

2 Mobile Communication Systems

The first real wireless radio communication was used in the late of 1890s when Guglielmo Marconi demonstrated the first wireless telegraphy to the English telegraphy office. Then in the early 1900s he managed to successfully transmit radio signals across the Atlantic Ocean from Cornwall to Newfoundland [She00]. The first mobile communication systems started appearing later in the US during the 40s, and within Europe during the 60s.

In 1982 the Global System for Mobile Communication (GSM) specifications started with an objective of achieving a European mobile radio network that is digital and capable of handling roaming. This work on the specification continued until 1990, where the first phase of the GSM specification was frozen. The first official GSM network was deployed in Germany in 1992, and at the end of 1997 almost 98% of the population was reachable. GSM was a big success and spread very rapidly not only within Europe but all over the globe. GSM is also known as the 2nd generation cellular wireless system (2G).

In the 1980s the International Telecommunication Union (ITU) started specifying the next generation mobile communication system. The specifications were finalized by the end of the 1990s and this system was called International Mobile Telecommunication-2000 (IMT-2000). Then the 3GPP finalized the first version of their mobile communication system following GSM which was known as Universal Mobile Telecommunication System (UMTS).

In 2004 the 3GPP started working on the next mobile system which is called Long Term Evolution (LTE). The 3GPP releases overview with their release schedule can be seen in Figure 2.1. The 3GPP Specifications and their numbering schemes can be found in [3GP12].

Over the next subsections, a brief introduction of GSM and UMTS is given. As LTE is the main focus of this thesis, chapter 3 is reserved for the description of the LTE system.

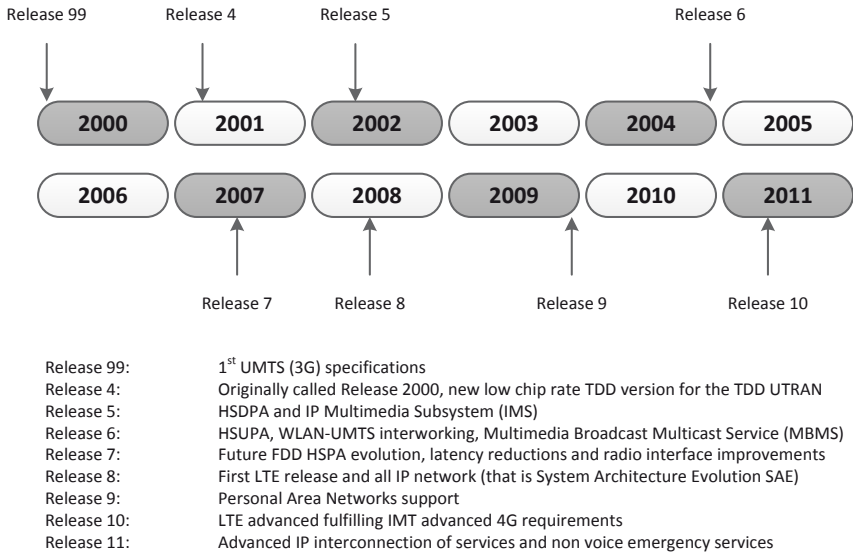


Figure 2.1: 3GPP releases overview [HT09] [Zah11]

2.1 Global System for Mobile Communication (GSM)

A mobile radio communication system by definition consists of telecommunication infrastructure serving users that are on the move (i.e., mobile). The communication between the users and the infrastructure is done over a wireless medium known as a radio channel. Telecommunication systems have several physical components such as: user terminal/equipment, transmission and switching/routing equipment, etc.

The GSM design has set the main basis and guidelines for all other mobile network generations to come. The GSM radio network consists of several radio cells each controlled by a Base Transceiver Station (BTS). A cell is a geographical representation of the coverage area within which a BTS can send and receive data. Cells are normally represented by hexagonal shapes for simplicity. Each base station serves a number of Mobile Stations (MS) representing the users, and a number of base stations are controlled by the Base Station Controller (BSC). The radio link from the BTS to the MS is known as Downlink (DL) and the other direction is known as Uplink (UL).

Figure 2.2 shows the general GSM network architecture. The GSM network architecture is divided into four main functional groups, these are:

- **Mobile Station (MS):** is also known as User Equipment (UE), this entity consists of the Subscriber Identity Module (SIM) and the terminal equipment.
- **Base Station Subsystem (BSS):** this entity handles the radio access functions, like radio resource management. It connects the UEs with the core network.
- **Core Network (CN):** includes the transport functions, mobility management, user/subscriber databases with their information, service controlling functions, billing, etc.
- **External Network:** these are the external networks that the UEs can communicate with and that the mobile network has to be connected to. It can be for example the public telephone network or any other GSM network.

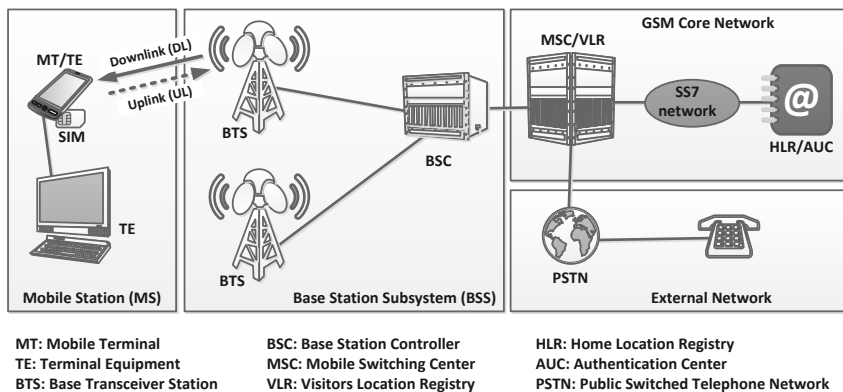


Figure 2.2: GSM network architecture ¹

¹Picture is redrawn from <http://en.wikipedia.org/wiki/GSM>

One of the important features of a mobile communication system is the radio interface. A radio interface is the interface between the mobile stations and the base station. This interface enables the users of the mobile networks to be mobile with wireless access. The radio spectrum is the term used to describe the amount of resources (i.e., frequency bandwidth/spectrum) that the air interface uses. In mobile communication the radio spectrum is one of the most important parts due to its high incurring cost. In addition, the radio spectrum is often limited and is treated as a scarce resource that the users of the mobile communication system need to share. The sharing of the spectrum is done using the so-called *multiple access scheme*.

In GSM, a mixture of Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) is used as the multiple access scheme. FDMA is used to divide the GSM spectrum into several carrier frequencies. Each carrier frequency is then divided using TDMA into 8 time slots that are then used by the mobile stations for their transmissions. The maximum spectrum/frequency band of GSM is 25 MHz, that is 124 carrier frequencies that are separated from each other by 200 kHz. In GSM, Frequency Division Duplex (FDD) is also used to separate the downlink frequency range from the uplink.

GSM uses circuit switched techniques to support voice calls. Due to the emerging needs for higher data rates the General Packet Radio Service (GPRS) has been developed. GPRS is seen as a step along the way from the second generation mobile communication GSM into the 3rd generation Universal Mobile Telecommunication System (UMTS). GPRS offered higher data rates between 56 - 114 kbps compared to the very low rates that can be offered by GSM. This enabled a multitude of possibilities and services to be offered by the mobile operators, for example web browsing. GSM offered for the first time in mobile communication systems the use of packet switching.

After GPRS, the evolution of the GSM system kept going to support even higher data rates. This led to the development of Enhanced Data for GSM Evolution (EDGE). The main feature of EDGE was that it enabled data rates up to 384 kbps, which is a significant improvement over GPRS. The increase in the data rate was achieved by changing the GSM modulation scheme from Gaussian Minimum Shift Keying (GMSK) to 8PSK¹. Figure 2.3 shows the evolutions of the GSM system with their respective data rates.

¹PSK stands for Phase Shift Keying.

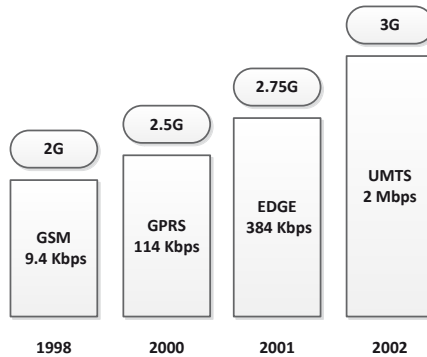


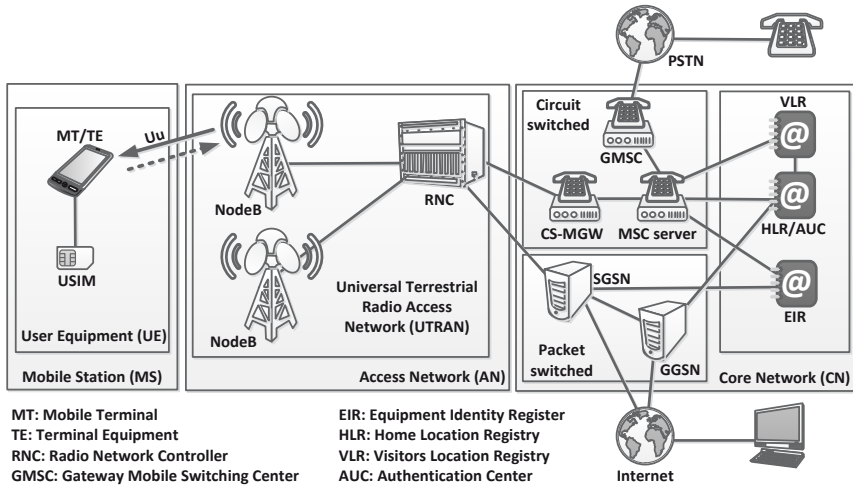
Figure 2.3: GSM system evolution

2.2 Universal Mobile Telecommunication System (UMTS)

The first version of the UMTS standards was finalized by the end of 1990, that is why UMTS is also sometimes referred to as release 99 or R99. The main motivation behind UMTS was to define a universal mobile communication standard that aims at higher peak rates, with the ability of dynamically adapting the user data rates. In addition, there were several other targets like the support of Quality of Service differentiation between the different new services offered by UMTS, as well as improving the overall spectral efficiency. UMTS uses Wideband Code Division Multiple Access (WCDMA) which is a completely new multiple access scheme compared to the one used in GSM. It also uses a larger bandwidth of 5 MHz for each of the downlink and uplink.

The UMTS architecture (Figure 2.4) is structured similarly to GSM with several modifications. The radio access network in UMTS is called UMTS Terrestrial Radio Access Network (UTRAN), and consists of Radio Network Controller (RNC) and several NodeBs (which represent the UMTS base stations). The UMTS network supports both circuit switched and packet switched connections. The circuit switched connections are used to carry voice services, whereas the packet switched connections are used for other data services, like web browsing through HTTP, and file downloads/uploads through FTP. More details related to UMTS can be found in [HT07].

Similar to GSM, two system enhancements have followed the UMTS system, to increase the data rates, increase the system capacity and reduce system latency.

Figure 2.4: UMTS network architecture ¹

These two enhancements are represented by new 3GPP releases that is release 5 or High Speed Downlink Packet Access (HSDPA), and release 6 High Speed Uplink Packet Access (HSUPA).

HSDPA is already mentioned before the 5th release of the UMTS specification. The goal of this release was to enhance the downlink data rates of the UMTS standard up to 14 Mbps, increase the spectral efficiency, as well as reduce the system latency. This is achieved by the introduction of several new functions:

- **Adaptive Modulation and Coding (AMC):** in each user transmission the modulation and coding schemes is adaptively changed depending on the user channel conditions, for example, a user with very good channel conditions is assigned a higher modulation and coding scheme.
- **Fast NodeB Scheduling:** the scheduling function is moved from the RNC to the NodeB compared to GSM. Which means the NodeB can track the instantaneous channel changes of the users and schedule the resources in a more efficient way thus gaining from the multi-user diversity principle.
- **Shorter Transmission Time Interval (TTI):** the TTI length is reduced in HSDPA to 2ms, instead of 10ms in UMTS R99. TTI is the duration of a trans-

¹Picture is redrawn from <http://en.wikipedia.org/wiki/UMTS>

mission over the radio link, it is also the rate of the radio scheduler at which it takes decisions on which UEs transmit over the next TTI.

- Use of Hybrid Automatic Repeat Request (HARQ): performing retransmissions of the erroneous packets between the NodeB and the UE instead of waiting for higher layer retransmissions. This of course will result in latency reduction. In addition, chase combining and incremental redundancy are also used to combine the two unsuccessfully decoded packets with the new retransmission to improve the decoding probability.

Similar to HSDPA, HSUPA aims at enhancing the performance of the UMTS R99 uplink in terms of improving the user data rates up to 5.76 Mbps and reducing the latency. HSUPA also uses concepts similar to HSDPA: shorter 2ms TTI (optional), HARQ and fast scheduling. However, the AMC is not used in HSUPA since it does not support any high order modulation schemes and it only uses QPSK. This is because higher modulation schemes require more energy per bit resulting in faster battery discharge. In HSUPA, both soft and softer handover are allowed, unlike HSDPA, because the UE is the entity performing the transmission and the neighboring NodeBs can also listen to the UE transmission without any extra effort.

The use of both enhancements (i.e., HSDPA and HSUPA) is often referred to as HSPA. Network operators deploy HSPA in coexistence with R99 UMTS networks. The instantaneous radio performance may vary overtime, sometimes achieving very high cell throughputs. However, the network operators dimension their backhaul by considering the average performance so as to reduce cost [LZW⁺08], which will cause short term congestions in the network backhaul. In order to mitigate the influence of this, congestion control schemes as well as traffic separation techniques are used to overcome the aforementioned issues and provide QoS differentiation between HSPA and R99 traffic [WZTG⁺09] [LZW⁺10] [LWZ⁺11].

3 Long Term Evolution (LTE)

LTE is one of the newest releases of the 3rd Generation Partnership Project (3GPP) specifications. It is also referred to as 3.9G or Release 8. The 3GPP started working on LTE in November 2004 with the Radio Access Network (RAN) Evolution workshop in Toronto - Canada. The main task was to standardize a system with new design goals that can exceed older mobile standards (like UMTS and HSPA), as well as being able to stay competitive at least for the next 10 years.

3.1 Motivation and Targets

In March 2005, a feasibility study on LTE was launched. The main focus of this study was to decide what architecture the new system should have and what multiple access techniques were to be used. The LTE network architecture can be seen in Figure 3.1. The main conclusions drawn from the feasibility study [25.05] can be summarized in terms of requirements and targets as follows:

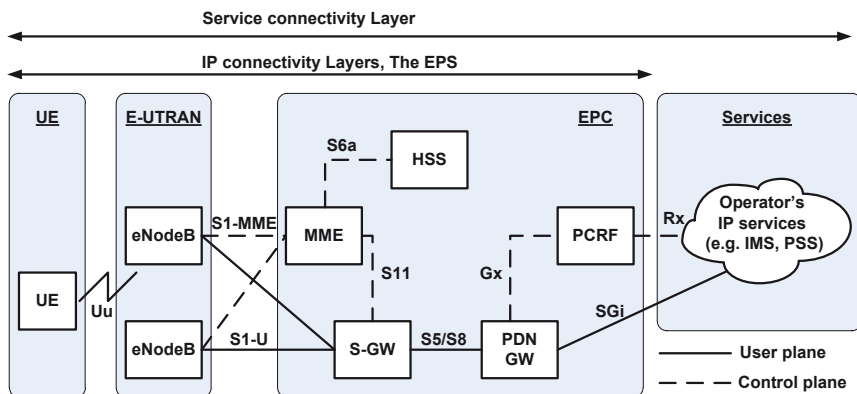


Figure 3.1: LTE EPS network architecture

- Simplified flat packet oriented network architecture
- High data rates up to 100 Mbps in the downlink and 50 Mbps in the uplink (even higher with Multi Input Multi Output (MIMO))
- Reduced latency
- Scalable usage of frequency spectrum from 1.25 MHz to 20 MHz
- OFDMA and SC-FDMA as the multiple access techniques for downlink and uplink respectively

3.2 LTE Multiple Access Schemes

In LTE the multiple access transmission scheme is based on the Frequency Domain Multiplexing (FDM). Two different versions are used: Orthogonal Frequency Domain Multiple Access (OFDMA) for the downlink, and Single Carrier Frequency Domain Multiple Access (SC-FDMA) for the uplink. OFDMA is a very efficient transmission scheme which is widely employed in many digital communication systems, e.g., Digital Video Broadcasting (DVB), WiMax, Wireless Local Area Network (WLAN). The reason behind the popularity of OFDMA comes from the fact that it has very robust characteristics against frequency selective channels. Frequency selectivity is one of the transmission problems that can be overcome through equalization, but the complexity of the equalization technique is very high. Another reason for choosing OFDMA as the downlink transmission scheme is the bandwidth flexibility it offers, since changing the number of sub-carriers used can increase or decrease the used frequency bandwidth.

SC-FDMA is the transmission scheme in the LTE uplink. It provides a low peak-to-average ratio between the transmitted signal; it is a very desirable characteristic for the uplink to have an efficient usage of the power amplifier. This provides a high battery life time for mobile devices.

3.2.1 OFDM

The basic principle of multi-carrier systems is the splitting of the total bandwidth into a large number of smaller and narrower bandwidth units, which are known as sub-channels. Due to the narrow bandwidth sub-channels frequency selectivity does not exist. As a result, only the gains of the sub-channels has to be compensated and no complex equalization techniques is required.

In OFDM the sub-channels are orthogonal to each other. This nice property does not require the addition of guard intervals between the sub-channels and hence

it increases the system spectral efficiency. Figure 3.2 shows the orthogonality principle of OFDM; the frequency representation of one OFDM sub-channel is a Sinc¹ function, where if the sampling is done at the exact spacing the result will only be at the sub-carrier of that sub-channel and zeros at every other sub-carrier frequency. This means that the sub-channels are orthogonal to each other.

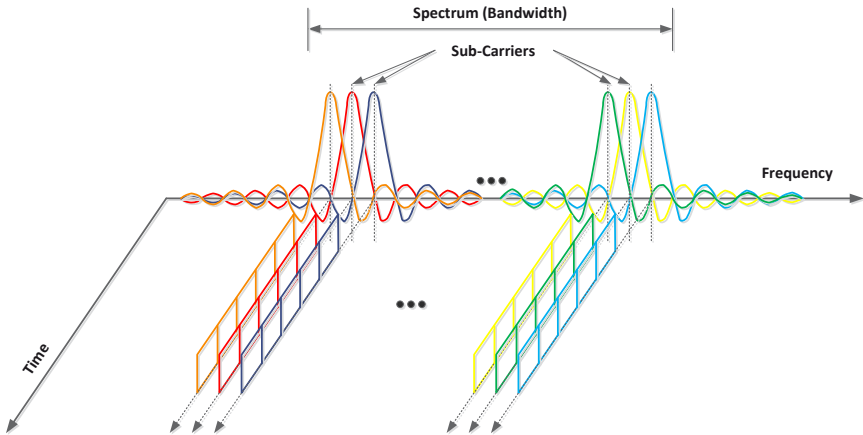


Figure 3.2: OFDM signal in frequency and time domain [Hoa05]

3.2.2 OFDMA

Orthogonal Frequency Division Multiple Access (OFDMA) is an access scheme that uses the OFDM principle to orchestrate the distribution of the scarce radio resources among several users enabling multi user communications. This is done by using the Time Domain Multiple Access (TDMA), where users dynamically get some resources at the different time instances of the scheduling.

The LTE MAC Scheduler (explained in chapter 6) makes use of the different user channel conditions to distribute the frequency resources (sub-carriers) to where it best fits. This can mean giving them to the users, for example with the best instantaneous channel conditions (Max-CI scheduling). This distribution process is determined by the used scheduler discipline.

¹The sinc function, sometimes also known as the sampling function, is a function that is widely used in signal processing and Fourier transforms. It is commonly defined as $\text{Sinc}(x) = \text{Sin}(x)/x$.

Future Mobile Communications

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