Jose Antonio Ji Li

Long Term Evolution: Air Interface, Capabilities and Performance

Helsinki Metropolia University of Applied Sciences

Information Technology Degree

Thesis

5 June 2014

Author(s) Title Number of Pages Date	Jose Antonio Ji Li LTE: Air interface, capabilities and performance 56 pages + 3 appendices 5 June 2014
Degree	Bachelor of Engineering
Degree Programme	Information Technology
Specialization option	Telecommunications Systems
Instructor(s)	Tarmo Anttalainen, Supervisor

The aim of this project was to describe the radio interface, characteristics and performance of LTE, the latest generation of mobile communications so far. To achieve that objective, first, a brief summary of the first and second generation of mobile communications was given. Then, the evolution of the third generation was studied in order to understand the changes produced in the LTE technology as well as the similarities between the third and fourth generation. To give an explanation about the performance, two measurement were made, a fixed-location test in Leppävaara, Espoo and a drive test from Leppävaara to Helsinki. Those measurements were done with TEMS Investigations software, which was also introduced in the project.

The results obtained from the measurement revealed that LTE, as expected, provides a higher data rate than in the third generation and better performance in general. These measurements gave a different point of view of the performance of LTE, since the drive test handled here was never done before.

Keywords	LTE, mobile communications, TEMS.

Contents

List of figures

List of tables

1 Introduction

The demand of mobile communications has been increasing for the last 30 years in an exponential way. What is more, the data rate has increased to reach the unbelievable quantity of 150 Mbps for Downlink (DL) and even the number of users has grown in the same way. To be sure about this evolution it is only needed to check the number of cellular users in the world, which has grown from 11 million in 1990 to 2000 million in 2006 [1].

This project is a study of digital mobile communications, specifically the last technology applied so far, Long Term Evolution (LTE). Due to the unbelievable evolution of the mobile since it began in the early 1980s, it is necessary to review the history of the mobile communications. The scope of this project is the study of the mobile communications, mostly LTE technology and its features and finally testing its performance with measurement cases. These measurement cases are possible due to the availability of using the leading software such as TEMS Investigations.

I decided to choose this topic since the mobile communications have become a life-changing technology of our generation, what is more, of my own life. Most of the population of developed countries owns a cell phone or a smartphone, because not only is it a way to communicate with relatives and friends but also because of the new added capability of phones to access the Internet, which is a huge source of information. In addition, here in Helsinki Metropolia University of Applies Sciences I have to the possibility of use TEMS Investigations, so it is possible to get some experience about real cases of communications.

2 Background

This project is divided into thre main parts. The different standards that will be described are divided into generations of mobile communications. The first part includes an overview of the first (1G) and second (2G) generations, about the first standards for mobile communications, which are Advanced Mobile Phone System (AMPS) and Nordic Mobile Telephone (NMT). Those standards were the first cellular systems in the world, developed in the USA and in Europe and the NMT was develop in the Nordic countries.

Concerning the 2G, the *Groupe Special Mobile* (GSM) is probably the most important standard for cellular systems, because it has brought along innovations such as the Short Message Service (SMS) and the possibility of roaming. Besides, another standard that improves GSM is the General Packet Radio Access (GPRS) but it is included in the 2.5 generation (2.5G).

The second part is based on the third generation (3G) and how this technology ended in the last and newest standard, LTE. In this section, the technologies used in LTE from the Universal Mobile Telecommunications System (UMTS), High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), which together are commonly known as High Speed Packet Access (HSPA), will be described.

Finally, the last part of the project and moreover, the principal aim of this project, is to study LTE, since it became one of the most important developments in the history of digital mobile communications, reaching unbelievable and unthinkable data rates decades ago. To offer real information about LTE, two different measurement cases will be done in the capital region of Helsinki and a comparison with HSPA in order to confirm the incredible evolution of the technology. Those two measurement cases are fixed-location and drive test, the first one using one specific location, a static measurement will be done with low mobile speed. Concerning the drive test, the measurement must be done in high mobility conditions, specifically in a vehicle or any kind of transport. Also along the thesis, some graphs will be added to illustrate the discussion and the cases. The measurement process will be detailed in the appendix 1, the project plan with methods and required equipment.

3 First Steps in Mobile Communications

3.1 Overview

In 1970, investigations for cellular systems started and 10 years later, the cellular systems were released for commercial use. This system is also known as 1G. This generation uses frequency modulation (FM), frequency division duplex (FDD) and frequency division multiple access (FDMA). The data rate was very low because of it was only designed for basic voice services [2, 68].

The first standard was the Postal Telephone and Telegraph (PTT) developed in Tokyo, Japan in 1979. Even though AMPS was created before in 1978 in the US, the commercial system was not released until 1982. Another important standard, this time in Europe, was the NMT, researched in the early 1970 and released in 1980 by Denmark, Finland, Norway and Sweden. In the following sections, AMPS and NMT will be explained briefly [2, 69].

At the end of the 1980s, the standardization of 2G started. This generation included changes in the features and the technologies were changed. For example, in addition to FDMA, the new access methods were Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) that lead to new features such as higher data rate and spectrum efficiency. A new very important feature was the possibility of the roaming that allowed extending the connectivity to another network different from the home network of the terminal [2, 69].

In Europe, the GSM was standardized in 1982 with a clear objective: to develop a pan-European standard in order to reorganize the different types of technologies that were set previously. Nowadays, it has become the most popular and used standard all over the world, to such a point that in 2011, it surpassed 6000 million subscriptions. The GSM standard will be explained in detail in the subsection 3.3.1 [1].

However, the GSM was not enough to satisfy the data communication needs of the user, which is just being able to pay minute by minute, bit by bit, so GSM continued this evolution until the new generation, the 2.5 G with backward compatibility. The new standard of 2.5 G is the GPRS, based on GSM but adding packet-switched functionality as mentioned in the ETSI [3].As the first generations of mobile communications are not very important for the aim of this project, a little explanation of the standards will be given. However, the most important features of each technology will be explained. Figure 1 is an illustration about the data rate has increased.

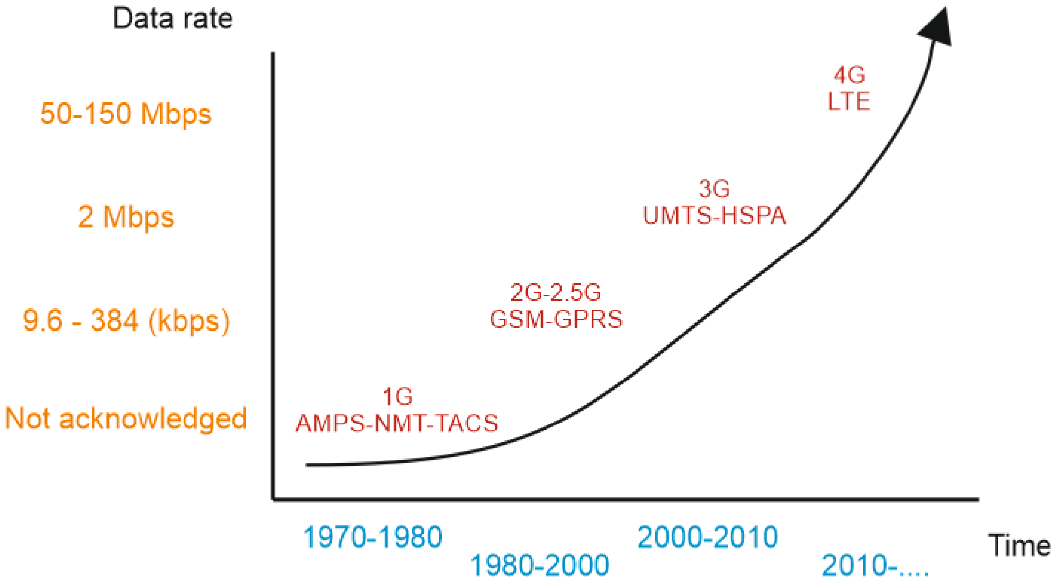


Figure 1. Timeline of technologies and data rates

As shown in figure 1, the growth of the data rate is huge.

3.2 First Generation

3.2.1 Advanced Mobile Phone System

Created in 1979 by the Bell laboratories, AMPS was the first cellular standard in the USA but it was not released for commercial use until 1982. AMPS radio connection was located in the 800-900 MHz band due to the lower frequencies set to the TV and the radio. Higher frequencies were unreliable because of the current technology [2, 69].

The architecture of AMPS consists of a network of cell-sites, provided by the Mobile Telephone Switching Office (MTSO) connected to the switching offices, which are connected to the landline network. The utilization of directional antennas is important to get a better carrier to interference ratio (C/I) and improving the capacity of the system. Figure 2 is the basic architecture of AMPS, as described in the paper [4, 12].

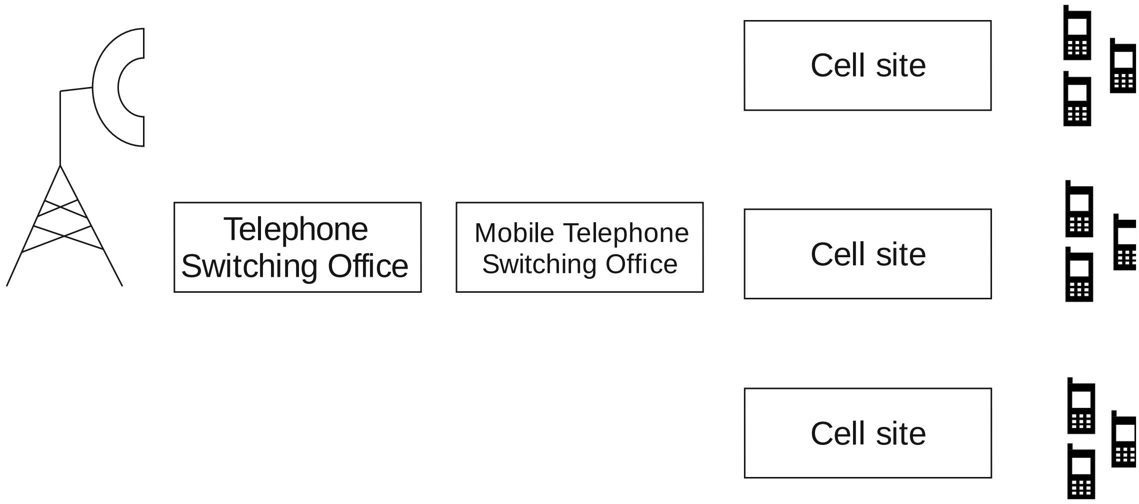


Figure 2. AMPS architecture. Data gathered from Ehrlich (1979) [4, 12]

Figure 2 illustrates the architecture explained above.

Frequency of operation

Frequency bands for AMPS are allocated in the 800-900 MHz band, 20 MHz for the UL and 20 MHz for the DL, specifically 825-845 MHz for UL and 870-890 MHz for DL. As expected, the DL frequencies are higher since the cell-site can transmit more power in order to compensate the free space losses because the higher frequency, the higher the loss [4, 11].

Cell interference

Due to the frequency reuse, it is necessary to establish a setup of cells to reduce the cell interference to the minimum. The assignment for the cells must be the same in each cluster and its size will be determined for the signal to interference plus noise ratio. Assigning radio frequency channels in cells divided into sections the interference between sections can be reduced and those cells can increase the system capacity.

3.2.2 Nordic Mobile Telephone

The Nordic Mobile Telephone was researched and released by Denmark, Finland, Norway and Sweden with a clear objective, to set a common standard of communications compatible in the Nordic countries. Although the research was started in the 1970s, the system was released in the early 1980s. Every user in the Nordic countries could have services in all the belonging countries (roaming possibility). Besides, there was no needed to the change the equipment of the mobile station because there was a full compatibility with the land-based network. The basic requirements are the following [5, 42]:

- Automatic setting and charging calls in DL and UL.
- Roaming, no changes needed in the land based network.
- Only the calling user has to pay for each call, the cost is based on the duration of the call [5, 40-43].

The NMT had 2 operating frequencies, 450 and 900 MHz, low and high capacity system, which would be converted in the next technology GSM that also used the same frequencies. The NMT-450 system used a higher maximum transmitter power level than NMT 900, while the NMT-900 system used a different frequency and less transmit power. The NMT-450 and NMT-900 could share the same switching center, which mean that if necessary, NMT-900 can be installed if the NMT-450 starts to be overloaded because within smaller cells there is more capacity. Also note that the terminal behaves differently depending on the frequency. No handover can be done between the NMT-450 and NMT-900. The size of the cell of the NMT-450 is bigger than NMT-900 but inside the same radius three NMT-900 cells are allocated, in the case that the NMT-450 is overloaded.

3.3 Second Generation

Groupe Special Mobile

Overview

The *Groupe Special Mobile* was established in 1982 with a clear objective: to develop a pan-European standard in order to reorganize the different types of technologies that were set in the 1980s, such as the, NMT or TACS. GSM has become the most popular and used standard all over the world to such a point that in 2008 it surpassed 3000 million subscriptions. The premises that define the GSM are the following:

- Roaming in the European Communities
- digital system
- efficient use of the spectrum
- great coverage and capacity [7, 43].

Originally, there were two different frequency bands of operation of the GSM, the 900 MHz band and the 1800 MHz band. The interval of operation for UL is 890-915 MHz and 935-960 MHz for DL. In the case of the 1800 MHz, the frequency range of operation is 1710-1785 MHz for UL and 1805-1880 MHz for DL, [8, 615]. However, these intervals could change between countries, until the European Union forced to free these frequency ranges.

As seen the bandwidth of the whole GSM system is 25 MHz and the bandwidth for FDMA channels is 200 kHz. The Gaussian Minimum Shift Keying (GMSK) modulation is used at the data rate of 270.833 kbit/s. The maximum data rate offered by the GSM is between 9.6 kbit/s and 14.4 kbit/s using Circuit-Switched Data (CSD) or High Speed Data (HSD) [7, 46]. However, with the inclusion of GPRS, CSD and HSD are no longer used.

Architecture

The GSM architecture is divided into three main parts: Network Switching Subsystem (NSS), Operation and Support Subsystem (OSS) and Radio Subsystem (RSS) The

RSS is the union between the base station and mobile station subsystems. Figure 3 describes the GSM architecture as described in [7, 47].

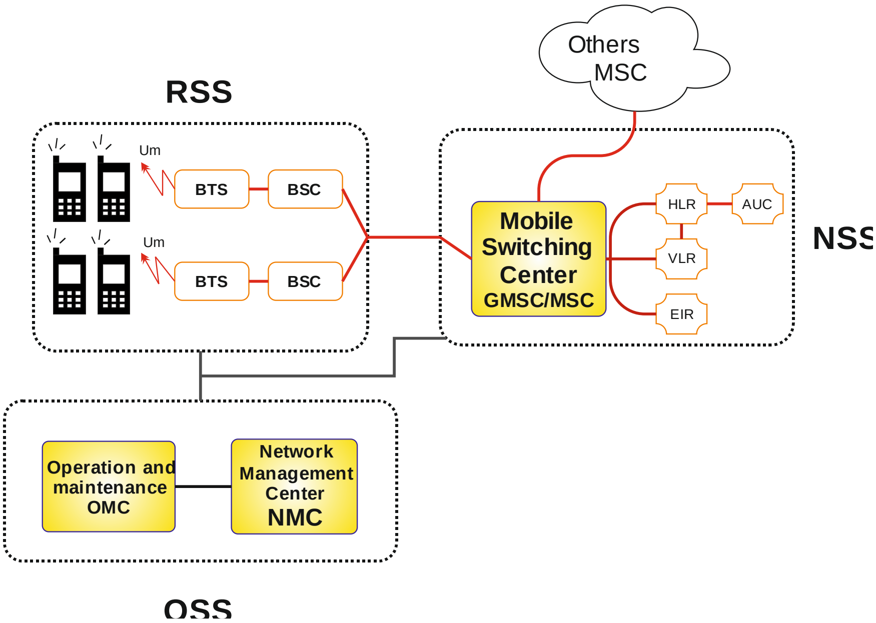


Figure 3. GSM architecture. Data gathered from Herradón (2009) [7, 47]

As seen in figure 3, the GSM architecture is divided into three parts

Network Switching Subsystem (NSS)

The NSS connects calls between users and contains a database with all the information about users. The NSS also handles the location management of the terminal, the tracking of the mobile stations. The principal system blocks are the following ones:

- Mobile Switching Central (MSC) – Smart interface between the system of base stations and the switching network.
- Inter-Working Function (IWF) – Associated with the MSC, allows the communication with other GSM networks
- Home Location Register (HLR) – Contains all the information about the subscribers.
- Visitors Location Register (VLR) – Contains dynamic information about the subscribers in the zone controlled by the MSC.
- Authentication Center (AuC) – Database with all the information concerning the authentication.
- Equipment Identity Register (EIR) – Contains information about the mobile equipment, such as the IMEI (International Mobile Equipment Identity) [7, 48-50].

Operation and Support Subsystem (OSS)

Connected to both subsystems mentioned above, the OSS performs the technical and administrative functions of control and managing of the network. The elements of OSS are the following:

- Operation and Maintenance Center (OMC) – Performs control and management functions in the GSM entity.
- Network Management Center (NMC) – Is responsible for all the operation and maintenance centers [7, 54].

Radio Subsystem (RSS)

The RSS is divided into two parts, the Base Station Subsystem (BSS) and the mobile station (MS).The BSS is responsible for the radio transmitting and receiving through the Um interface, surveillance and setup of calls, handover, voice processing and control and maintenance of the equipment. The elements of RSS are the following:

- Base Transceiver Station (BTS) – Composed of radio transmitters and receivers, connecting elements and antennas; BTS handles the management of radio channels.
- Base Station Controller (BSC) – Responsible for the radio resources, assigning and releasing among others [7, 51-52].

3.4 2.5 Generation

3.4.1 General Packet Radio Access

The GPRS standard as mentioned in section 3.1, adds the packet-switched feature to the GSM. One difference with the GSM is that with the GPRS only introduces new management nodes and new links between the MSC and the GSM network. The origin of this change comes from the excessive time that the circuit-switched system takes to connect to the network. As explained in section 3.1, GPRS satisfies the need of subscribers to be able to pay minute by minute, bit by bit, which means huge savings for all of them.

Although the GPRS offers a maximum data rate of 171.2 kbit/s, there is another standard faster than this, which is the Enhanced Data Rates for GSM Evolution (EDGE), also known as Enhanced GPRS (EGPRS), described in subsection 3.4.2, which gives a 384 kbit/s maximum data rate. Table 1 is a comparison of all the data rates from 2G and 2.5G.

Table 1. Comparison of data rates [7, 105]

	Maximum Data Rate (kbit/s)
GSM	9,6
GSM/CSD	14,4
GSM/HSCSD	57.6
GPRS/GSM	171,2
EGPRS	384

This comparison makes even more obvious the evolution of mobile communications.

Architecture

The GPRS architecture is based on the GSM network but it introduces three new elements and updates some GSM nodes. These three important elements are the GPRS Support Node (GSN), specifically Serving GSN (SGSN), Gateway GSN (GGSN) and the Border Gateway (BG), as seen in figure 4.The main goal of the GPRS was to grant access to the data network while the 3G was still under development. As shown in figure 4, access to the Internet is granted by the GGSN. Regarding voice calls, as the GPRS is built above the GSM network there is no change in this matter. The MS is connected to the BTS, which is also connected to the BSC. Figure 4 illustrates the architecture of GPRS as described in [7, 109].

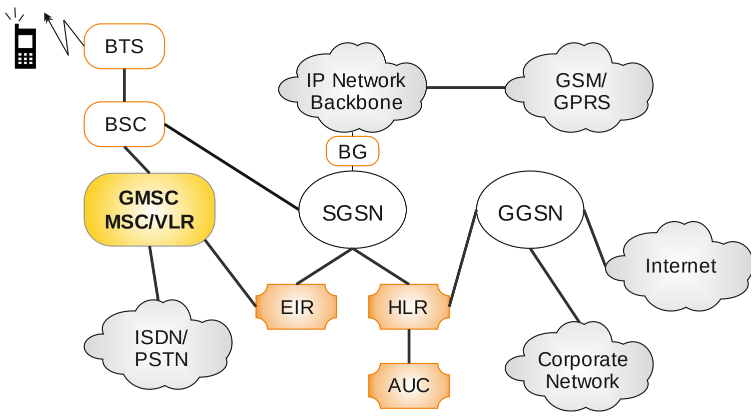


Figure 4. GPRS architecture. Data gathered from Herradón (2009) [7, 109]

GPRS nodes

The SGSN and GGSN both have billing and routing functions in IP, but only the SGSN collects information about each MS in the internal network and the GGSN retrieves information for the external use. The GGSN manages every SGSN and every SGSN controls each BSC connected to it. When an MS is detected, the SGSN performs all the procedures to register the MS in the system. The following lists enumerate the functions of the SGSN and GGSN. SGSN has the following main functions:

- Transmitting and routing IP packets.
- Encoding and authentication
- Session and mobility management [9, 19]

On the other hand, the GGSN has the following features:

- Management of GPRS session
- Associate correct subscriber to his SGSN
- Routing packets between SGSN and external network [7, 110].

Finally, the BG is responsible for connecting different Internet Service Providers from different countries.

3.4.2 Enhanced Data rates for Global System for Mobile Communications Evolution

The Enhanced Data rates for GSM Evolution (EDGE), defines perfectly its objective, to increase the data rate of the GSM or GPRS, because EDGE works on a GSM system with GPRS features. Two of the most important features of EGPRS are the enhanced bit rate and the error control coding due to the changing modulation [7, 129].

EDGE is using the Phase Shift Keying (8-PSK) modulation, whose bit rate is three times higher than the modulation of the GSM, GMSK. However if there is much interference, the modulation changes to lower order modulation to compensate for the losses and maintain the same bite rate.

To conclude this chapter, figure 5 represents the comparison of data rates between the 2G and 2.5 G technologies. As seen in figure 5, the increase of the data rate is huge.

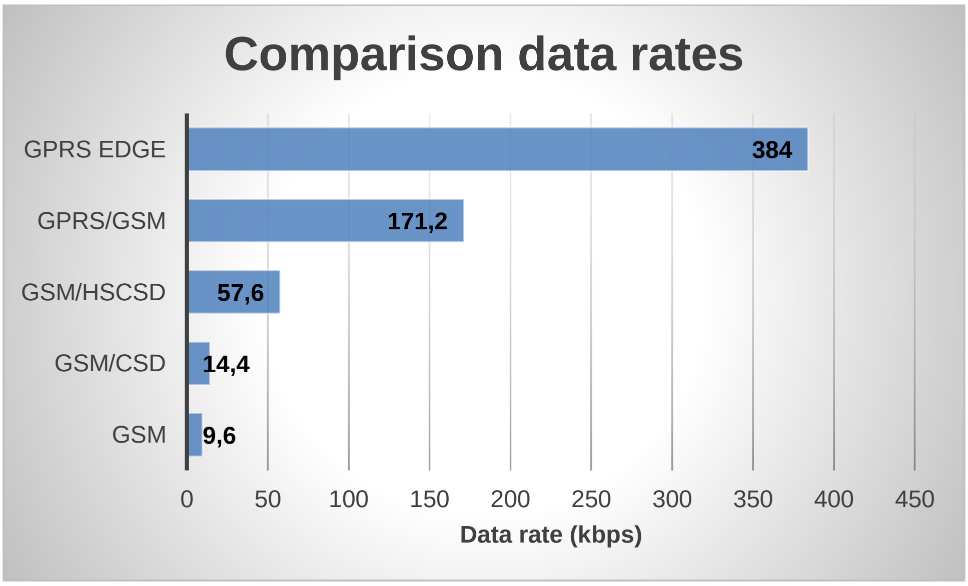


Figure 5. Comparison chart about 2/2.5G

4 Evolution to Long Term Evolution/Fourth Generation

4.1 The Beginning of 3G Systems

In 1990 the ITU-R, a section of the ITU related to radio communication, released the first recommendation named Future Public Land Mobile Telecommunications Systems (FPLMTS). Later the designation for 3G was changed from FPLMTS to International Mobile Telecommunications-2000 (IMT-2000). The World Administrative Radio Congress (WARC-92) established a 230 MHz spectrum for IMT-2000, a 2 x 60 MHz paired spectrum for FDD and a 35 MHz unpaired spectrum for the Time Division Duplex (TDD) for terrestrial use. In the ITU-R recommendation M.1225 it is possible to know the first benchmark for the data rates [10, 5]:

- Up to 2 Mbps for indoor environment.
- Up to 144 kbit/s for pedestrian environment.
- Up to 64 kbit/s for vehicular environment [7, 131].

Research on 3G started in parallel in every part of the world such as Europe, Japan, China, Korea and the USA. Specifically in Europe, the project Research into Advanced Communications in Europe (RACE) was responsible for the first stage of 3G research, Universal Mobile Telecommunications Services (UMTS). Every organization in the world that was responsible for research on 3G was proposing different kinds of technologies. Finally, in 1998, the European Telecommunications Standards Institute (ETSI) selected the Wideband CDMA (WCDMA) for the paired spectrum and Time Division CDMA (TD-CDMA) for the unpaired spectrum. After the standardization of the WCDMA, all the projects around the world stuck to one organization, the Third Generation Partnership Project (3GPP) to resolve the project of parallel research, which was very difficult to maintain [7, 131-132].

The 3GPP handles the research of the radio access in 3G. The radio interface is known as the Universal Terrestrial Radio Access (UTRA). There are different 3GPP partnership projects. In this part of the thesis the focus will be on the 3GPP Technical Specification Group Radio Access Network (TSG RAN), which developed WCDMA, HSPA and LTE.

According to the official website of 3GPP [11], there are five Working Groups (WGs) that handle all the research. The WGs are divided into different layers:

- RAN WG1: the physical layer
- RAN WG2: layer 2 and 3 of radio interface specifications
- RAN WG3: UTRAN requirements
- RAN WG4: Radio Frequency (RF) and Radio Resource Management (RRM)
- RAN WG5: terminal performance testing [11]

The other 3GPP partnerships were also developing 3G but instead of using WCDMA, 3G was based on CDMA2000 or TD-Synchronous CDMA (TD-SCDMA) in China [7, 132].

4.2 Wideband – Code Division Multiple Access

As long as the air interface is completely different from the previous ones such as TDMA and FDMA, an explanation is needed to understand the new technologies. In this interface, FDD and TDD are both supported. WCDMA is a hierarchical architecture that introduces the idea of the NodeB that performs the physical-layer processing, for example error-correcting coding, modulation and spreading as well as conversion from baseband to an RF signal [10, 129]. Figure 7 illustrates is the hierarchical architecture of WCDMA as described in [10, 129]..

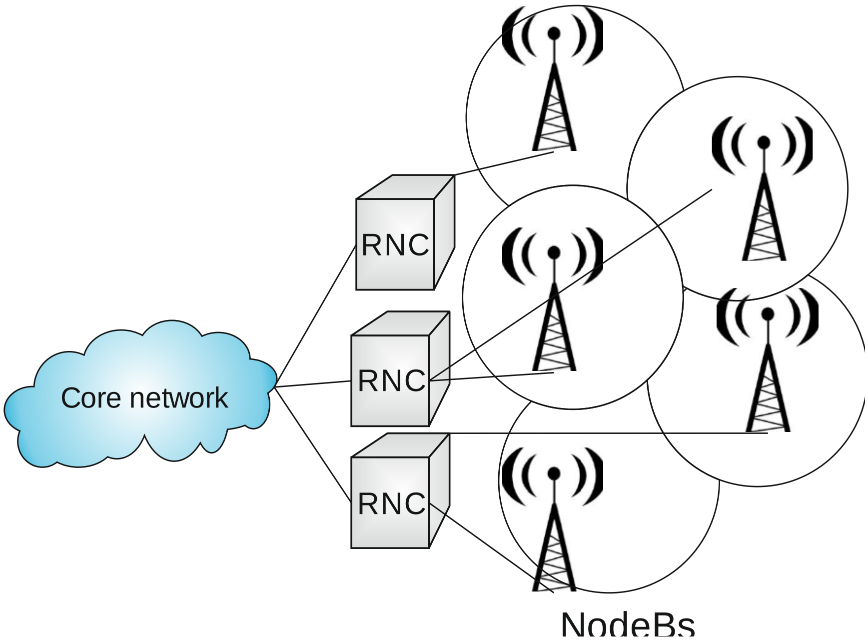


Figure 6. WCDMA architecture. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 129]

A terminal, also known as User Equipment (UE), notifies the NodeBs through the air interface. The Radio Network Controller (RNC) controls multiple NodeBs, which could be even one hundred NodeBs, but a NodeB only is connected to one RNC. The RNC is responsible for call setup, QoS and management of the radio resources in the cells, even the Automatic Repeat-reQuest (ARQ). As the other systems, WCDMA uses the layered system, dividing the communication process into different layers. Figure 8 represents the protocol architecture of WCDMA as described in [10, 130].

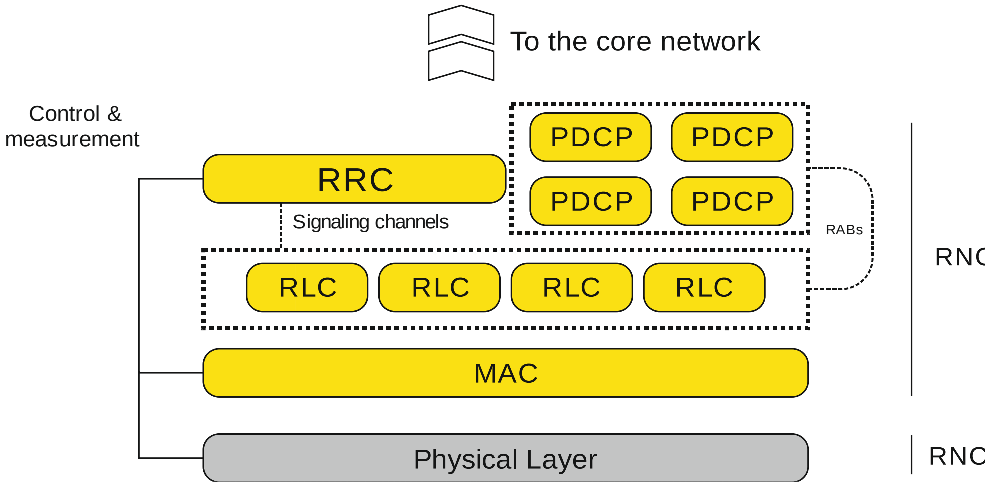


Figure 7. WCDMA protocol architecture. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 130]

The process from the user starts with the Packet Data Convergence Protocol (PDCP), where the IP packet can be compressed. IP packets header have different size, 40 bytes for IPv4 or 60 for IPv6 [10, 131].

The Radio Link Control (RLC) is in charge of the division of the IP packets into RLC protocol Data Units (RLC PDUs). The RLC also handles the ARQ protocol, since the RLC is located inside the RNC. For packet data services, error free delivery data is required. For each incorrect PDU received, the RLC send a request for a resend to its peer [10, 131].

The Medium Access Control (MAC) with the Logical Channels offers services to the upper layer. It is responsible for determining the date rate user over the radio link of the data sent to the physical layer, which is called Transport Format (TF). This interface between the physical layer and the MAC layer is specified through transport channels, where the Transport Blocks (TB) are sent. Depending on the size of the TB, the data rate can be changed. In each Transmission Time Interval (TTI), the transmission period of the radio link, specifically the time used to send TBs to the physical layer, which handles, among others, coding, interleaving, multiplexing and spreading information. In the first release TTI lengths were 10, 20, 40 and 80 ms, but HSPA will introduce 2 ms TTI to reduce latency [10, 132].

After this brief but necessary explanation about the principles of WCDMA, which is the air interface used in the 3G, UMTS and its improved evolution, HSPA, will be explained.

4.3 Universal Mobile Telecommunications System

UMTS was the proposal made by the ETSI for the 3G standard technology [7, 132]. One of the main important differences compared to the 2G was the air interface, the UMTS Terrestrial Radio Access (UTRA), which means that unlike GPRS or EDGE, a new architecture is needed, with new elements and frequencies allocations. As mentioned in section 4.1, UMTS could offer a maximum data rate of 2 Mbps in an indoor environment or 384 kbit/s in a pedestrian environment [7, 131]. The basic characteristics of UMTS are the followings:

- Roaming between the IMT-2000 service providers.
- Circuit switching and packet switching services both supported.
- Simultaneous connections, voice and Internet connection at the same time [7, 133].

Overview of the UMTS Architecture

In the structure of UMTS architecture three different blocks can be distinguish, the UE, the terminal, the UMTS Terrestrial Radio Access Network (UTRAN), which handles the radio interface, and the Core Network (CN), responsible for the call setup and data connections to external networks. Figure illustrates a functional architecture of UMTS, showing the changes mentioned before [7, 141].

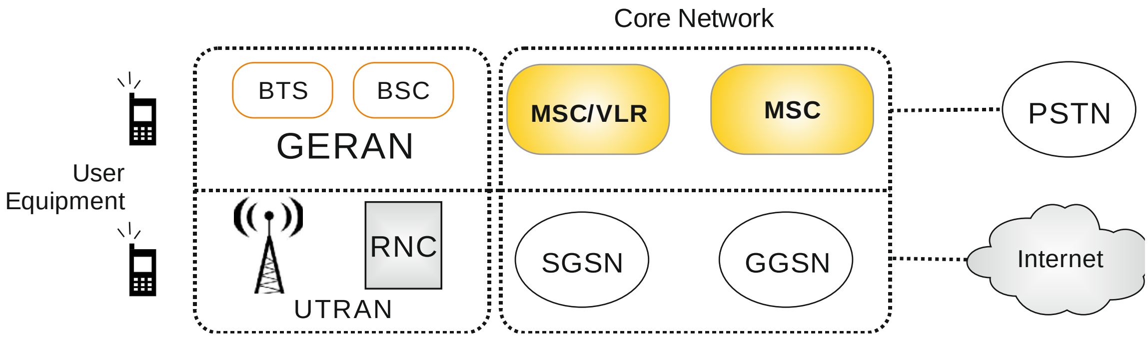


Figure 8. UMTS architecture. Data gathered from Herradón (2009) [7, 141]

User Equipment

The UE includes two parts, the Mobile Equipment (ME) and the UMTS Subscriber Identity Module (USIM). The ME is the terminal itself, which is connected to the UMTS architecture, specifically to the UTRAN through the Uu interface. The USIM is a smart card that contains the International Mobile Subscriber Identity (IMSI) and is responsible for the authentication and storing the keys for it. [7,142]

Universal Terrestrial Radio Access Network

The UTRAN is the most important part in the UMTS since is the only element, which has changed along the UMTS's evolution. UTRAN establish a connection between the UE and the CN through the Radio Access Bearer (RAB).

Core Network

The CN provides services such as a call setup and data connection, and, as shown in figure 9, initially it was based on the GSM/GPRS network. There are two modes of performance, packet switching, the lower side in the figure, and circuit switching, the upper side in figure. The main elements of the CN are the followings:

- Mobile Switching Center/Visitor Location Register (MSC/VLR) – Includes switching elements and the database with the location of the UE.
- Gateway MSC (GMSC) - Switching system for connection of the UMTS network to the external network.
- Serving GSN (SGSN) and Gateway GSN (GGSN) from GPRS. [7, 143]

Besides, there is another part in the architecture of CN which does not take part in the communications directly, but it is also very important because it contains vital information about the terminal such as addressing, positioning and information about the identity. Those elements are similar to the GSM elements for information about the terminal

- Home Location Register (HLR) – Stores the information about the subscriber
- Authentication Center (AuC) – Generates the security parameters for VLR and SGSN
- Equipment Identity Register (EIR) – Contains all the information related to the UE hardware. [7, 144]

4.4 UMTS Terrestrial Radio Access Network

UTRAN contains Radio Network Subsystem (RNS), which contains an RNC and several NodeBs, as shown in figure 7. These blocks carry out different actions in order to achieve the best performance possible for the UMTS. The RNC is responsible for the management of the UTRAN resources with the Radio Resource Management (RRM) protocol. The RRM also handles the resources management in the UE as well as in the RNC and NodeB. One of the actions performed is the handover, to increase the mobility of the user through the mobile network. The decision of the handover will be made depending on the following circumstances:

- Improve the quality
- Reduce the level of interference
- Limit the coverage provided by the cell
- Avoid the congestion in the cell [7, 157]

One example is the soft handover where the UE is connected simultaneously to more than one base station. Each separate link from a base station is called soft-handover branch and it is typically used in the cell boundary areas where cells overlap. The soft handover reduces the risk of interferences because it allows to use less transmit power.

4.5 High Speed Packet Access

HSDPA is the next step in the evolution, using the WCDMA technology, and was standardized as part of the 3GPP Release 5. The following step in chronological order is the HSUPA, from the 3GPP Release 6. As mentioned in chapter 2 those technologies together are called HSPA. There is no big difference in hardware between HSPA and WCDMA because HSPA reuses the same network, specifically RNC, base stations and the GPRS elements such as GGSN and SGSN, which means that the cost is low. The main point of HSPA comes from the software; the packets sent through the network are different and some changes in the hardware might be needed.

The major additions to the features are the voice, video and data services using both packet-switched and circuit-switched systems. With HSPA, the UTRA goes beyond and includes broadband data connection. HSPA introduces high bit rates depending of the modulation used, fast (channel-dependent) scheduling and rated control, and fast HARQ with soft combining. Altogether, it provides 14.4 Mbit/s in DL and 5.8 Mbit/s in UL. Also brings efficient support for broadcast through the introduction of Multimedia Broadcast Multicast Services (MBMS).

HARQ with Soft Combining

The HARQ technique with soft combining detects and stores the erroneous packets and requests a new transmission unlike the ARQ operation, which deletes the erroneous packet. To detect this erroneous reception, a Cyclic Redundancy Check (CRC) code is needed. The reason why the packet is stored is that later, with the new received packet, making a combination between the two packets the resulting packet will be more reliable.

5 Long Term Evolution

5.1 Overview

As explained in section 4.5 HSPA was using WCDMA, and the LTE was an evolution of HSPA even though it was developed in parallel with HSPA by the 3GPP. Besides, the System Architecture Evolution (SAE) is the new core network. In this chapter, the most important part in the thesis, an explanation about the design targets, radio access, interface and performance will be given. The air interface in LTE is called Evolved UMTS Terrestrial Radio Access (E-UTRA). The performance will be evaluated with different measurements, which are explained in appendix 1, and with an assignment about 4G LTE, about retrieving information from the log files created from the measurement case.

The most important changes brought by LTE are Orthogonal Frequency Division Multiplexing (OFDM), SAE and Multiple Input Multiple Output (MIMO). OFDM is explained in subsection 5.3.1 and MIMO in subsection 5.3.3.

5.2 LTE Design Targets

5.2.1 Capabilities

The target for downlink and uplink data rate are 100 Mbps and 50 Mbps (UE category 3) with a bandwidth of 20 MHz [12, 7]. It is possible to use FDD or TDD, but TDD cannot occur in UL and DL at the same time and not even reach that speed since it has to share the data rate. FDD uses two different frequency ranges for UL and DL, so LTE is able to transmit and receive data at the same time. About latency, the design targets are split into two groups, control-plane and user-plane. Control-plane refers to the delay for activating a terminal from a non-active state to an active state where the mobile can provide services. Depending if the terminal is known or unknown to the RAN, either the RAN does not have any context of the terminal or the terminal does not have any radio resources and the maximum delay must be 100 ms or 50 ms. Furthermore, LTE should support 200 terminals with a 5 MHz bandwidth (400 terminals a with wider bandwidth), including a high number of inactive terminals.

5.2.2 System Performance

The design targets of LTE system performance are high user throughput, mobility and coverage amongst others. The user throughput is defined depending on the amount of users taken, which can be the average or the fifth percentile of the user distribution.

The data rate depends on the mobility of the user, The maximum data rate is provided to low terminal speeds, 0-15 km/h. Speeds between 15 and 120 km/h should have a worse performance but still quite good, even though between 120 to 350 km/h the communication shall be maintained to maximum 500 km/h depending on the bandwidth used. Figure 9 show a comparison of mobility and performance [12, 9].

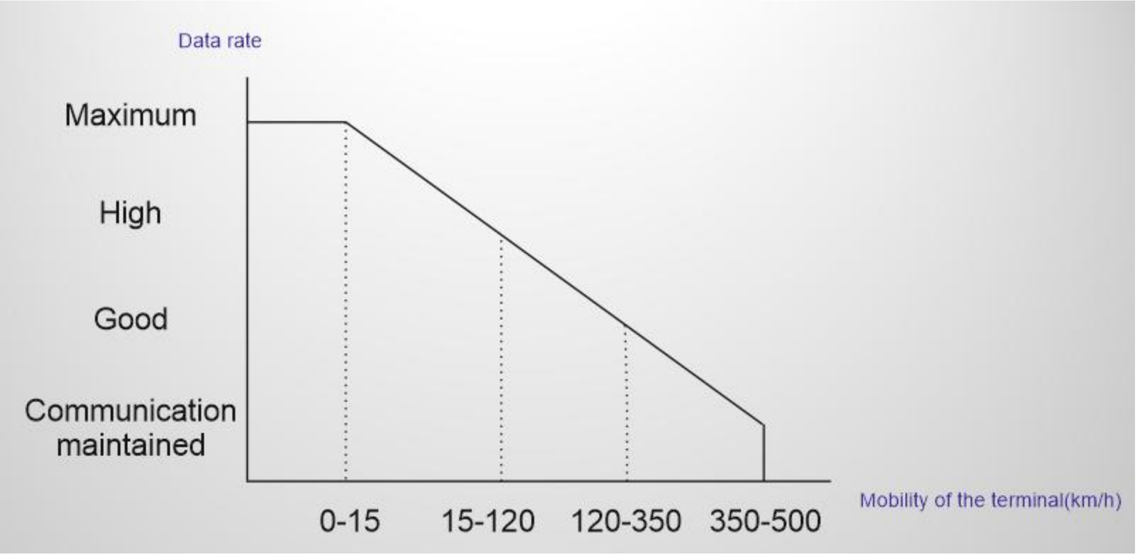


Figure 9. Comparison of performance vs. mobility of the terminal

Figure 9 illustrates than even though with a high mobility, the communication is maintained.

5.2.3 Deployment Scenarios and Mobility

Concerning the coverage, Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) should provide a different quality of service depending on the deployment scenario, specifically the radius of the cell. Up to 5 km, the maximum data rate possible is achieved; high spectrum efficiency and mobility should be achieved. From 30 km to 100 km, the data rate and spectrum efficiency might suffer from some problems, but still the mobility should not be a problem and must be achieved [12, 10].

On another level of the scenario, E-UTRAN should provide service to two types of scenarios, standalone deployment and integration scenario. The standalone deployment scenario consists of a scenario without any UTRAN/ GSM EDGE Radio Access Network (GERAN) network deployed within the area. On the other hand, the integration scenario is based on an area with an existing UTRAN/GERAN network deployed with full or partial coverage [12, 11]. As expected, the network operator will decide finally in which kind of scenario the network might be deployed depending on the possible demands of the current or future users.

5.3 Radio Access

After the explanation of the targets of the LTE technology, an overview of the radio access will be given, as well as the radio interface.

5.3.1 Transmission Schemes

LTE uses different access methods in UL and DL. The DL transmission scheme is Orthogonal Frequency Division Multiplexing Access (OFDMA). ODFM defines multiple subchannels using an orthogonal carrier frequency. This multicarrier method is used due to the possibility to transmit information divided into parallel streams with a lower data rate. Another benefit of the multiple channels is that not all of the channels are affected by the interferences or multipath, so the whole system will not be collapsed if one carrier falls. Figure 10 shows a single subchannel and figure 11 the OFDM signal with five channels and their five own carriers [10, 43-45].

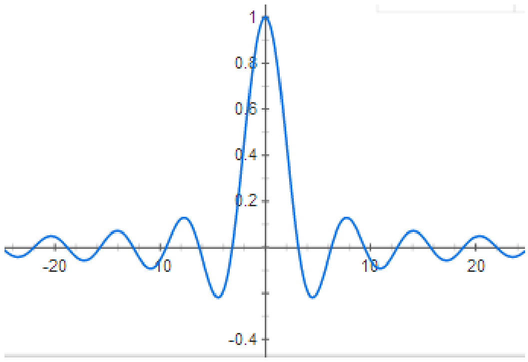


Figure 10. OFDM subchannel

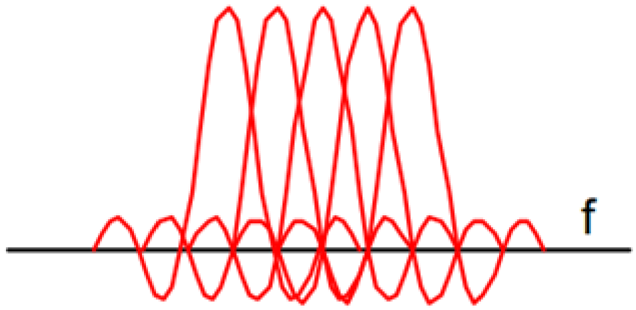


Figure 11. OFDM spectrum

For UL, the transmission scheme is Single Carrier-FDMA (SC-FDMA), more specifically Discrete Fourier Transform Spread - OFDM (DFTS-OFDM). This scheme is used because of the benefits mentioned above from the OFDM and the use of the low peak-to-average ratio of the transmitting signal in order to make it appropriated to the power that the UEs are able to transmit. Figure 12 shows the SC-FDMA spectrum. As can be seen there is some separation between carrier's users, because of FDMA.

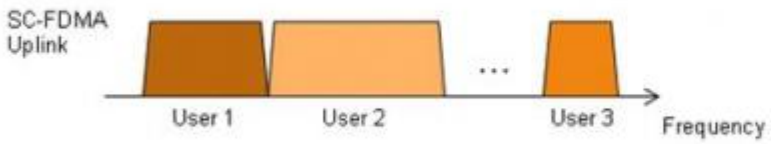


Figure 12. SC-FDMA spectrum

The separation seen in figure 12 is because of the FDMA system.

5.3.2 Scheduling

In LTE, because the of the shared-channels transmission, a scheduler of channels is required to organize and manage the use of the network, which the end user will transmit in every moment. Hence, the scheduler is one of the most important part on LTE to achieve the best system execution in the downlink, especially in a high loaded network. Unlike the previous technologies, the LTE scheduler can also access all domains, frequency and time due to the use of OFDM in DL and SC-FDMA in UL. The decisions can be taken every 1 ms and the granularity in the frequency domain is 180 kHz. The granularity is illustrated in figure 13. The process will be explained in subsection 5.4.2.1.

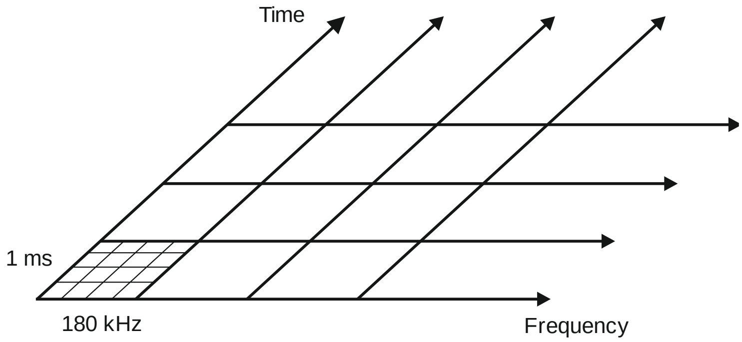


Figure 13. Granularity of the scheduler

The granularity mentioned above corresponds to the division shown in figure 13.

5.3.3 Multiple Antenna

From the very beginning, LTE supports multiple antennas for transmitting, receiving or both at the same time. Multiple transmitting antennas are used to perform diversity and beam forming to improve signal-to-noise ratio (SNR) and signal-to-interference ratio (SIR), as well as in the next case, and the improvement of capacity and coverage. In the case of receiving antennas, it is used to reduce the fading that affects to the down-link in the terminals since the signal could reach the terminal from different directions (multi-path).

Another feature of LTE is the use of spatial multiplexing, MIMO. The use of multiple receive and transmit antennas has the goal of reducing the interferences by suppressing the fading and doubling the capacity of the cell. MIMO systems are an essential part of LTE in order to achieve the requirements for throughput and spectral efficiency. The base configuration for DL is 4x4 for eNB and 2x2 for UE [10, 375]. However, there is a proposal of a higher order MIMO for LTE-Advanced, 8x8 for eNB and 4x4 for UE. Figure 14 is an illustration of MIMO in LTE.

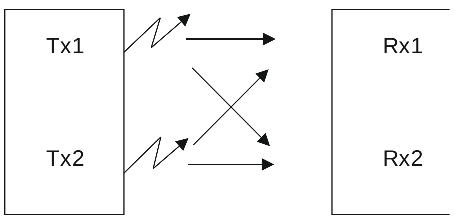


Figure 14. MIMO 2x2 [13, 69]

5.4 Radio Interface Architecture

The radio transmission in LTE is divided into four protocol layers. The incoming IP packets pass through these layers [10, 300-301]:

- Packet Data Convergence Protocol (PDCP) handles the IP header compression by Robust Header Compression (ROHC), ciphering and integrity protection of the transmitted data.
- Radio Link Control (RLC), which is located in the eNodeB, is responsible for segmentation, reassembly and in-sequence delivery to higher layers.
- Medium Access Control (MAC) performs logical-channel multiplexing, the HARQ retransmissions and the scheduling.
- Physical Layer (PHY) handles coding, modulation, multi-antenna mapping and other physical layer functions and offers services to the MAC layer in the form of transport channels.

The different layers will be explained in the following sections, from the information of [10, 301-315]. Figure 15 is a description of the layers.

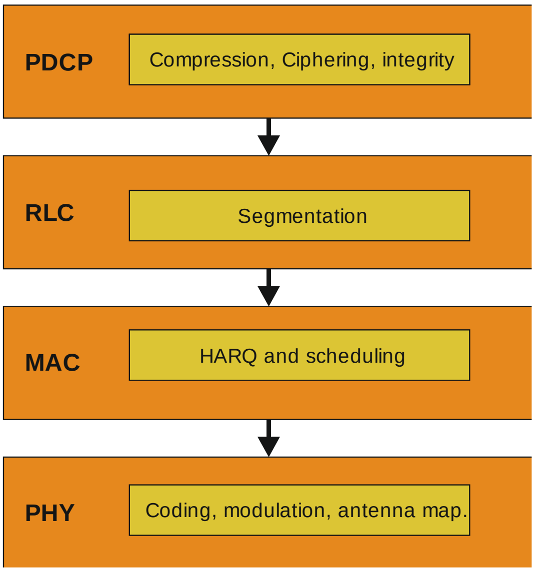


Figure 15. LTE protocol layers. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 300-301]

Figure 15 also shows the order followed in the communication.

5.4.1 Radio Link Control

As mentioned in section 5.4, RLC layer is responsible for of erroneous received packets (ARQ and the segmentation and reassembly of the compressed IP packets from PDCP, also known as RLC Service Data Unit (RLC SDU). Besides, the RLC must en-sure that the packets are received in the correct order. The scheduler decides how much data from each packet coming from the PDCP must be selected to be in the RLC SDU buffer in order to create the RLC PDU. Therefore, the size of the LTE PDU varies, unlike the HSPA PDU, which, for high data rates could be useful because a larger PDU would cause a small overhead. Figure 16 is a representation of the segmentation process.

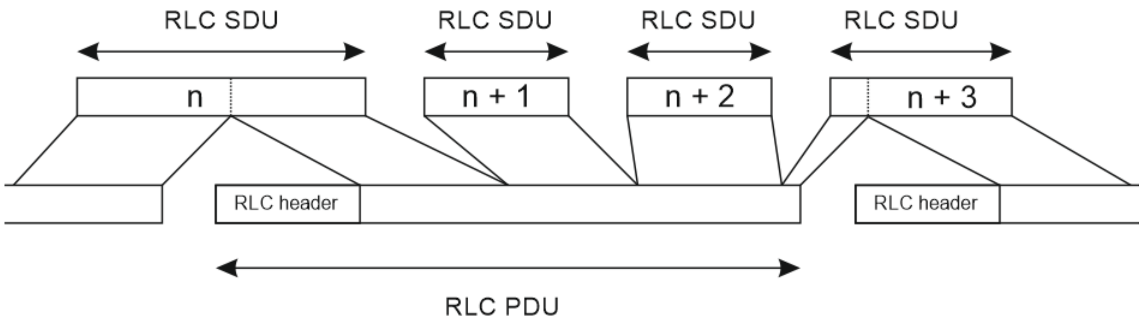


Figure 16. Segmentation of IP packets. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 302]

Since the RLC is set-in the eNodeB, dynamic PDU sizes can be easily used, as seen in figure 16. RLC also provides error-free delivery of data to higher layers. To achieve this goal, the RLC controls the number in the header of the incoming PDUs so later it can identify the missing PDUs and give feedback about the erroneous packets.

5.4.2 Medium Access Control

The actions of the MAC layers were mentioned in section 5.4 so the only remaining matter is how those actions are performed, and the answer is by channels, logical and transport channels. There are two kinds of logical channels: control channel, which is used to transmit control and configuration information and the traffic channel, which is used for the user data. All of these channels are illustrated in figures 17 and 18. The control channels in DL are the followings ones:

- Broadcast Control Channel (BCCH) – The network sends core information to the provided terminals in a cell such as Evolved Absolute Radio Frequency Channel Number (EARFCN) from the neighbor cells.
- Paging Control Channel (PCCH) – To acknowledge the power level of terminal, also known as paging.
- Multicast Control Channel (MCCH)–Transmission of control information required for reception of the MTCH.

- Multicast Traffic Channel (MTCH) – Used for downlink transmission of MBMS. [10, 303]

The following three control channels work also in UL direction.

- Common Control Channel (CCCH) – With no RRC, this channel share control information with the network.
- Dedicated Traffic Channel (DTCH) – This channel is used for all UL user data for a point-to-point connection.
- Dedicated Control Channel (DCCH) – Works as CCCH but point-to-point. [10, 303]

The transport channels are characterized by the kind of carried information as well as the way of transporting it. The data embedded in a transport channel is divided into TBs. In each TTI (Transport Time Interval), at most one TB is sent but in the case of applying MIMO the maximum raises to two blocks per TTI. In each TB there is a TF which specifies how the TB must be transmitted, the size, modulation and antenna mapping. The following transport channels are defined for LTE, illustrated in figures 17 and 18:

- Broadcast Channel (BCH) – Used in the BCCH, transports the Master Information Block (MIB), which includes information about DL cell bandwidth, PHICH configuration and the system frame number (SFN).
- Paging Channel (PCH)–Connected to the PCCH, sends paging information
- Downlink Shared Channel (DL-SCH) – Most important channel for transmission of DL data.
- Multicast Channel (MCH)– Used for MBMS. [10, 304]

Now these two transport channels work in UL direction:

- Uplink Shared (UL-SCH)– Is the UL counterpart to the DL-SCH
- Random Access Channel (RACH) – Does not carry any TBs, it is considered a transport channel and used only in UL. [10, 304]

Besides, MAC is responsible of multiplexing different logical channels and mapping logical channels to the appropriate transport channels. Figure 17 and 18 are the different mappings for DL and UL.

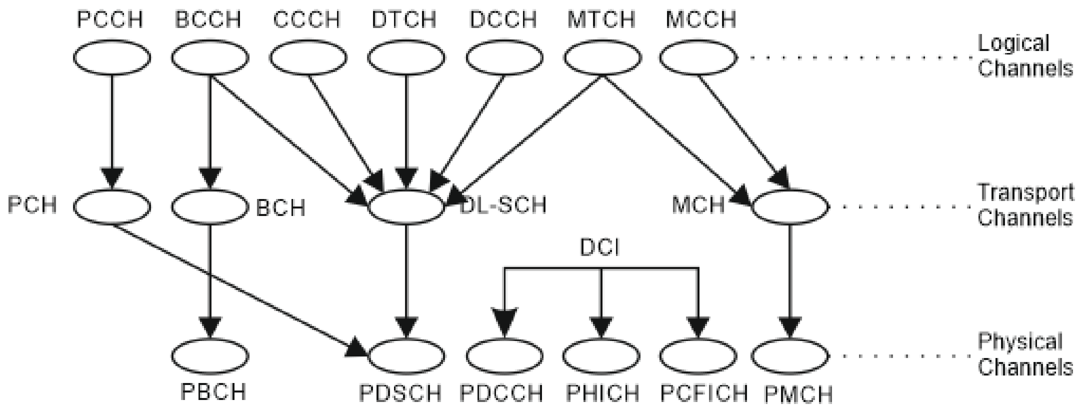


Figure 17. LTE Mapping for DL. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 129]

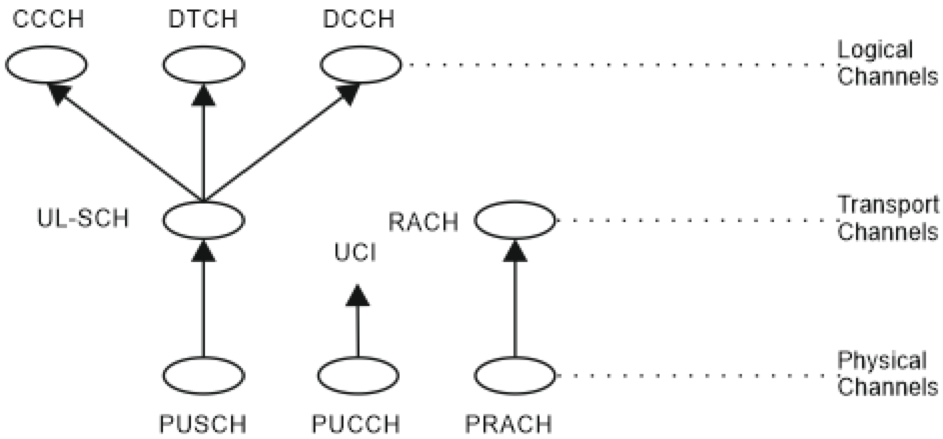


Figure 18. LTE Mapping for UL. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 129]

Obviously, the mapping for DL and UL are not the same but they share some channels as seen in figures 17 and 18.

Scheduling

The scheduler decides the assignment of the UL and DL resources since LTE is a standard with a shared-channel transmission feature. It performs the dynamic scheduling, making a decision each TTI. Decisions from DL and UL are independent.

The DL scheduler controls the amount of resource block (RB) sent by the terminal and when it can transmit. The eNodeB controls the transport-format, everything regarding the selection of the transport-block size, modulation scheme and antenna mapping. Those RBs is a unit spanning of 180 kHz, which map the data to physical resources. In one TTI, the scheduler assigns RB for DL-SCH and UL-SCH independently. Apart the functions of the eNodeB, it is known that the UL scheduler take its decision by terminal and not by radio bearer.

In LTE, the scheduling in time and frequency domains produces in larger bandwidth a significant amount of frequency-selective fading. Each terminal must report a channel-status to inform about the quality of the DL channel. Figure 19 is an example of how scheduler assigns resources depending on the users and the channel quality.

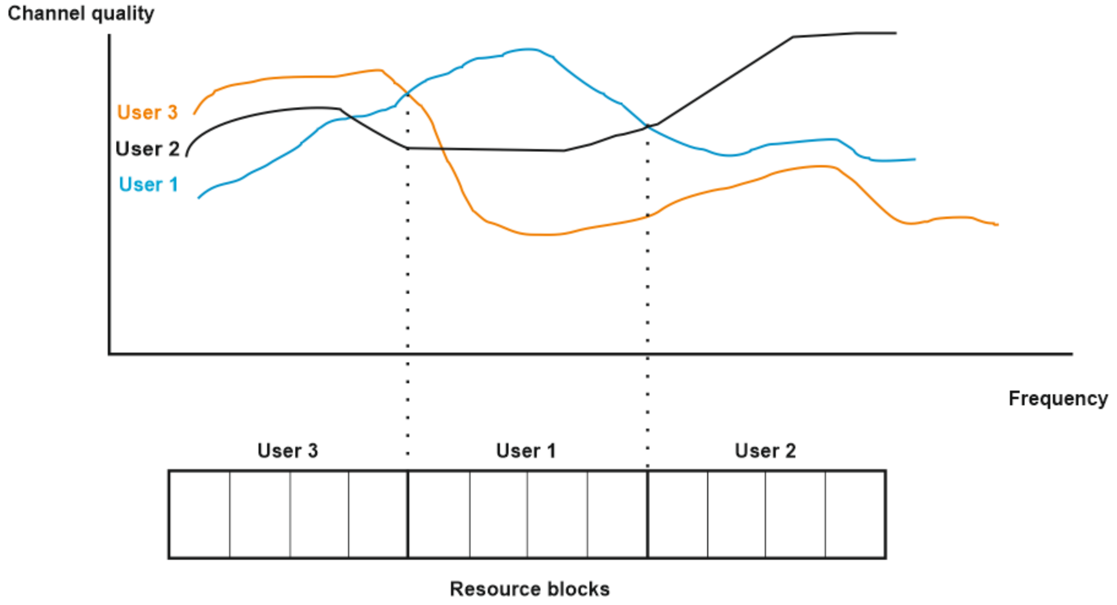


Figure 19. Scheduling in LTE [10, 292]

As seen figure 19, the scheduler grants the RBs to the user depending on his channel quality.

5.4.3 Physical Layer

The physical layer handles coding, modulation, multi-antenna mapping as well as it offers services to the MAC layer in the form of transport channels. In the MAC subsection 5.4.2 the process for transport channels was explained. The maximum TBs per TTI is one, two in case of spatial multiplexing. This TB is carried through the DL-SCH with a CRC code followed by a Turbo coding for error detection and correction. The UL-SCH operation is quite the same as the DL but it does not support the antenna mapping. The antenna mapping goes after the modulated coded bits using QPSK, 16-QAM or 64-QAM. There are different kinds of antenna mapping such as multi-antenna transmission schemes like transmit diversity, beam forming and spatial multiplexing. Figure 20 is diagram of the process in the physical layer.

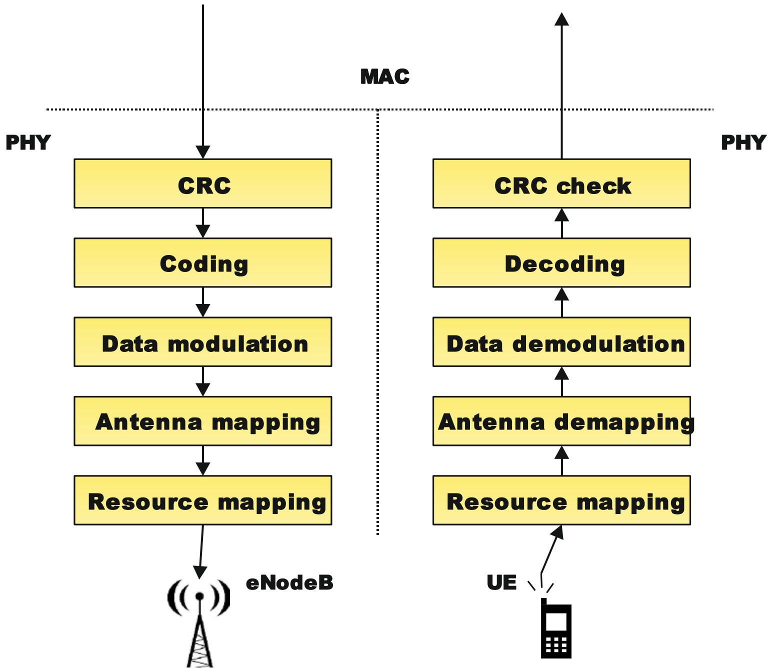


Figure 20. Physical layer processing for DL-SCH. Data gathered from Evolution HSPA and LTE for Mobile Broadband (2008) [10, 311]

Mainly the transport channels are mapped in physical channels, a set of time-frequency resources. Not all physical channels carry transport channels. The physical channels are the following:

- Physical Downlink Shared Channel (PDSCH)
- Physical Broadcast Channel (PBCH)
- Physical Multicast Channel (PMCH)
- Physical Downlink Control Chanel (PDDCH)
- Physical Hybrid-ARQ Indicator Channel (PHICH)
- Physical Control Format Indicator Channel (PCFICH)

The three following channels are only and exclusively for UL.

- Physical Uplink Shared Channel (PUSCH)
- Physical Uplink Control Channel (PUCCH)
- Physical Random Access Channel (PRACH) [10, 312-313]

The mapping between the physical channel and the transport channels were illustrated figures 17 and 18.

5.5 Comparison of 3G and 4G

To give a conclusion regarding 3G and 4G, the following tables summarize the main characteristics of the main standards in this technologies as well as some extra important information about the project. Note that the data rate for LTE is the first design target, data rate achieved with a UE category 3, as seen in table 2.

Table 2. Comparison between 3G and 4G

	3G				4G
	UMTS	HDSPA	HSPA	HSPA+	LTE
Max DL and UL data rate (Mbps)	384 kbit/s to 2	7.2	14.4/5.76	42.2	100/50
Access mode	WCDMA				DL:OFDMA UL:SC-FDMA
Duplex mode	FDD				
Bandwidth (MHz)	5				1.4, 3, 5, 10, 15, 20

There is also a new standard called LTE-Advanced that promises an increased peak data rate up to 3 Gbps in DL and 1.5 Gbps in UL. LTE-Advanced promises higher spectral efficiency, improved performance on cell edges and more users within the cell. New functionalities will be added such as Carrier Aggregation (CA), enhanced use of multi-antenna techniques and support for Relay Nodes (RN). The 3GPP defines different UE categories depending on the maximum data rate supported. Table 4 summarizes the different categories.

Table 3. UE Categories and the data rates supported

UE Category	Data rate for 20MHz bandwidth (DL/UL) (Mbps)
1	10/5
2	50/25
3	100/50
4	150/50
5	300/75
6	300/50
7	300/100
8	3000/1500

6 Measurement Cases

6.1 Background

The aim of this project was to carry out measurements to evaluate LTE performance. Since there is nothing better than a practical case, a measurement was carried out in the Helsinki capital region, in particular Leppävaara, Espoo. The drive test measurement was carried out from Leppävaara to Helsinki by train. In the fixed-location measurement, a file was downloaded from the Dropbox server. On the other hand, in the drive test, a high definition video was watched on streaming. The details of the measurement are explained in the Appendix 1.

The software chosen for the measurement case was TEMS Investigation and Data Collection 15.3. According to the description on the official website of ASCOM, TEMS can be characterized as:

> *"TEMS Investigation performs geographically positioned air interface and service quality measurements with devices used by subscribers (e.g., smartphones and iPad tablets) in a variety of indoor and outdoor drive-test scenarios. It can also work in combination with TEMS Pocket-supported test phones and tablets. This measurement and troubleshooting data can be viewed on the collection device or sent to a PC for analysis by TEMS Investigation or the TEMS™ Discovery post-processing tool.*
> *TEMS Investigation supports more than 300 measurement devices, including phones, smartphones, scanners, PC cards, USB modems, fixed wireless terminals, etc., from all major vendors across multiple technologies. TEMS Investigation uses these devices to collect geographically positioned data from a user's perspective."[14]*

TEMS is an industry-leading air interface test tool that provides high quality measurements, fixed-location and drive test measurements, of devices used by the subscribers. TEMS can illustrate information about the air interface that the UE knows and stores it in a logfile. The setup done to take the measurement is described in figure 21.

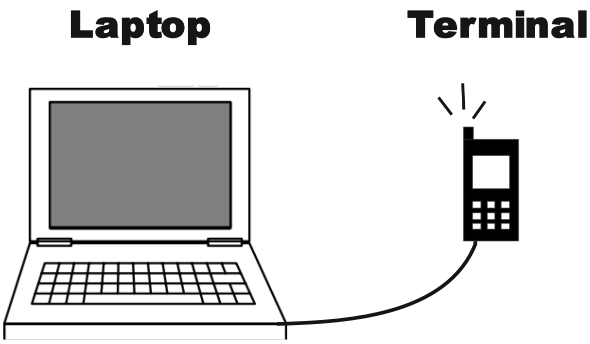


Figure 21. Setup done to make the measurement

As seen in figure 21, the setup is only the terminal connected to the workstation with a cable.

6.2 Measurement Results

The measurement in the Sello shopping mall gave the following results. The information given here regarding LTE will be about the basic information about the serving cell, radio parameters and other considerations related to the layer 3, concerning the information sent between the UE and the E-UTRAN and finally all the information concerning the data rate of UL and DL. There will be also a brief explanation how and where this data can be found. On the other hand, about HSPA just the data rate will be displayed since a deep analysis it is not a goal of this project. Finally, in the drive test, the results will show the different procedures made by the terminal and the network to maintain a viable connection and high speed during the all trip but only with one operator, Elisa.

6.2.1 Results Obtained in Fixed-Location Measurement

In this subsection, the results are explained briefly and in section 6.3 they are analyzed in more detail.

Using the predesign LTE working, the results start with the overview worksheet. In figure 22, there are three windows with relevant information, the LTE Serving/Neighbor Cell Line Chart, LTE Serving Cell and LTE Radio Parameters.

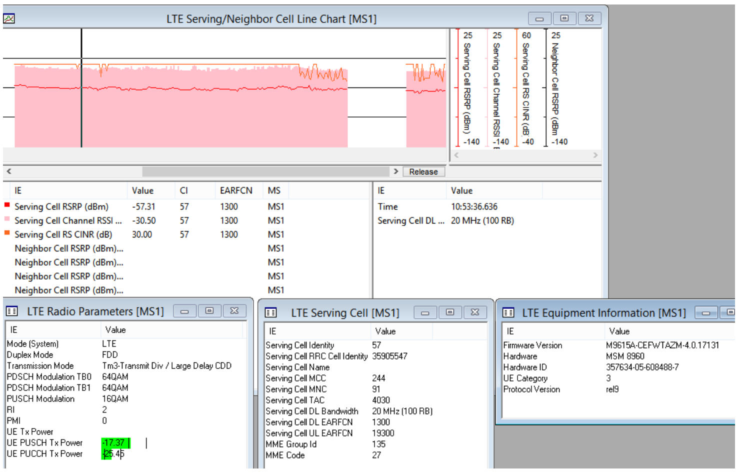


Figure 22. Overview worksheet in Sonera

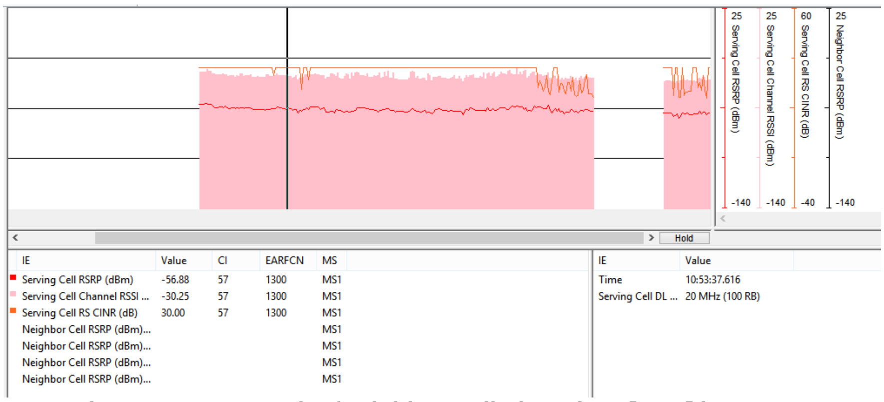


Figure 23. LTE Serving/Neighbor Cell Line Chart [MS1] in Sonera

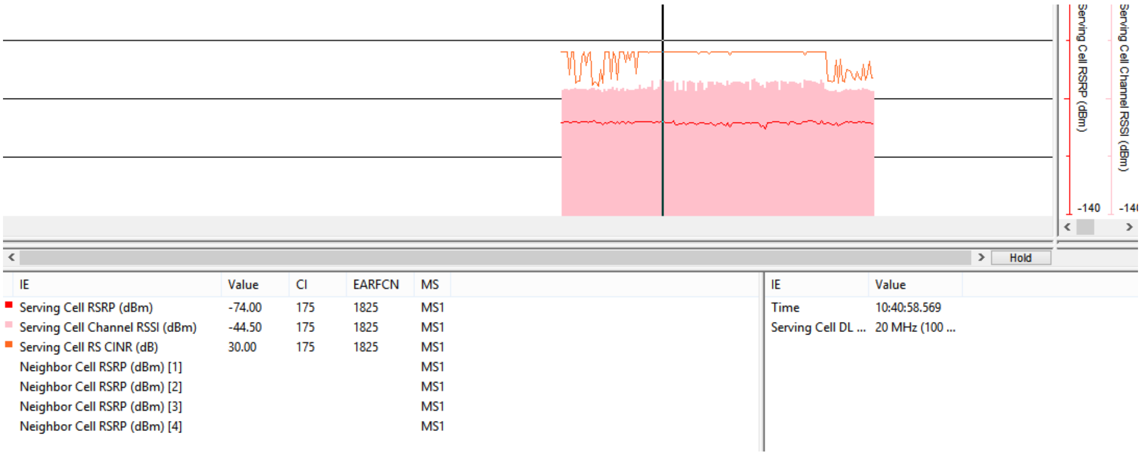


Figure 24. LTE Serving/Neighbor Cell Line Chart [MS1] in Elisa

In figures 23 and 24, the Reference Signal Receive Power (RSRP), the Received Signal Strength Indicator (RSSI) and the Reference Signal Carrier to Interference-plus-Noise Ratio (RS CINR) are shown from both operators. Then, the results are collected into table 5 in subsection 6.3.1 to compare.

Continuing with the overview worksheet, the next windows are LTE Serving Cell and LTE Radio Parameters. The LTE Serving Cell as expected, provides information about the cell that is connected to the used UE such as cell ID, Mobile Country Code (MCC), Mobile Network Code (MNC), bandwidth, carrier frequencies, etc.

IE	Value	IE	Value
Serving Cell Identity	57	Serving Cell Identity	175
Serving Cell RRC Cell Identity	35905547	Serving Cell RRC Cell Identity	133121
Serving Cell Name		Serving Cell Name	
Serving Cell MCC	244	Serving Cell MCC	244
Serving Cell MNC	91	Serving Cell MNC	5
Serving Cell TAC	4030	Serving Cell TAC	29121
Serving Cell DL Bandwidth	20 MHz (100 RB)	Serving Cell DL Bandwidth	20 MHz (100 RB)
Serving Cell DL EARFCN	1300	Serving Cell DL EARFCN	1825
Serving Cell UL EARFCN	19300	Serving Cell UL EARFCN	19825
MME Group Id	135	MME Group Id	2432
MME Code	27	MME Code	5

Figure 25. LTE Serving Cell in Sonera and Elisa

Figure 25 is an illustration of the window where the information can be extracted and then the results are collected into table 6 in subsection 6.3.1 to compare.

Moving to the next part, the LTE Radio Parameters show the used duplex mode, transmission mode, modulation used, amongst others.

IE	Value	IE	Value
Mode (System)	LTE	Mode (System)	LTE
Duplex Mode	FDD	Duplex Mode	FDD
Transmission Mode	Tm2-Transmit Div	Transmission Mode	Tm1-Single Antenna Port 0
PDSCH Modulation TB0	QPSK	PDSCH Modulation TB0	64QAM
PDSCH Modulation TB1	64QAM	PDSCH Modulation TB1	
PUSCH Modulation	16QAM	PUSCH Modulation	16QAM
RI	1	RI	1
PMI	0	PMI	0
UE Tx Power		UE Tx Power	
UE PUSCH Tx Power	-17.41	UE PUSCH Tx Power	-9.00
UE PUCCH Tx Power	-25.45	UE PUCCH Tx Power	-27.18

Figure 26. LTE Radio Parameters [MS1] in Sonera and Elisa

Figure 26 is an illustration of the window where the information can be extracted and then the results are collected into table 7 in subsection 6.3.1 to compare.

Finally, in the data worksheet, the LTE Throughput Line Chart can be found, giving information about the different data rates in DL such as, PDCP DL Throughput, RLC DL PDCP DL Throughput and PDSCH Physical PDCP DL Throughput. Figures 27 and 28 are the windows where the data rate can be checked. Also in subsection 6.3.1, table 7 is created with the collected data.

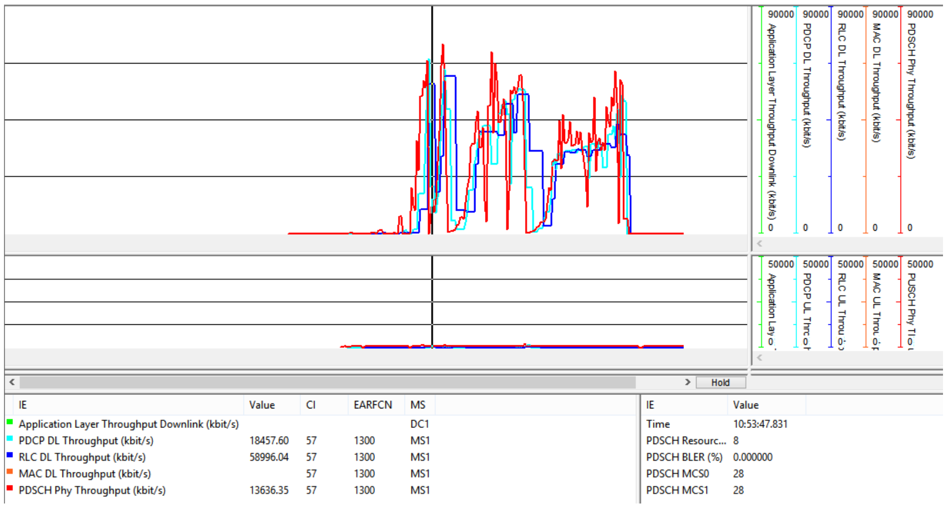


Figure 27. LTE Throughput Line Chart [MS1-DC1] in Sonera

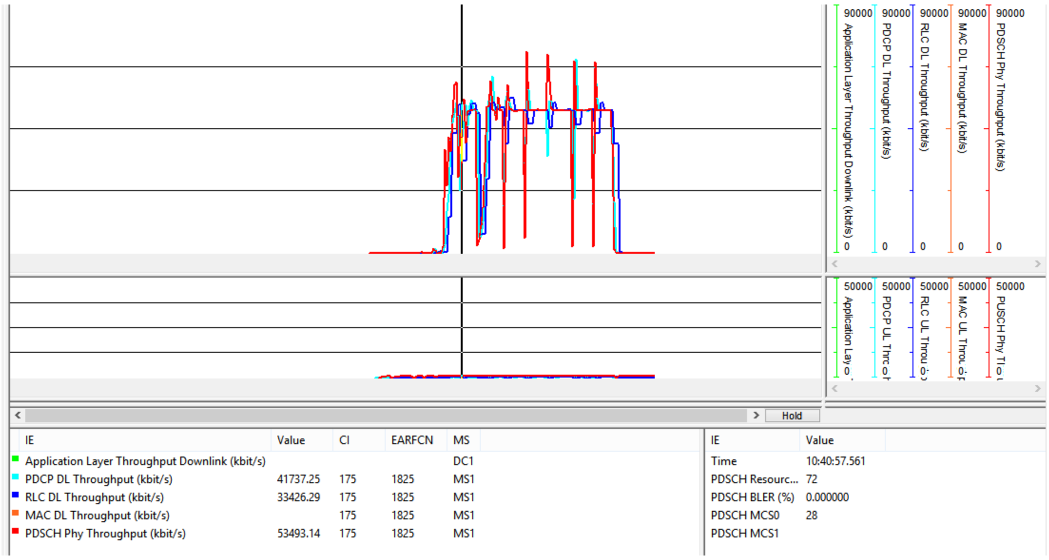


Figure 28. LTE Throughput Line Chart [MS1-DC1] in Elisa

On the other hand, in the HSPA case, for the aim of this project the only important analysis that is needed to do is about the data rate, in order to compare it with the LTE data rate transmission. Figures 29 and 30 are the windows where the data rate can be checked.

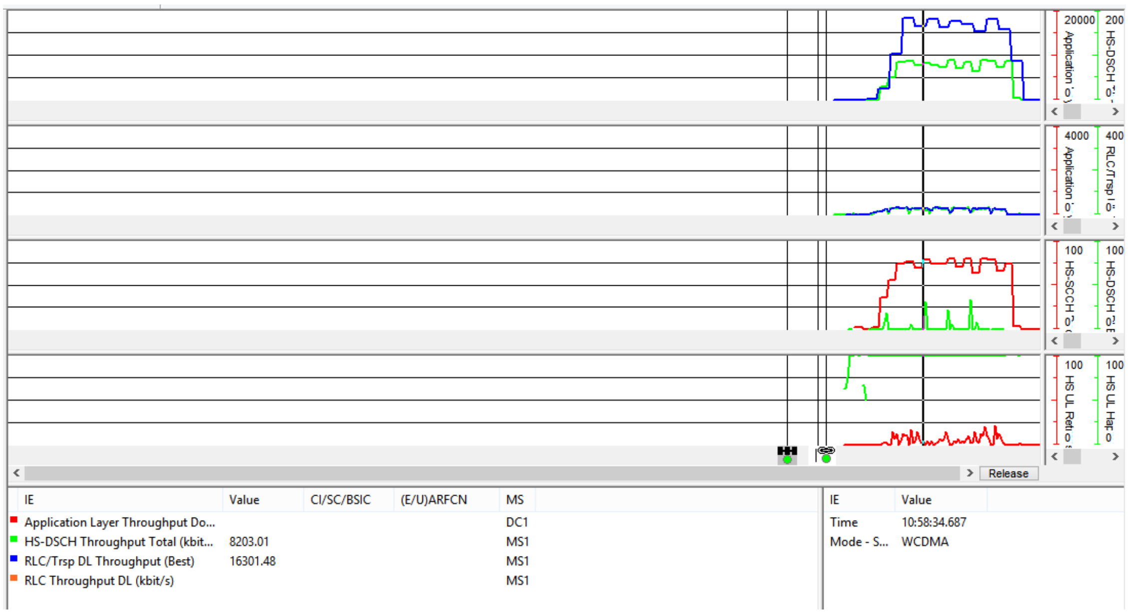


Figure 29. WCDMA HSPA/GSM Data Line Chart in Sonera

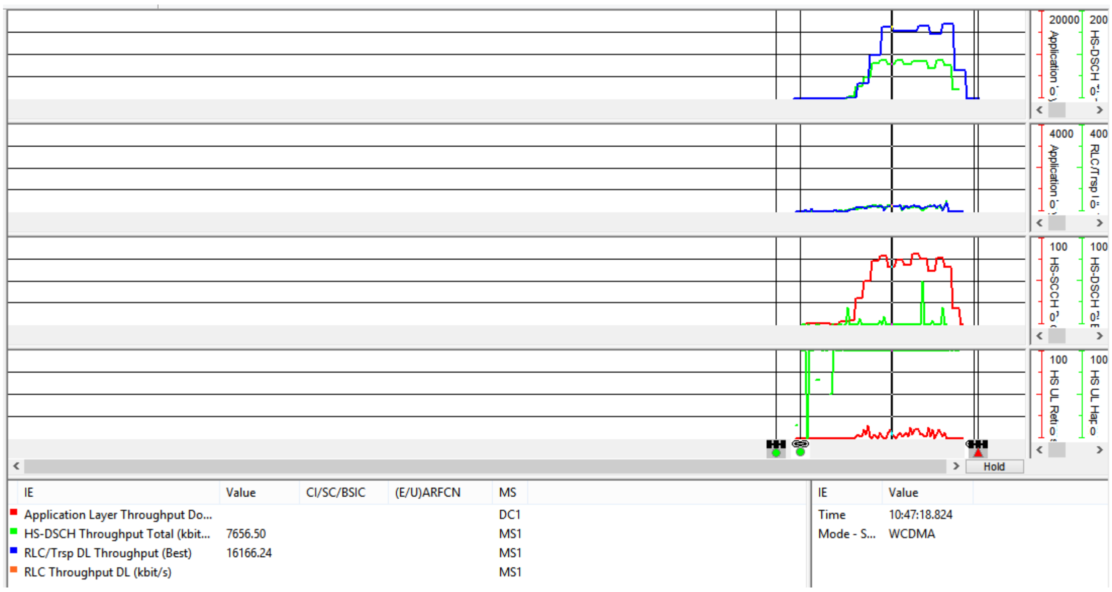


Figure 30. WCDMA HSPA/GSM Data Line Chart in Elisa

As seen in figures 29 and 30 and in table 4, the data rate is practically the same in both operators. In Sonera case, the data rate is slightly better but still it is the almost the same.

Table 4. Comparison of HSPA data rates

	Sonera	Elisa
HS-DSCH Throughput Total (Mbit/s)	8.7	8.43
RLC/Trsp DL Throughput (Mbit/s)	16.3	15.24

Table 4 reveals the similarity mentioned above.

6.2.2 Results Obtained in the Drive Test

As explained in appendix 1 and in section 6.1, the drive test was made from the Leppävaara Railway Station to Helsinki Railway Station. The results showed interesting information about how the terminal and the E-UTRAN behaved concerning the serving cells in the HSPA and LTE modes.

Figures 31 and 32 show one of the goals of the drive test, to check if the LTE connection was maintained in the whole train trip, but as seen there, there was a short time period that the mode changed into WCDMA.

Figure 31. LTE/WCDMA Line Chart (1/2)

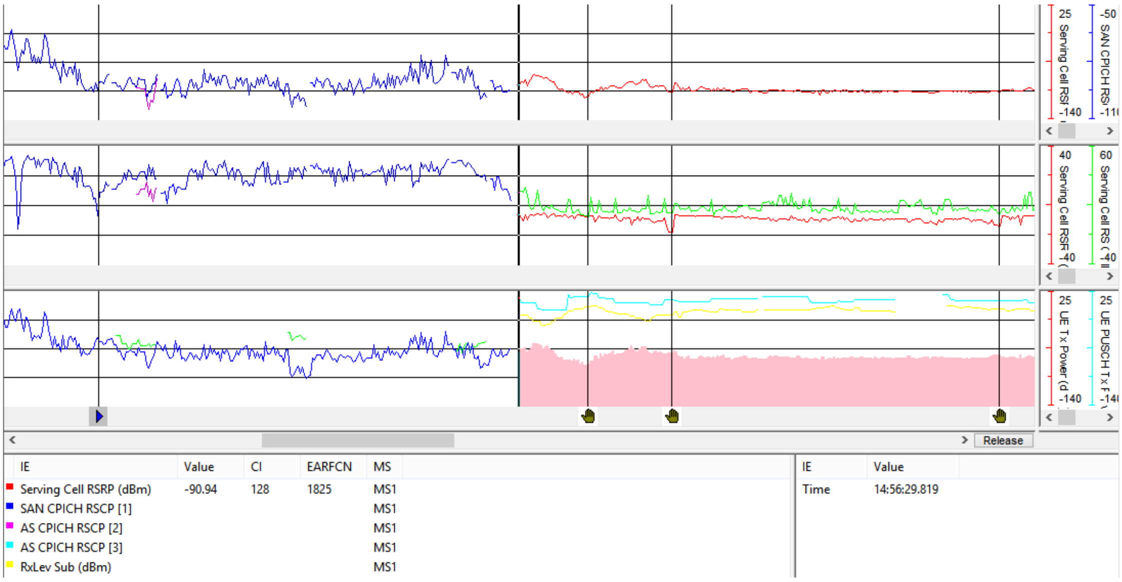


Figure 32. LTE/WCDMA Line Chart (2/2)

Finally, figure 33 is the illustration about how the connection between the terminal and the cells work.

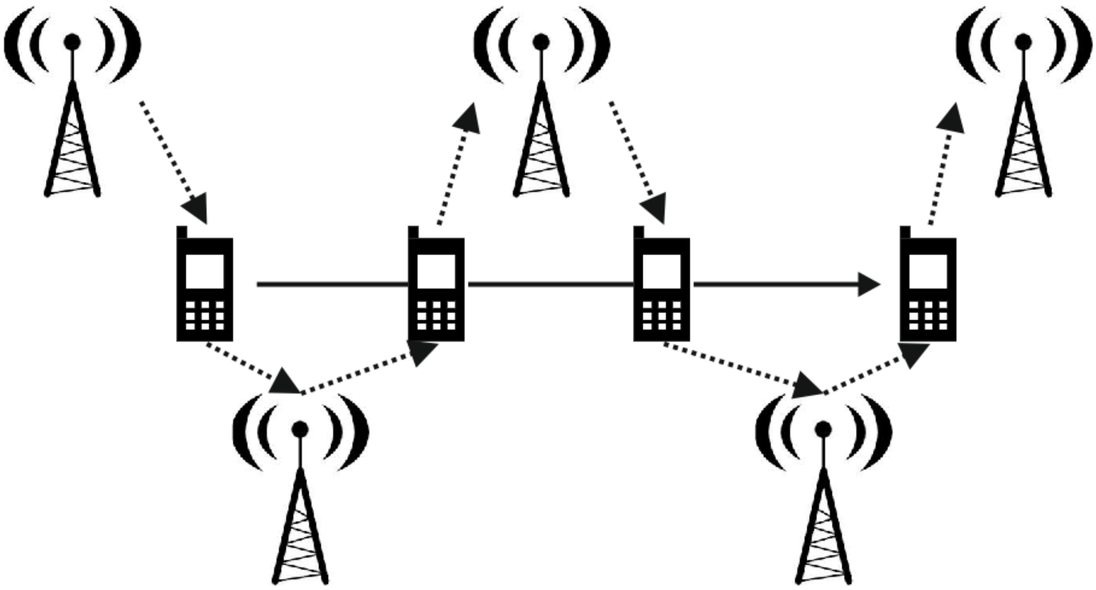


Figure 33. Connection with the cells

The terminal is in the train following its path and the arrows from the cells to the terminal represent the connection between both.

6.3 Analysis of Results and Comparison with HSPA

6.3.1 Fixed-Location Measurement Analysis

To start with the analysis of the measurement case, let us begin from the tables built from the data collected in subsection 6.2.1, data extracted from TEMS Investigations 15.3.

Table 5. LTE Serving Neighbor Cell Line Chart comparison

	Sonera	Elisa
RSRP (dBm)	-58.88	-75.13
RSSI (dBm)	-30.25	-44.5
RS CINR (dB)	25	22

In table 5, the RSRP is related to average receive power. The RSSI is the wideband power received, including all the symbols, interferences and noise, on a given frequency band. Finally, the RS CINR, is just a measure of SNR.

Table 6. Parameters of LTE Serving Cell comparison

Serving Cell	Sonera	Elisa
MCC	244	244
MNC	91	5
Bandwidth (MHz)	20	20
DL EARFCN	1300	1825
UL EARFCN	19300	19825

Concerning the parameters of the LTE Serving Cell, the following information can be found in table 6:

- The MCC shows information about the country where the cell belongs. Finland's code is 244 [15].
- The MNC combined with the MCC represents the operator that owns the serving cell and provides service. In this case, Sonera's code is 91 and Elisa's code is 5 [15].
- The bandwidth used for this connection is 20 MHz.

- The EARFCN is related to the carrier frequency by the formulas:

$$F_{DL} = F_{DL\_low} + 0.1(N_{DL} – N_{Offs\text{-}DL})$$

$$F_{UL} = F_{UL\_low} + 0.1(N_{UL} – N_{Offs\text{-}UL})$$

  where F_{DL_low}, F_{UL_low}, $N_{Offs\text{-}DL}$, $N_{Offs\text{-}UL}$ can be found in [16, 34]. The N_{DL} and N_{UL} are the EARFCN for DL and UL shown in table 6. Using the formula found in the document it is easy to calculate the interval of frequencies.
  - Sonera -> DL = 1815 MHz and UL = 1720 MHz
  - Elisa -> DL = 1825 MHz and UL = 1772.5 MHz

Table 7. LTE Radio parameters comparison

Serving Cell	Sonera	Elisa
Duplex mode	FDD	FDD
Transmission mode	TM2-Diversity at transmission/ Tm3-Transmit Div / Large Delay CDD.	TM1-Single antenna port 0
PDSCH Modulation used in each antenna	QPSK-64QAM-16QAM	
PUSCH Modulation		

Finally, the radio parameters used in the connections concerning LTE as shown in table 6 can be described as follows:

- The duplex mode used in both operators is FDD.
- Sonera operator uses diversity at transmission and MIMO, while Elisa only uses one antenna for the whole connection. (“Tm2”: Transmit diversity “Tm3”: Open-loop spatial multiplexing with cyclic delay diversity)

The signaling worksheet is shown in figure 34. In the case of Sonera’s SIM attach to network, download and detach and attach to the network processes are performed. This information about the process is extracted from Layer 3 Messages and is the same procedure for both SIMCards. The process start with a request of an RRC connection and security process from the UE. After that, depending on the service requested, different actions are performed.

For example, in the download of the file, the E-UTRAN is constantly requesting the position because since it is downloading a file, the power level must be maintained in case a handover is needed. The UE sends this information with a measurement report. The following window shows the different packets sent and the channels of Layer 3 seen in figure 34. There are two main cases to be explained, attach to the network and the download processes.

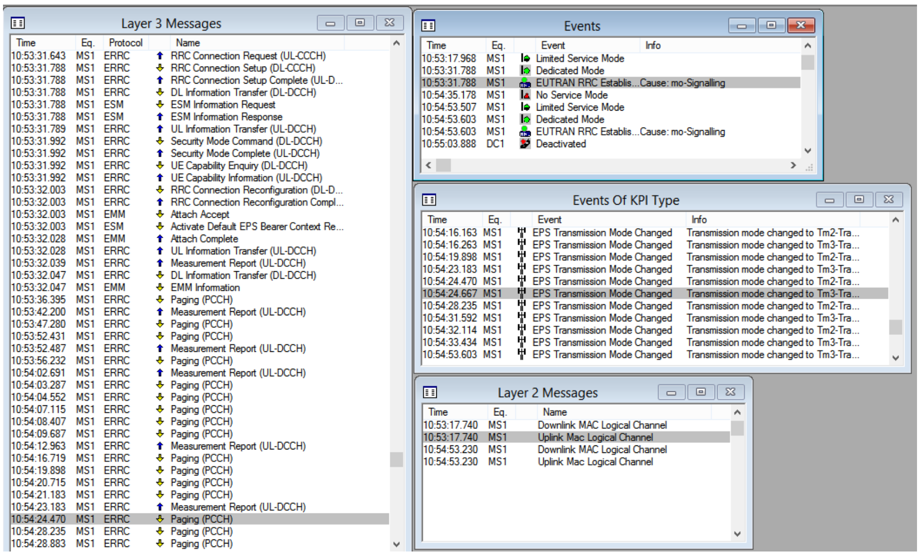


Figure 34. Signaling worksheet in Sonera

Attach to network

Figures 35, 36, 37, 38 and 39 represent the signaling messages exchanges in the processes explained. For the different processes, the signaling messages will be described and then a figure to illustrate the procedure.

- Attach Request - Message within RRC CONNECTION SETUP COMPLETE message.
- PDN Connectivity Request – The Packet Data Network connectivity procedure is used by the UE to request the setup of a default Evolved Packet System bearer to a PDN.

Figure 35 represents the attach request and PDN Connectivity request messages, sent from the UE to the network.

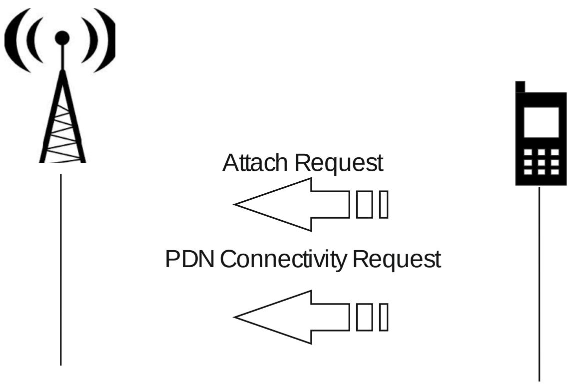


Figure 35. Request from UE to the network

Then the process with an RRC connection request:

- RRC Connection Request (UL-CCCH) (Common Control Channel) - UE requests an RRC connection via CCCH.
- RRC Connection Setup (DL-CCCH) – The network establishes the Signaling Radio Bearers and Data Radio Bearers based on the establishment cause.
- RRC Connection Setup Complete (UL-DCCH) – UE acknowledges the setup with SRB and DRB

Figure 36 describes the signaling messages explained above, from the location to the terminal and vice versa, to establish the RRC connection.

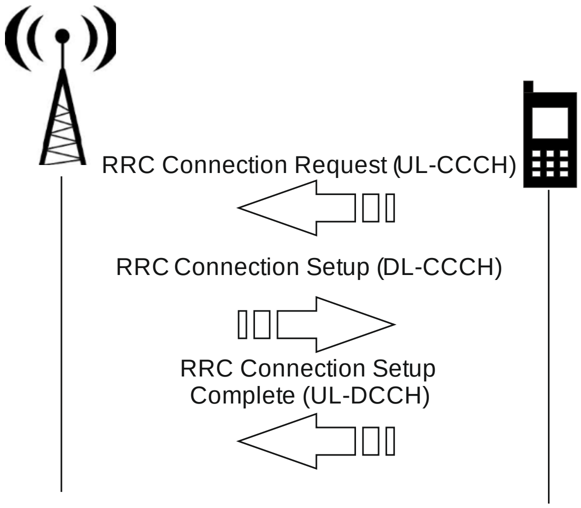


Figure 36. RRC Connection establishment

After the RRC connection establishment, an identity request is necessary:

- Identity Request - The identification procedure is used by the network to request a particular UE to provide specific identification parameters, e.g. IMSI, IMEI etc.
- Identity Response – The response from the UE with the information required by the E-UTRAN.

Figure 37 represents the signaling message sent by the network to request the identity and the response of the terminal.

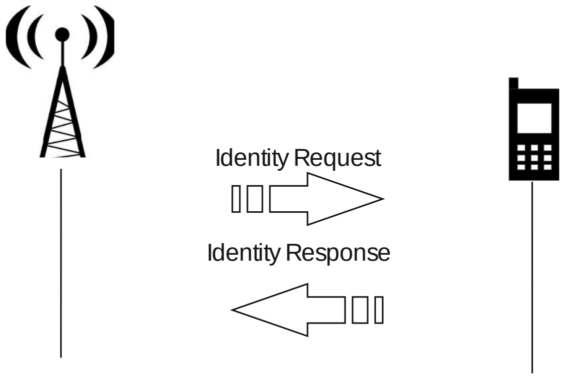


Figure 37. Request of the identity of the terminal

Then continuing with the process, the security mode is performed:

- Security Mode Command (DL-DCCH) – E-UTRAN command the UE for the activation of Access Stratum security. Obviously, it happens after the establishment of SRBs and DRBs.
- Security Mode Complete (UL-DCCH) – The UE confirms the completion of Security Mode Command.

Figure 38 describes the signaling messages explained above, from the location to the terminal and vice versa, to establish the security mode.

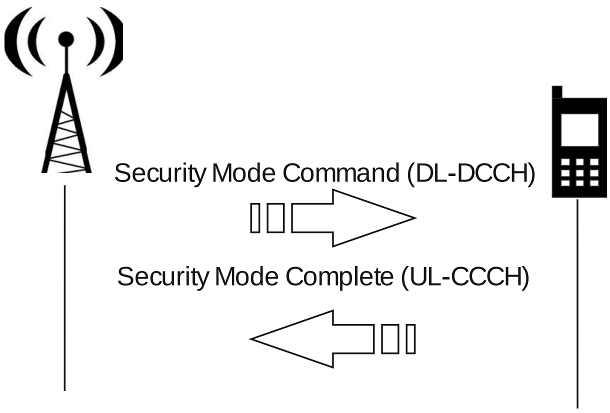


Figure 38. Security mode establishment

After the security mode the remaining enquiries:

- UE Capability Enquiry (DL-DCCH) - The UE CAPABILITY ENQUIRY message is used to request the transfer of UE radio access capabilities for E-UTRA as well as for other RATs (UTRA, GERAN-CS, GERAN-PS, and CDMA2000)

- UE Capability Information (UL-DCCH) – The UE CAPABILITY INFORMATION message is used to transfer of UE radio access capabilities requested by the E-UTRAN in UE CAPABILITY ENQUIRY.

Figure illustrates the process explained above, the direction of the signaling messages.

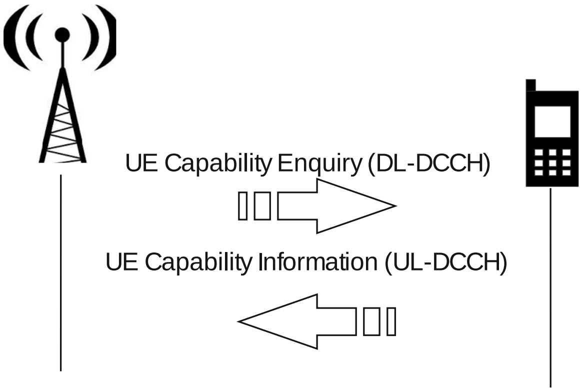


Figure 39. UE Capabilities request

Finally the last signaling messages.

- Attach Accept - The attach request has been accepted by the E-UTRAN.
- Activate Default EPS Bearer Context Request – The purpose of the default bearer context activation procedure is to establish a default EPS bearer context between the UE and the EPC.
- Paging (PCCH) – For paging UE whose location is not known to the network.

Download of a file

Since the RRC connection is described above, only the measurement report from the UE as result of the request needs to be explained:

- Measurement Report (UL-DCCH) – The UE sends a report of measurement about the power of the received signal to inform if a change of serving cell is needed.

Finally, to finish the analysis of the information, the last remaining information to know are the performance of LTE, the data rate of both technologies in both operators, LTE and HSPA for Sonera and Elisa. The data rate of HSPA is also included to provide more proofs about the high performance of LTE compared to the 3G technology.

Table 8. LTE Throughput comparison

	Sonera	Elisa
PDCP DL Throughput (Mbit/s)	50.01	51.02
RLC DL Throughput (Mbit/s)	51.2	51.4
PDSCH Physical Throughput (Mbit/s)	53.2	51.5

As seen in table 8, about the LTE throughput comparison, the data rates shown are PDCP DL throughput, RLC DL throughput and the PDSCH Physical Throughput. Concerning the DL throughput, the lower the layer, the higher the DL throughput. To finish the analysis, as seen in figure 36, using the Android application “Speedtest.net” from the *Ookla* developer, the analysis done is very similar to the data shown in figure 40.

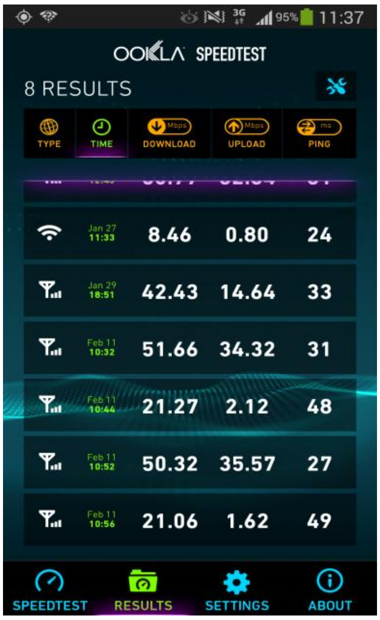


Figure 40. Screenshot from Samsung Galaxy S4

6.3.2 Drive Test Analysis

This analysis is very similar to the fixed-location measurement but instead of comparing two different operators, the drive was only done with Elisa’s SIMcard since the results were supposed to be almost equal. The main goal of the drive test was check is the LTE cells are available all over the area, not to compare both operators as in the fixed-location measurement.

At a certain moment, LTE mode was not available and an intersystem handover to HSPA was performed. As shown in figures 35 and 36, the system mode changed from LTE to WCDMA, from 14:52:51.034 to 14:56:29.819 where the functional mode was WCDMA. In WCDMA mode is easy to distinguish the different handovers checking the Serving/Active set + Neighbors Common Pilot Channel Received Signal Code Power

(SAN CPICH RSCP) of the cell. As seen in some particular points in the chart, the SAN CPICH RSCP is decreasing until the drop threshold where the handover is done.

As seen in the Events window from the “Signaling” worksheet it is possible to check the different handovers that occurs during the train trip. There are two different handovers in WCDMA, intra-frequency and inter-frequency. During the intra-frequency handover, the UE stays in the same frequency and just switches to another cell, while within the inter-frequency handover both changes are needed. Figures 37, 39 and 41 illustrate both swaps and checking the LTE Serving Cell window is quite easy to see how the serving cell identity is different in figures 38, 40 and 42 but only during the inter-frequency handover the frequency changes.

Figures 41 and 42 illustrate the first stage of the handover

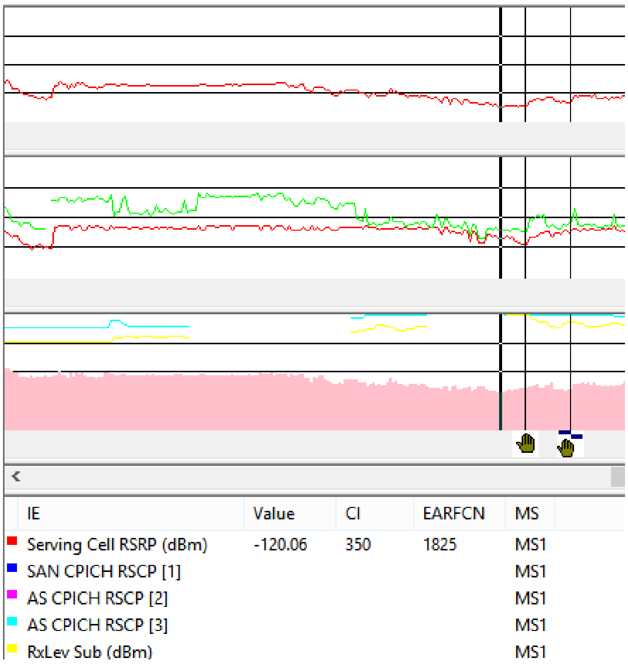


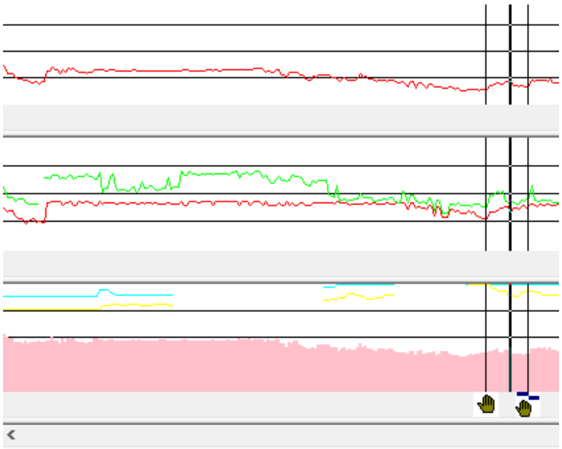
Figure 41. Handover first stage

Figure 42 is the information concerning the first cell during the two handovers.

IE	Value
Serving Cell Identity	350
Serving Cell RRC Cell Identity	443138
Serving Cell Name	
Serving Cell MCC	
Serving Cell MNC	
Serving Cell TAC	29053
Serving Cell DL Bandwidth	15 MHz (75 RB)
Serving Cell DL EARFCN	1825
Serving Cell UL EARFCN	19825
MME Group Id	2432
MME Code	5

Figure 42. First cell in the process

Figures 39 and 40 show the new serving cell, but with the same frequencies, which implies an intra-frequency handover.



IE	Value	CI	EARFCN	MS
Serving Cell RSRP (dBm)	-105.75	114	1825	MS1
SAN CPICH RSCP [1]				MS1
AS CPICH RSCP [2]				MS1
AS CPICH RSCP [3]				MS1
RxLev Sub (dBm)				MS1

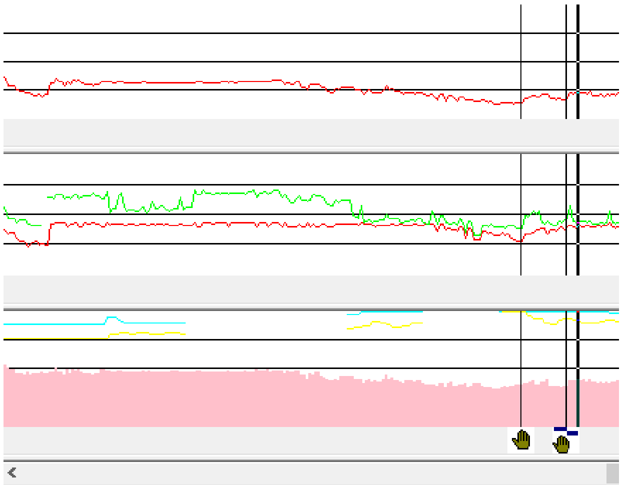
Figure 43. Handover second stage

Figure 44 is the information concerning the first cell during the two handovers.

IE	Value
Serving Cell Identity	114
Serving Cell RRC Cell Identity	284930
Serving Cell Name	
Serving Cell MCC	
Serving Cell MNC	
Serving Cell TAC	29053
Serving Cell DL Bandwidth	15 MHz (75 RB)
Serving Cell DL EARFCN	1825
Serving Cell UL EARFCN	19825
MME Group Id	2432
MME Code	5

Figure 44. Second cell in the process

And finally the inter-frequency is shown in the last two figures, as seen in figures 42 and 44, the serving cell and the frequencies are different from the previous figures.



IE	Value	CI	EARFCN	MS
Serving Cell RSRP (dBm)	-103.13	50	3300	MS1
SAN CPICH RSCP [1]				MS1
AS CPICH RSCP [2]				MS1
AS CPICH RSCP [3]				MS1
RxLev Sub (dBm)				MS1

Figure 45. Handover final stage

Figure 46 is the information concerning the first cell during the two handovers.

Serving Cell Identity	50
Serving Cell RRC Cell Identity	68099
Serving Cell Name	
Serving Cell MCC	
Serving Cell MNC	
Serving Cell TAC	29053
Serving Cell DL Bandwidth	20 MHz (100 RB)
Serving Cell DL EARFCN	3300
Serving Cell UL EARFCN	21300
MME Group Id	2432
MME Code	5

Figure 46. Last cell in the process

Those handovers can be also seen in the "Signaling" worksheet, in the list of events. Every time the threshold for the power level is overtaken, a handover is performed in order to keep the quality of the signal. In figure 47 it is possible to check how the power level is overtaken.

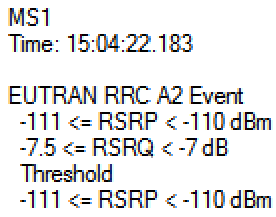


Figure 47. Powel level overtaking the thresholds

Another fact shown in figures 44 and 46 about the LTE serving cells is that the bandwidth is not the same as the previous measurement case. It changes between 15 MHz and 20 MHz, which is directly proportional to the amount of RBs granted to the UE.

Finally, about the data in the drive test, in this case the throughput line chart is completely different. At the beginning of the streaming, a high peak is detected and then during the whole video a low data rate is maintained, as seen in figure 48, with some isolated peaks. The seamless data flow is not needed during the streaming because of the buffering; the UE is capable of storing the data and then showing the video. Regarding the next two figures, in the first one a high peak appears at the beginning of the streaming to load in the buffer a large amount of data in order not to need a constant data flow. In figure 49 it can be perceived how periodically a big peak of data rate is detected because the buffer is getting emptier so sometimes a data flow is required periodically.

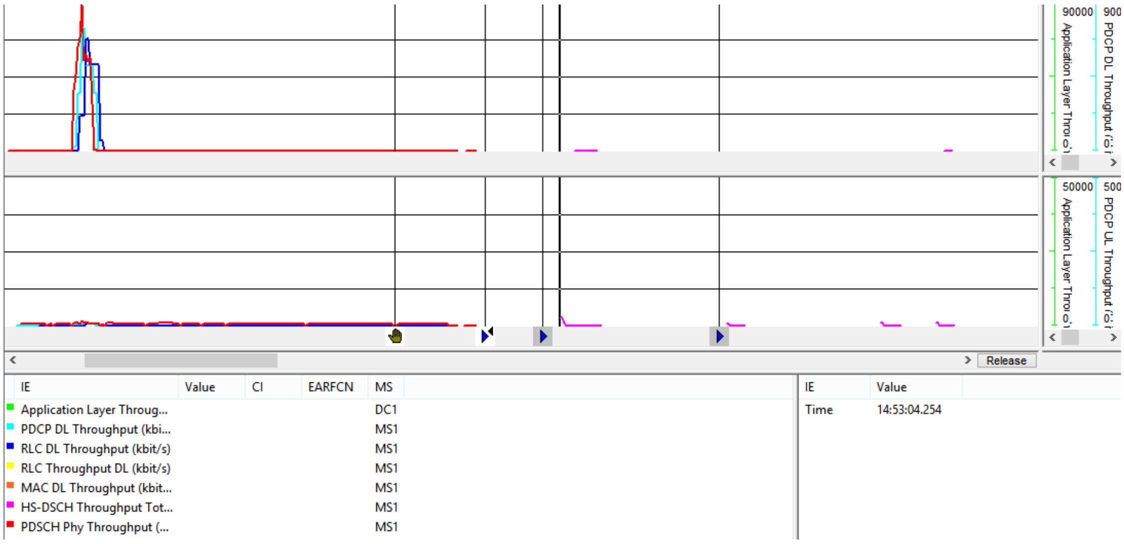


Figure 48. Throughput Line Chart at the beginning

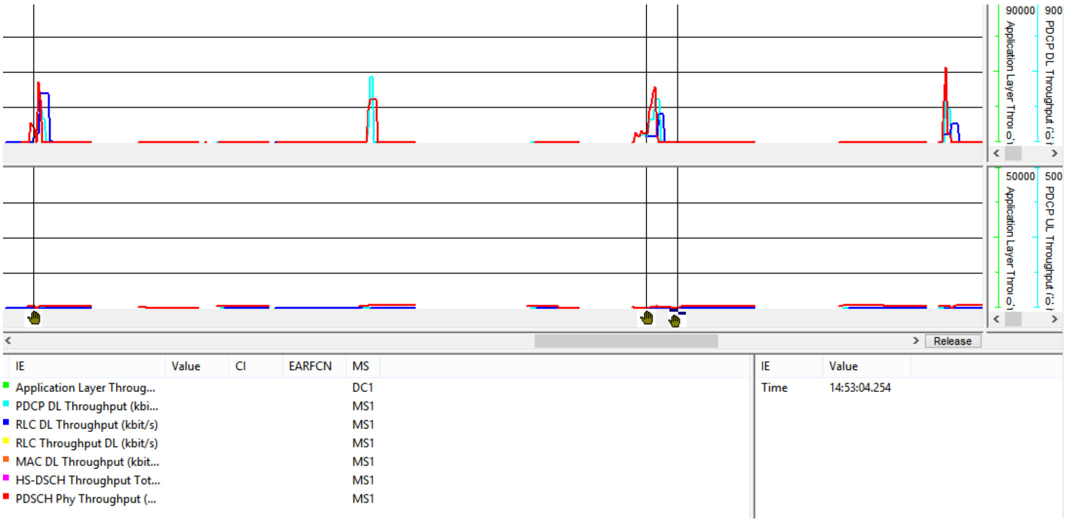


Figure 49. Throughput Line Chart at a time in the measurement

As seen in figures 48 and 49, the high peak at the beginning and the periodic downloads are appreciated.

6.4 Summary of the Results

First, starting with the fixed-location measurement case, an overview shown in the first worksheet analyzed. There are three comparisons in this worksheet, the LTE Serving Neighbor Cell Line Chart, the parameters of the LTE serving cell and the parameters of the LTE radio access. Table 5 provides basically a comparison between the power of the signal received in the UE and the CINR received. Comparing both results, as seen in table 5, the power received in the place where the measurements were taken, Sonera seems to provide more RSRP and RSSI compared to Elisa. The difference between those two values, -58.88 dBm and -75.13 dBm, can be easily explained with the distance of the cell: the further the cell is, the less powerful the signal is. Finally, the RS CINR, 25 dB for Sonera and 22 dB in Elisa, as seen in table 4 is basically the SNR and it can be concluded that the signal has a quite good quality, being 30 dB, the best quality possible.

Table 6 represents all the information about the parameters of the serving cell LTE. Some similarities were found between the measurement with Elisa and Sonera as expected. Both measurements where done with 20 MHz as expected taking into account the technology used. Another feature but not very important similarity is the Mobile Country Code, 244, which belongs to Finland. Concerning the frequencies, both operators in this location with the terminal used for the measurement are working in the LTE band 3, around 1800 MHz, even though in Finland there are 2 more usable band, the number 7 and 20, 2600 MHz and 800 MHz, this last one only for Elisa [17].

Finally, the last table about this worksheet is the LTE radio parameters of the serving cell. As seen in table 7, both operators use the FDD duplex mode. The reason that FDD is used at the expense of TDD is because FDD is widely implemented and it uses the spectrum more efficiently than FDD, without idle times where either the terminal or base station do not transmit.

Moving to the drive test, as suspected and lately confirmed in subsection 6.3.2, the results were quite similar to the fixed-location measurement but with a few changes. The main point of this measurement was to confirm that the connection remained stable during the entire train trip and check to the procedures of the different handovers. As mentioned before in the subsection 6.3.2, the UE performs handovers during the train trip, even an inter-system handover from LTE to WCDMA. However, the connection was never lost during the train trip.

Concerning the data rates, obviously due to buffering, the non-continuous data flow helps to save resources to E-UTRAN since the UE just needs a little time to get all the data and store it in the buffer and not the seamless data flow.

7 Conclusion

The main goal of this project was to study the performance of LTE, to check and confirm the improvement of the mobile communication in the last ten years. Starting with the results of the fixed-location measurement and reviewing the data about both operators it is easy to come to this conclusion:

- Sonera seems to provide better quality of signal than Elisa probably because of the distance between UE and base station.
- Sonera's antenna performed diversity and MIMO so it seemed to provide better services than Elisa in worse conditions of interferences, fading or multipath.
- In the same way as LTE, the performance of HSPA in Sonera was somewhat better than in Elisa.

The next step in this project was the drive test. The goal to achieve in this case was to confirm that the connection remained stable and to check out the different handovers performed. As expected, extracting and analyzing the data it is possible to conclude:

- The connections were never lost on the train trip, even though an inter-system handover occurred due to the unavailability of LTE in some specific cells. Also, it was quite easy to know when the handover was about to happen just by checking the power level of the signals received.

An interesting point in this case was that now was not always possible to maintain a connection with 20 MHz of bandwidth, probably due to the high mobility of the train, since the train's speed was around 60 and 100 km/h, at its maximum peak.

- Finally, about the measurement, as it was made with a streaming video, the UE was not always requesting data to the E-UTRAN, so in that case, the resources were not reserved all the time by the UE.

This project was carried out to confirm the better performance of LTE compared to HSPA. LTE is one of the most influential technologies in the daily life of everyone. The goal of this study was to give a new point of view about the performance of the new technology using an industry leading tool such as TEMS Investigations. There are plenty of studies about LTE, about its data rate and performance but not so many handling drive tests on a train in Finland.

Regarding the software, TEMS Investigations, there was at the same time an advantage and a disadvantage within this project, because since the beginning there were plenty of problems with the installation and the license, as well as with the workstation. After fixing all the issues, a conclusion was made that a workstation without any security software about networks was required. However, without this tool the measurement and the consequent analysis would have been much harder and not very precise. It is well known that not every phone is capable of having an LTE connection, Nowadays there are just a few phones able to use this new technology. Specifically in this project, due to the availability of the Samsung Galaxy S4 it was not needed to acquire a new terminal, which would have implied more funding.

To summarize, without the issues with the license and the workstation, the measurements could have been finished sooner and faster. For the next measurement case, to make a better analysis, the same measurement cases, fixed-location and drive could be taken, but using the three main operators in Finland, Sonera, DNA and Elisa in more locations and regarding the drive, more routes in other areas such as Vantaa or Kontula should be done and with those three operators. For further and deeper studies I strongly recommend to carry out a new measurement case. Another suggested study could be the research of the fifth generation (5G) of mobile communications, the new standard that promises an instantaneous speed, with no delay while browsing or using any application. However, since 5G is still only theory, as expected a measurement would be impossible to perform.

References

[1] History | About Us (GSMA) [homepage on the Internet]. London: gsma.com; 2011- [updated 2011]. URL: www.gsma.com/aboutus/history. Accessed 4 June 2014.

[2] Kumar A, Liu Dr. Y, Sengupta Dr. J, Divya. Evolution of Mobile Wireless Communication Networks: 1G to 4G. IJECT. 2010; volume 1: 68-72

[3] ETSI - GPRS [homepage on the Internet]. Sophia Antipolis: etsi.org; 2014 URL:http://www.etsi.org/index.php/technologies-clusters/technologies/mobile/gprs. Accessed 17 January 2014.

[4] Ehrlich N. The Advanced Mobile Phone Service. IEEE Comm. Magazine. 1979: 9-15.

[5] H.Blecher F. Advanced Mobile Phone Service, IEEE Trans. on Vehicular Tech.May 1980; volume 2: 238-244.

[6] Harte L. Introduction to Mobile Telephone Systems.2nd ed. ALTHOS. 2006

[7] Herradón Diez R. Comunicaciones móviles digitales. Madrid, Spain. Departamento de Ingeniería Audiovisual y Comunicaciones E.T.S.I.S.T., UPM. 2009

[8] Patil CS, Karhe RR, Aher MA. Review on Generations in Mobile Cellular Technology. IJETAE. 2012; volume 2: 614-618.

[9] Halonen T, Romero J, Melero J. GSM, GPRS and EDGE Performance. 2nded.Cornwall, England. Wiley. 2003

[10] Dahlman E, Parkvall S, Sköld J, Beming P. 3G Evolution HSPA and LTE for Mobile Broadband. 2nd ed. Cornwall, England. Academic Press. 2008.

[11] TSG RAN [homepage on the Internet]. Sophia Antipolis: 3gpp.org; 2014 URL: http://www.3gpp.org/specifications-groups/ran-plenary

[12] “3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (Release 7)” 3GPP, 3GPP TR 25.913.

[13] Rumney M. LTE and the Evolution to 4G WirelessDesign and Measurement Challenges. 2nd ed. Singapore.Wiley. 2013

[14] TEMS™ Investigation [homepage on the Internet]. TEMS™ Investigations Options [online]. URL: http://www.ascom.com/nt/en/index-nt/tems-products-3/tems-investigation-5.htm#tab3. Accessed 11 March 2014.

[15] “Mobile Network Codes (MNC) for the international identification plan for public networks and subscriptions”, ITU-R, Recommendation ITU-T E.212

[16] “3rd Generation Partnership Project; Technical Specification Group Radio Access Network Working Group 4; Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 11)” 3GPP, 3GPP TR 36.101.

[17] Elisa awards LTE rollout contract to NSN; launches LTE-800 [homepage on the Internet]. TeleoGraphy. San Diego, USA. telegeopraphy.com; [updated 24 January 2014]. URL http://www.telegeography.com/products/commsupdate/articles/2014/01/24/elisa-awards-lte-rollout-contract-to-nsn-launches-lte-800/. Accessed 17 March 2014.

[18] Commuter service route map - VR [homepage on the Internet]. VR. Helsinki, Finland. vr.fi; [updated daily] URL: http://www.vr.fi/en/index/aikataulut/asemien_aikataulut/paakaupunkiseudun_asemat.html. Accessed 20 March 2014

Measurement Case

The aim of this project is to analysis the wireless communication network using the industry-leading tool called TEMS- Investigation and Data Collection 15.3. The project is carried out in the regions of Espoo and Helsinki, Finland. Creating log files for testing data rate of LTE and finally analyzing those log files.

Requirements

The following devices and software are needed for successful completion of the project.

i) TEMS Investigation 15.3:
It is the main requirement of the project, a network analyzer of LTE. It is able to handle every features of LTE/4G mobiles network analysis. And naturally, the proper license for the software

ii) Work station:
A workstation/laptop is required for this project to run the specified software. In this case, the laptop of the person who is going to carry the project.

iii) Mobile terminal:
Since project is a terminal side measurement for data rate, mobile device is required for the project. As per agreement, it was decided to use Samsung Galaxy S4/LTE model for the project which supports every LTE features.

TEMS is industry-leading air interface test tool that provides high quality indoor and outdoor measurements of devices used by the subscribers, location and drive test based measurement. TEMS can illustrates information about the air interface that the UE knows and stores it in a logfile. The setup done to make the measurement is described in Figure. The setup for this measurement is illustrated in Figure.

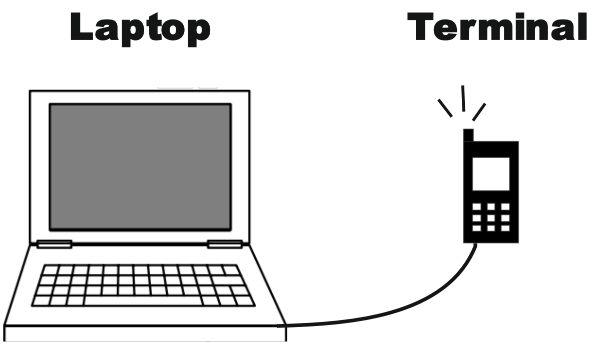


Figure 50. Setup used for measurement

Fixed-location measurement

The location chosen for the fixed-location measurement is the region of Espoo. As shown in the next figure, with Elisa, the chosen service provider, the zones with LTE coverage are not so many. The area selected for the measurement is Leppävaara, more specifically the Sello Shopping Mall, figure 51 and 52 for both Sonera and Elisa, since it is well known that in the big shopping malls, plenty of cells are needed to provide users with service.

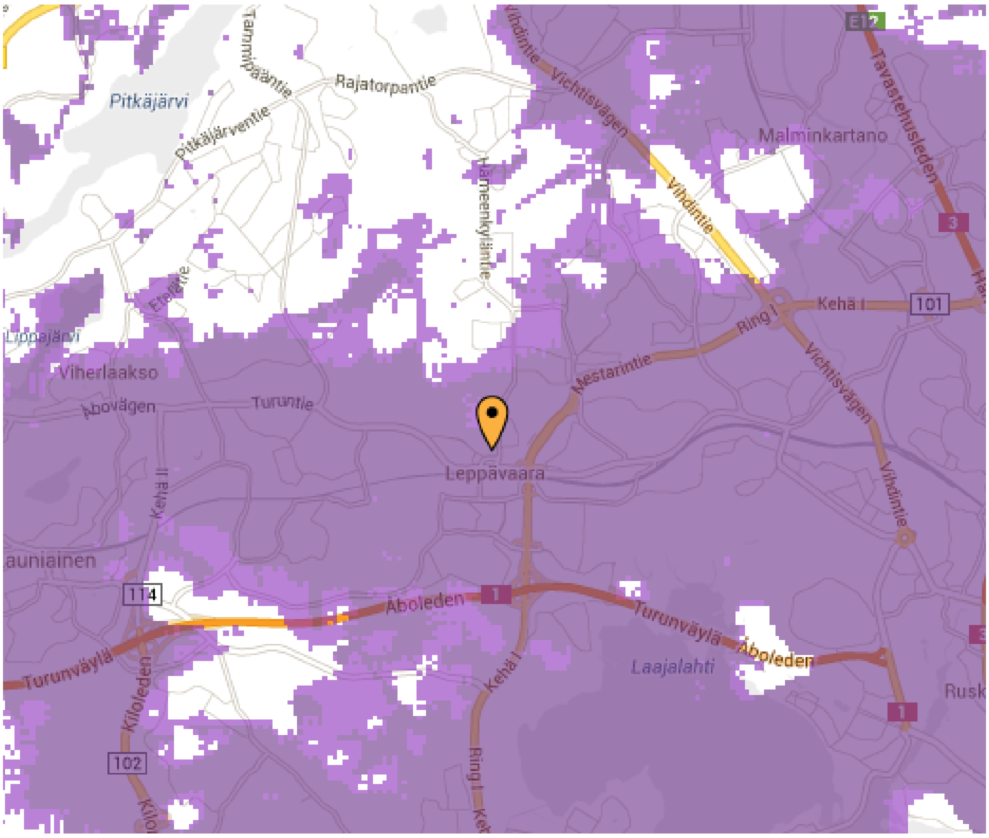


Figure 51. Coverage of Sonera in Leppävaara

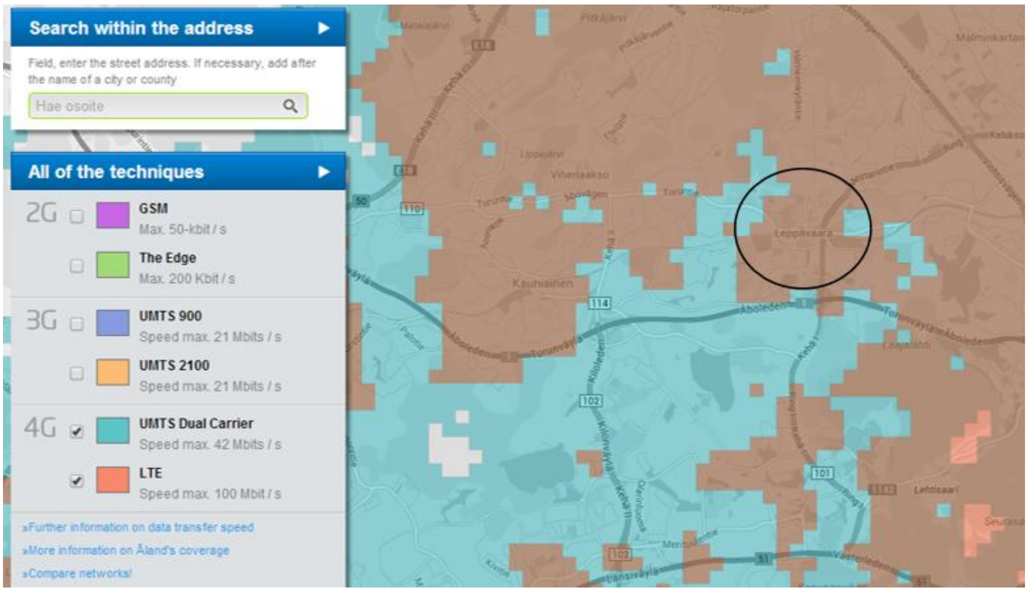


Figure 52. 4G Coverage of Elisa in Leppävaara

Drive test measurement

The drive test consists in a measurement done while the terminal is moving, in this case specifically between two locations, Leppävaara and Helsinki, which journey is shown in figure 54 from the official website of public transportation in Finland [18]. The chosen transport is the commuter train, the A train, which route is shown in figure 53. The measurement will be taken while the terminal is playing a video on streaming to try to maintain a constant data flow in the whole train trip. The URL of the video is the following one, is a video about a TED conference.

Video: https://www.youtube.com/watch?v=yVwAodrjZMY

Figure 53. Route of A train

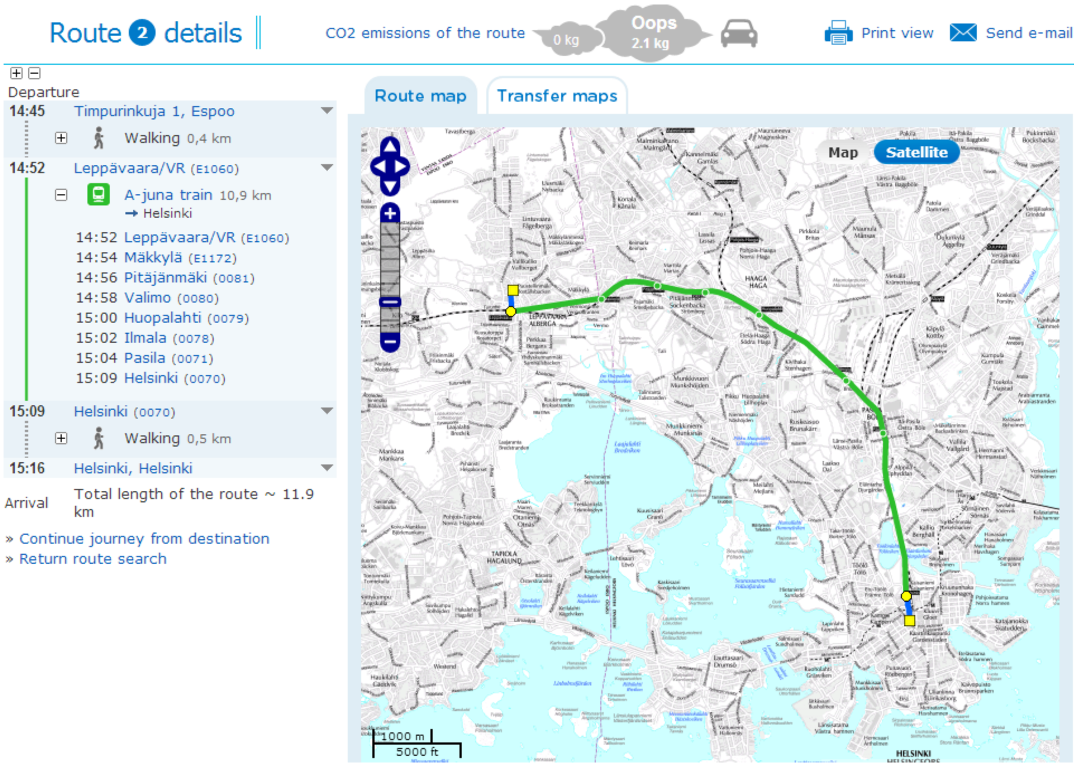


Figure 54. Plan of the journey in the A train

Task to be done

This project is entitled to measures the data rate of two different service providers. To find it out it is necessary the use of USIM and TEMS software with the help of browsing and downloading techniques. The following tasks are specified for the process.

i) Web Server:

To measure the data rate a file is going to be downloaded from the web-site http://www.dropbox.com. To the personal account of the trainee a large file, a WinRAR archive with photos, 261211 KB size, will be uploaded so afterwards this file can be downloaded and create the log files.

ii) Speed Test via App:

Once the measurement plan for field study is done it is needed to check the data rate of LTE with an application in order to compare reliability of our result. The chosen application is Speedtest.net from the OOKLA Developer, downloaded from the official Play Google, official apps store from Android.

Concerning the fixed-location measurement, it will be done with LTE connection and also with HSPA connection, in order to compare the both data rates from each generation and finally get a better conclusion about the performance. Finally, related to the drive test, the main goal of this case is to study how the terminal behave about the changes of the serving cells, concerning the cells that are providing services to the terminal and the types of transmissions used in the connections.

Assignment for 4G: Long Term Evolution

Answer briefly to the questions about the given log file “Test Sonera LTE.trp”, which was recorded with TEMS Investigations 15.3. TEMS Investigations is an industry-leading tool to analysis the wireless communication network such as HSPA or LTE amongst others.

TEMS is industry-leading air interface test tool that provides high quality indoor and outdoor measurements of devices used by the subscribers, location and drive test based measurement. TEMS can illustrates information about the air interface that the UE knows and stores it in a logfile. The setup done to make the measurement is described in Figure. Figure illustrates the connection that has to be done to perform a measurement with TEMS.

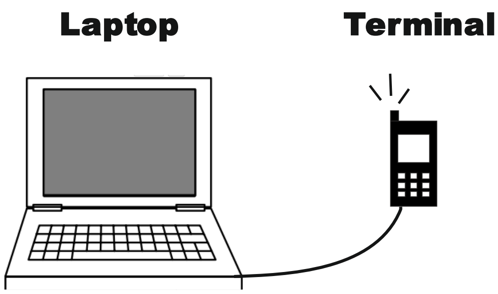


Figure 55. Setup for TEMS Software

After opening TEMS, there are three main worksheets where all the information asked in the assignment can be found. Those three worksheet are called Overview, Signaling and Data, shown in figures 56, 57 and 58.

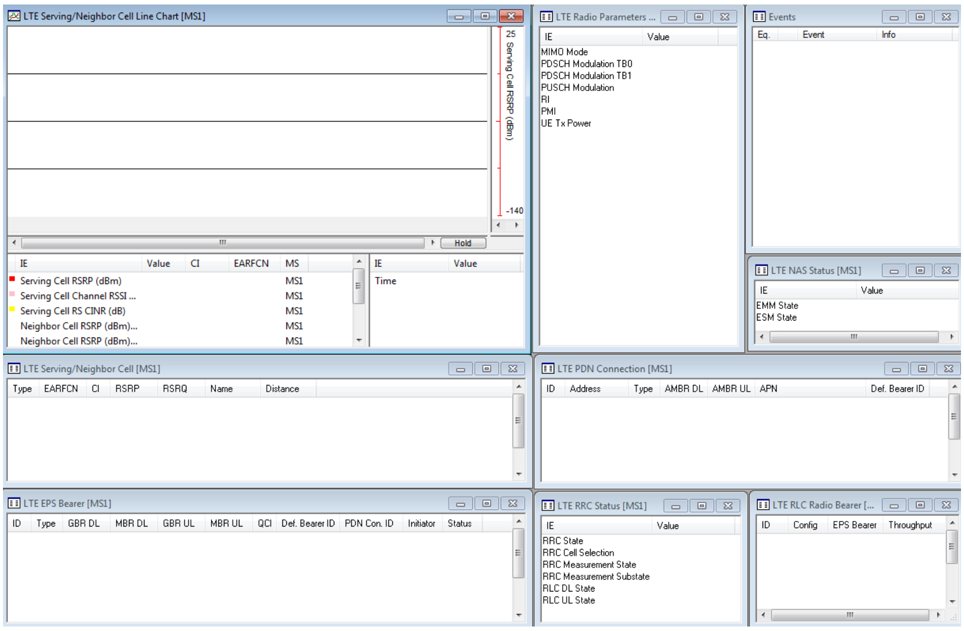


Figure 56. Overview worksheet

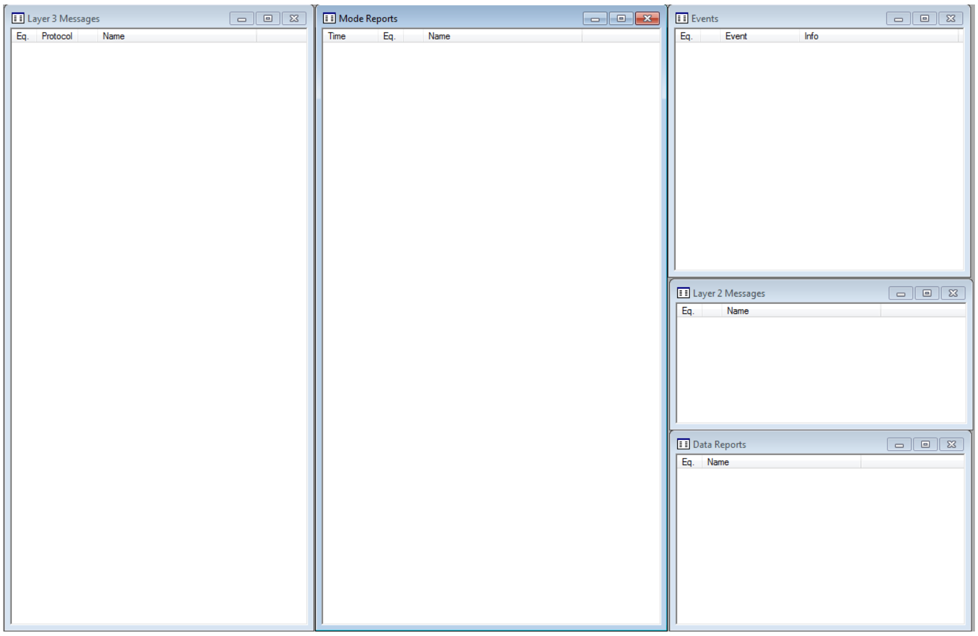


Figure 57. Signaling worksheet

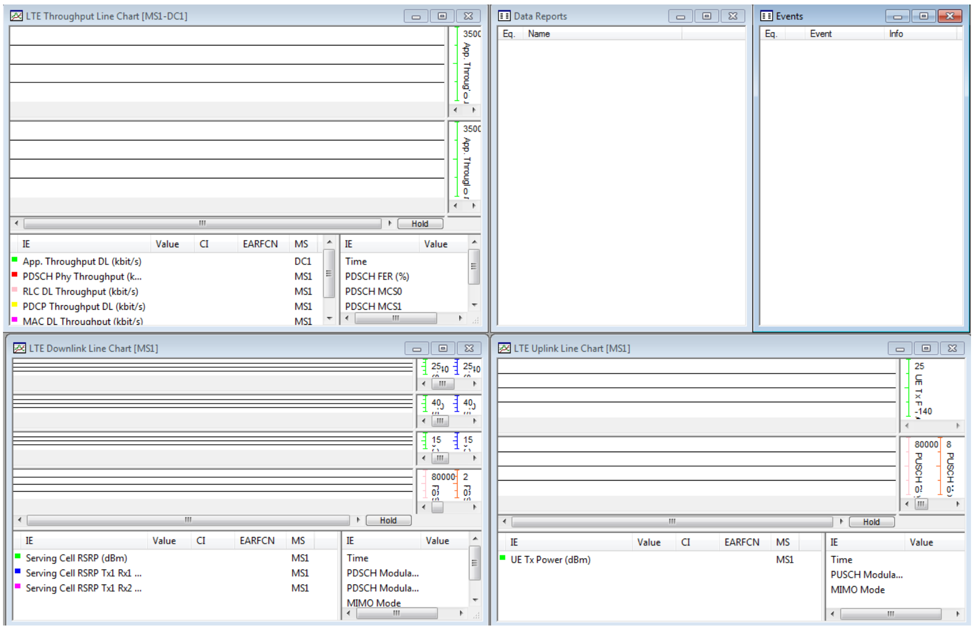


Figure 58. Data worksheet

Questions

1. What actions have been performed in the log file? (Calls, downloads, SMS…)
2. Explain briefly the process in the download.
3. Explain briefly the radio access process during the attach connection, when the phone is deactivating the flight mode.
4. Which one is the maximum user throughput of the user for DL?
5. Which company and country are providing service to the terminal? Explain the source of the information, do not use the map.
6. Which is the bandwidth of the serving cell?
7. Which are the frequencies for UL and DL in the serving cell?
8. List the remaining the parameters.
9. List the radio parameters of the log file.
10. Is MIMO been used in this screenshot? If affirmative answer, specify which one.

Answer to the Assignment 4G

1. This information can be in the “Events” window in the “Signaling” worksheet. This log file is performing flight mode, attach to network, download and detach and attach to network.

2. Can be found in the “Signaling” worksheet, in the “Layer 3 Messages” and “IP Protocols Reports” windows.

Steps in the file download

- Service Request – Is a message is sent by the UE to the network to request the establishment of a NAS signaling connection and of the radio and S1 bearers. The UE is requesting the download.
- RRC Connection Request (UL-CCCH) (Common Control Channel) - UE request RRC connection via CCCH.
- RRC Connection Setup (DL-CCCH) - Network establishes the Signaling Radio Bearers and Data Radio Bearers based on the establishment cause.
- RRC Connection Setup Complete (UL-DCCH) – UE acknowledged the setup with SRB and DRB. The process of RRC Connection is illustrated in figure 59.

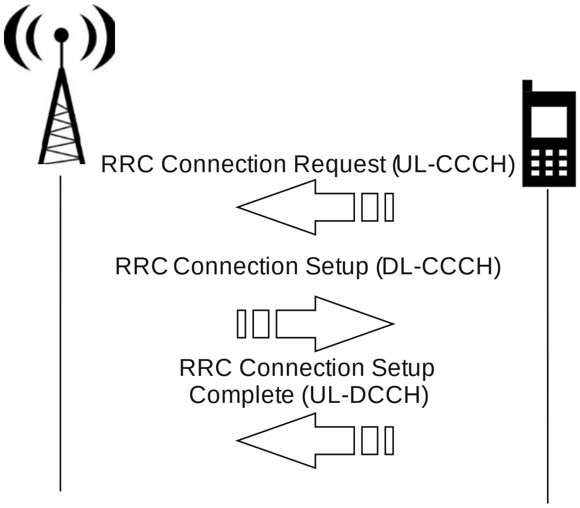


Figure 59. RRC Connection procedure

- Security Mode Command (DL-DCCH) – E-UTRAN command the UE for the activation of Access Stratum security. Obviously, it happens after the establishment of SRBs and DRBs.

- Security Mode Complete (UL-DCCH) – The UE confirms the completion of Security Mode Command. This process represented in figure 60.

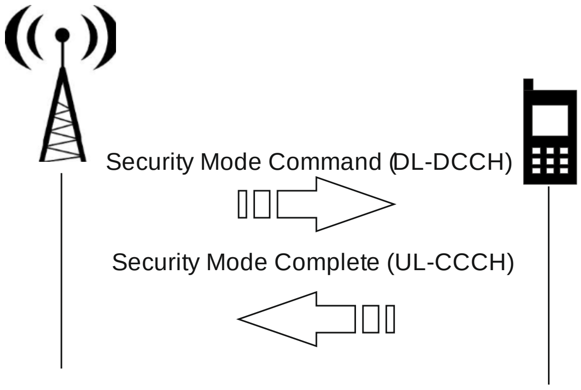


Figure 60. Security Mode procedure

- RRC Connection Reconfiguration (DL-DCCH) – Message from the E-UTRAN to modify the current RRC connection, such as:
  - To establish/modify/release Radio Bearers
  - To perform Handover
  - To setup/modify/release Measurements
  - To add/modify/release Secondary Cells
  - Dedicated NAS Information might also be transferred from eNodeB to UE
- RRC Connection Reconfiguration Complete (UL-DCCH) – Confirm the previous operation by the UE. The process is described in figure 61.

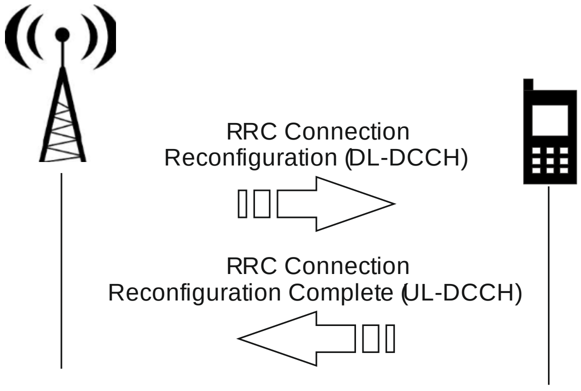


Figure 61. RRC Connection Reconfiguration procedure

- Paging (PCCH) – For paging UE whose location is not known to the network.
- RRC Connection Release (DL-DCCH) – The previous RRC connection is release

3. Can be found in the Signaling worksheet, in the “Layer 3 Messages” window.

Deactivating flight mode

- Attach Request - Message within RRC CONNECTION SETUP COMPLETE message.
- PDN Connectivity Request – The Packet Data Network connectivity procedure is used by the UE to request the setup of a default Evolved Packet System bearer to a PDN.
- RRC Connection Request, Setup, Complete
- DL Information Transfer (DL-DCCH) – To transfer NAS or non-3GPP dedicated information
- Identity Request - The identification procedure is used by the network to request a particular UE to provide specific identification parameters, e.g. IMSI, IMEI etc.
- Identity Response – The response from the UE with the information required by the E-UTRAN.
- ESM Information Request – EPS Session Management information request procedure is used by the network to retrieve ESM information, i.e. protocol configuration options, APN, or both from the UE during the attach procedure if the UE has indicated (in the PDN CONNECTIVITY REQUEST) that it has ESM information that needs to be sent security protected
- ESM Information Response – The response with the required information
- Security Mode Command, Complete
- *Once the RRC connection is complete and the UE identified, the security procedures are done again.*
- UE Capability Enquiry - The UE CAPABILITY ENQUIRY message is used to request the transfer of UE radio access capabilities for E-UTRA as well as for other RATs (UTRA, GERAN-CS, GERAN-PS, and CDMA2000)
- UE Capability Information (UL-DCCH) – The UE CAPABILITY INFORMATION message is used to transfer of UE radio access capabilities requested by the E-UTRAN in UE CAPABILITY ENQUIRY.
- RRC Connection Reconfiguration, Complete
- Attach Accept - The attach request has been accepted by the E-UTRAN

- Activate Default EPS Bearer Context Request – The purpose of the default bearer context activation procedure is to establish a default EPS bearer context between the UE and the EPC.
- Attach complete – Message from the UE
- Information Transfer, UL and DL
- EMM Information - EPS Mobility Management, information about network name, local time, etc.

4. In the "Data" worksheet checking the approximately peak of DL throughput in the chart.
Between 50-60 Mbps in DL in the peaks.

5. In the worksheet "Overview", in the window "LTE Serving Cell", searching the information about the "Serving Cell MCC" (Mobile Country Code).
The mobile country code is 244 since the measurement was done in Finland and mobile network code is 91 because of the network used, TeliaSonera Finland Oyj.

6. In the "Overview" worksheet, in the "LTE Serving Cell" window.
20 MHz.

7. In the "Overview" worksheet, in the "LTE Serving Cell" window, searching information about the EARFCN. The formulas are FDL = FDL_low + 0.1(NDL – NOffs-DL) and FUL = FUL_low + 0.1(NUL – NOffs-UL)

  - Sonera -> DL = 1815 MHz and UL = 1720 MHz

8. In the "Overview" worksheet, in the "LTE Serving Cell" window
Mobility Management Entity used to allocate a Globally Unique Temporary Identity (GUTI) to the UE. MME Identifier (MMEI): MME Group Id (MMEGI) and MME Code (MMEC)

9. In the “Overview” worksheet, in the “LTE Radio Parameters” window. Mention also that those parameters change along the connection, not always is using MIMO and in the same way, not the same type of MIMO. The next screenshot is a specific moment in the connection.

IE	Value
Mode (System)	LTE
Duplex Mode	FDD
Transmission Mode	Tm2-Transmit Div
PDSCH Modulation TB0	64QAM
PDSCH Modulation TB1	
PUSCH Modulation	16QAM
RI	1
PMI	0
UE Tx Power	
UE PUSCH Tx Power	10.79
UE PUCCH Tx Power	4.94

Figure 62. LTE Radio Parameters

10. In the “Overview” worksheet, in the “LTE Radio Parameters” window, “Transmission mode”.

Diversity at transmission, as seen in figure 63.

IE	Value
Mode (System)	LTE
Duplex Mode	FDD
Transmission Mode	Tm2-Transmit Div
PDSCH Modulation TB0	64QAM
PDSCH Modulation TB1	
PUSCH Modulation	16QAM
RI	1
PMI	0
UE Tx Power	
UE PUSCH Tx Power	10.79
UE PUCCH Tx Power	4.94

Figure 63. LTE Radio Parameters