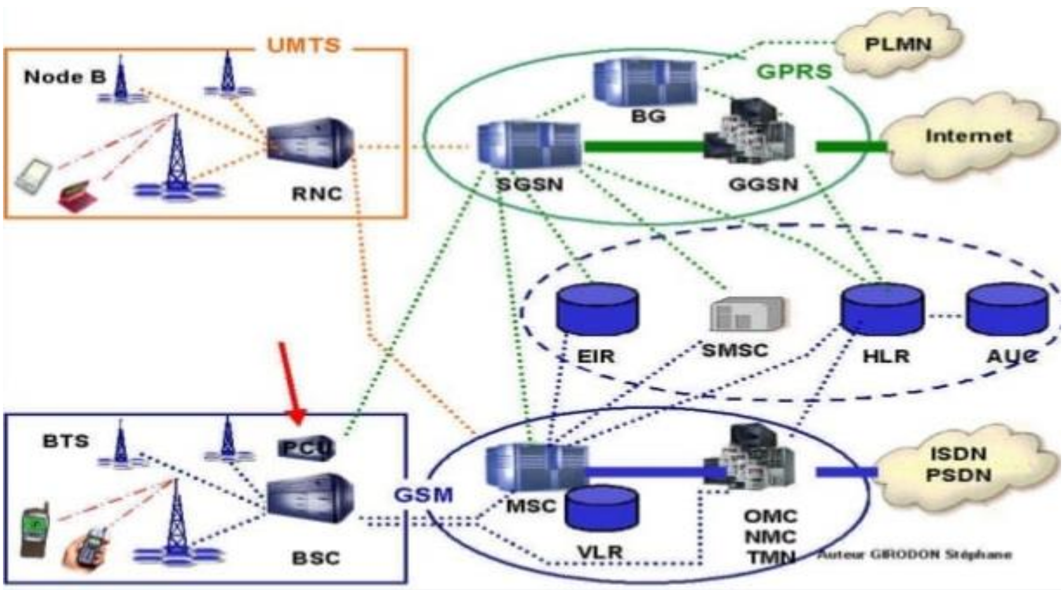

Figure 1-14: *UMTS architecture*

The UMTS network is combined with existing networks. The existing GSM and GPRS networks provide respective Voice and Data functionalities; the UMTS network then brings the Multimedia functionalities.

the Core Network, UTRAN (UMTS Terrestrial Radio Access Network) and the mobile terminal UE (Figure 1-15).

***Figure 1-15:** Block diagram of UMTS architecture*

The core network is based on the core network of GSM technology (HLR, MSC/VLR, GMSC (Gateway MSC), SGSN (Serving GPRS Support Node) and GGSN (Gateway GPRS Support Node).

UTRAN consists of one or more RNCs (Radio Network Controllers). These RNCs are linked by Node B

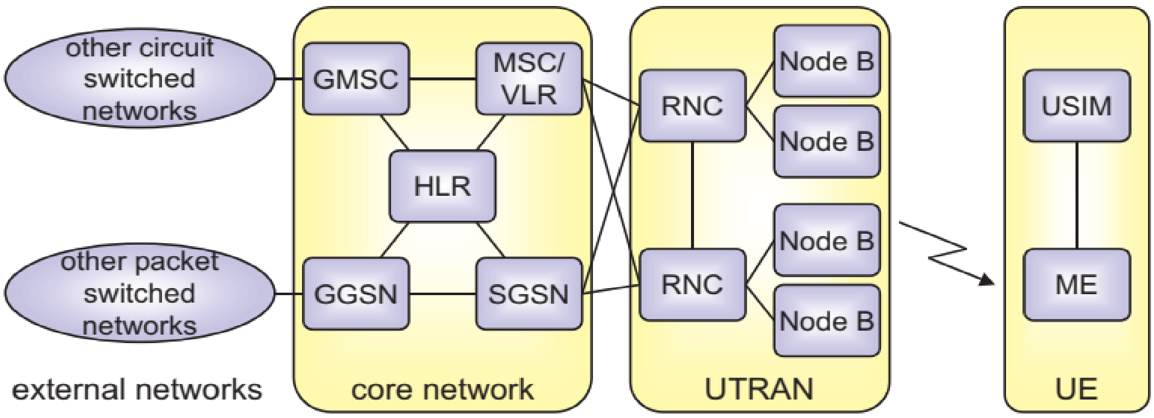

***Figure 1-16:** Simple architecture of UMTS system*

Table 1-3: Comparison between the different technologies of mobile network.

NOM	**GSM**	**GPRS**	**EDGE**	**UMTS**
Acronym	**2G**	**2.5 G**	**2.75 G**	**3 G**
Frequency	900/1800MHz	900/1800MHz	900/1800MHz	1900/2000 MHz
Max rate	9.6 Kbits/s	171.2 Kbits/s	384 Kbits/s	2 Mbits/s
Real rate	9.6 Kbits/s	30 Kbits/s	177 Kbits/s	384 Kbits/s
Access Technique	TFDMA			WCDMA
Modulation	GMSK	GMSK	8PSK	QPSK