INDEX

1 BASICS OF ANTENNA, EM COMMUNICATION, GSM INTRODUCTION AND ARCHITECTURE

1.1 LEARNING OBJECTIVE

This chapter deals with basic antenna theory, structure of antenna , EM Theory. This chapter gives basic idea about frequency and selection of frequency. Also GSM technology is covered in this chapter.

1.2 BASICS OF ANTENNA, EM COMMUNICATION

1.2.1 ELECTRO MAGNETIC WAVES:

Electro Magnetic waves are used for transmission and reception of information in wireless communication .An Electro Magnetic wave consists of an Electrical component and a Magnetic component. The directions of the Electric component, the Magnetic component and Propagation are mutually perpendicular to each other.

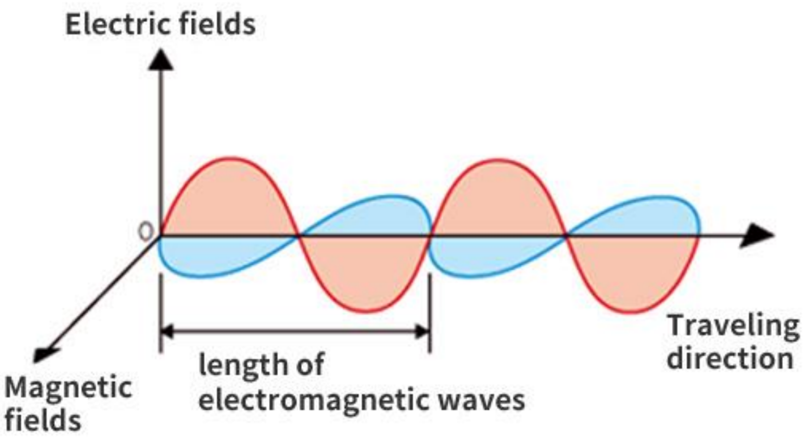


Figure 1: Electromagnetic Wave

A wave consists of successive troughs and crests, and the distance between two adjacent crests or troughs is called the wavelength. Waves of the electromagnetic spectrum vary in size, from very long radio waves of the size of buildings to very short gamma rays smaller than atom nuclei. Frequency of wave is inversely proportional to wavelength, according to the equation:

$$v = f\lambda$$

Where v is the speed of the wave (c in a vacuum, or less in other media), f is the frequency and λ is the wavelength.

Interference is the superposition of two or more waves resulting in a new wave pattern. If the fields have components in the same direction, they constructively interfere, while opposite directions cause destructive interference.

1.2.2 ELECTRO MAGNETIC SPECTRUM:

The electromagnetic spectrum is the entire range of electromagnetic radiation according to the wavelength or frequencies. Electromagnetic radiation is classified into several types according to the frequency of its wave; these types include (in order of increasing frequency and decreasing wavelength): radio waves, microwaves, terahertz radiation, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

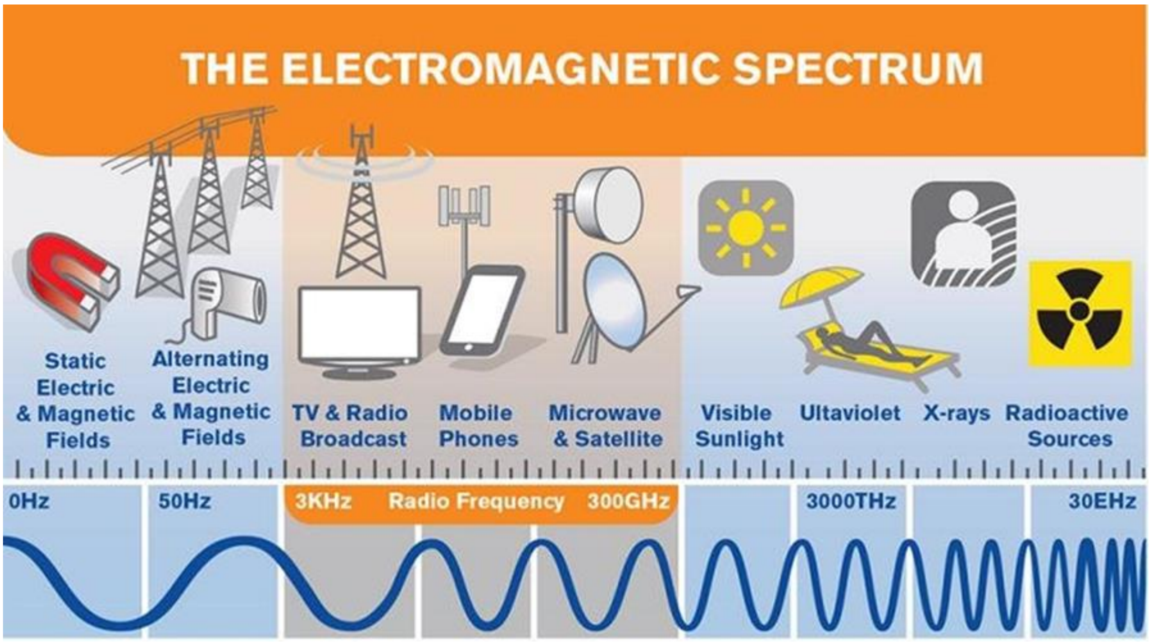


Figure 2: The Electromagnetic Spectrum

1.2.3 RADIO WAVE

The radio spectrum is the part of the electromagnetic spectrum with frequencies extending from around 3 kHz to 300 GHz. Electromagnetic waves in this frequency range, called radio waves, are widely used in telecommunication. To prevent interference between different users, the generation and transmission of radio waves is strictly regulated by national laws, coordinated by an international body, the International Telecommunication Union (ITU).

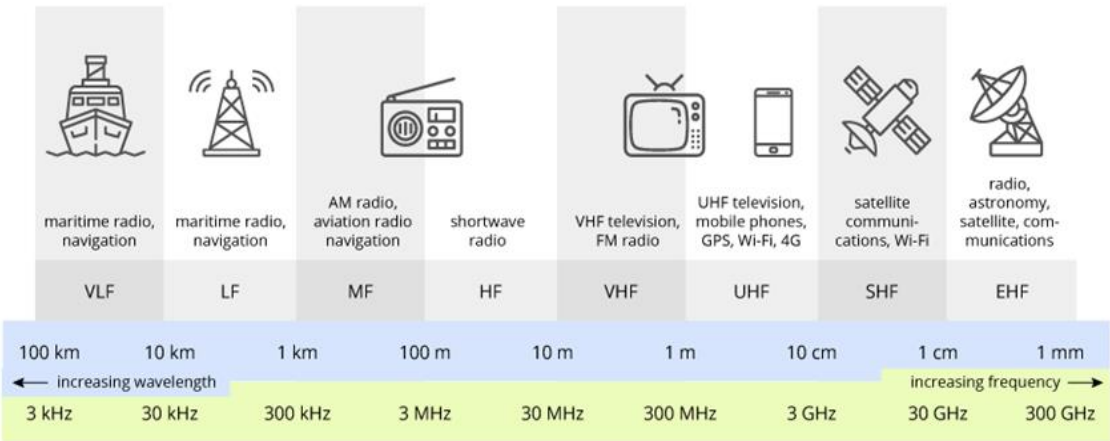


Figure 3: Radio Waves

1.2.4 RADIO FREQUENCY BAND :

Different parts of the radio spectrum (RF bands) are allocated by the ITU for different radio transmission technologies and applications. The ITU divides the radio spectrum into 12 bands as shown in the table below.

Name of Band	Frequency	Wavelength
ELF (Extremely low frequency)	3–30 Hz	105–104 km
SLF (Super low frequency)	30–300 Hz	104–103 km
ULF (Ultra low frequency)	300–3000 Hz	103–100 km
VLF (Very low frequency)	3–30 kHz	100–10 km
LF (Low frequency)	30–300 kHz	10–1 km
MF (Medium frequency)	300 kHz – 3 MHz	1 km – 100 m
HF (High frequency)	3–30 MHz	100–10 m
VHF (Very high frequency)	30–300 MHz	10–1 m
UHF (Ultra high frequency)	300 MHz – 3 GHz	1 m – 10 cm
SHF (Super high frequency)	3–30 GHz	10–1 cm
EHF (Extremely high frequency)	30–300 GHz	1 cm – 1 mm
THF (Tremendously high frequency)	300 GHz – 3 THz	1 mm – 0.1 mm

Table 1. Radio Frequency Bands

1.2.5 WHAT IS AN ANTENNA?

An antenna in the communication system behaves like an interpreter between the transmitter and free space as well as the free space and the receiver.

Antennas are metallic structures designed for radiating and receiving Electro Magnetic waves. Antennas transform wire-propagated waves into space-propagated waves. A receiving antenna receives electromagnetic waves and passes them onto a receiver. A transmitting antenna transmits electromagnetic waves in to space. One side of the antenna is connected to RF cable and the other side it is the environment, therefore the surroundings of the antenna have a strong influence on the antennas electrical features.

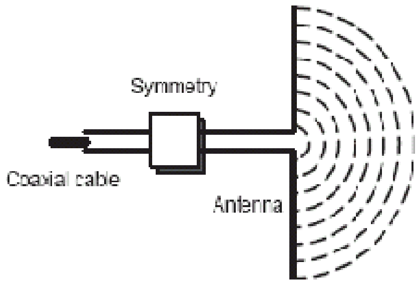


Figure 4: Antenna Basics

1.3 ANTENNA: ELECTRICAL PROPERTIES

1.3.1 RADIATION PATTERN:

Radiation pattern is the Graphical representation of the radiated power as function of direction. In most cases the propagation characteristic of an antenna can be described horizontal and vertical radiation patterns. Very often a 3-dimensional description is chosen to describe a complex antenna. The radiation patterns shows Major and Minor Lobes of an antenna. Major Lobes of an antenna indicate the direction of the maximum signal strength. Minor Lobes are those in which the signal strength is less.

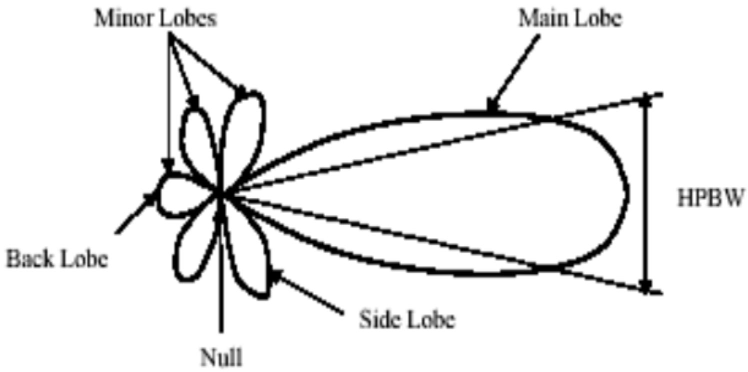


Figure 5: Radiation Lobes

1.3.2 HALF POWER BEAM WIDTH:

This term defines the aperture of the antenna. The Half Power Beam Width is defined by the points in the horizontal and vertical diagram, which show where the radiated power has reached half the amplitude of the main radiation direction. These points are also called 3 dB points. Normally only the major lobe is considered for this.

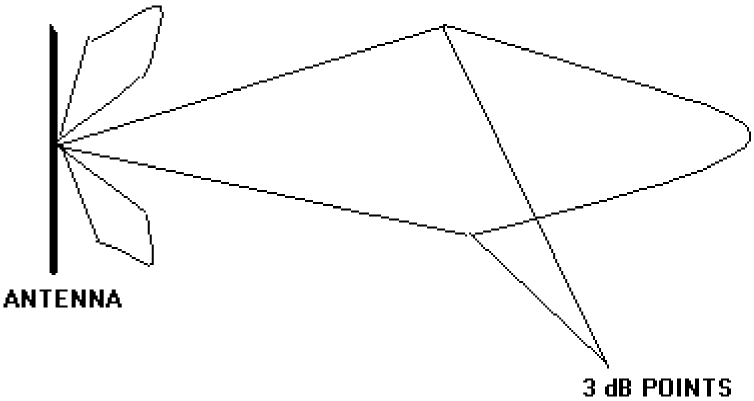


Figure 6: 3 db Point

1.3.3 ANTENNA GAIN:

An antenna without gain radiates energy in every direction. An antenna with gain concentrates the energy in a defined angle segment of 3-dimensional space. A dipole is used as a reference for defining gain. At higher frequencies the gain is often defined with reference to the isotropic radiator. The isotropic radiator is a non-existent ideal antenna, which has also an Omni directional radiation characteristic in the E-plane and H-plane.

The ratio of the power flux density produced by the antenna to that produced by an isotropic radiator at the same distance is called Effective isotropic radiated power or Effective Radiated Power (ERP and EIRP). The radiated power in a particular direction is equal to actual transmitter power time's antenna gain in that direction.

Radiated power = Input power x Antenna gain

1.3.4 IMPEDANCE:

The impedance of the antenna is simply equal to the voltage applied to its input terminals divided by the current flow. Input impedance of the antenna and transmission impedance of the feeder cable should be equal. It is 50 ohm.

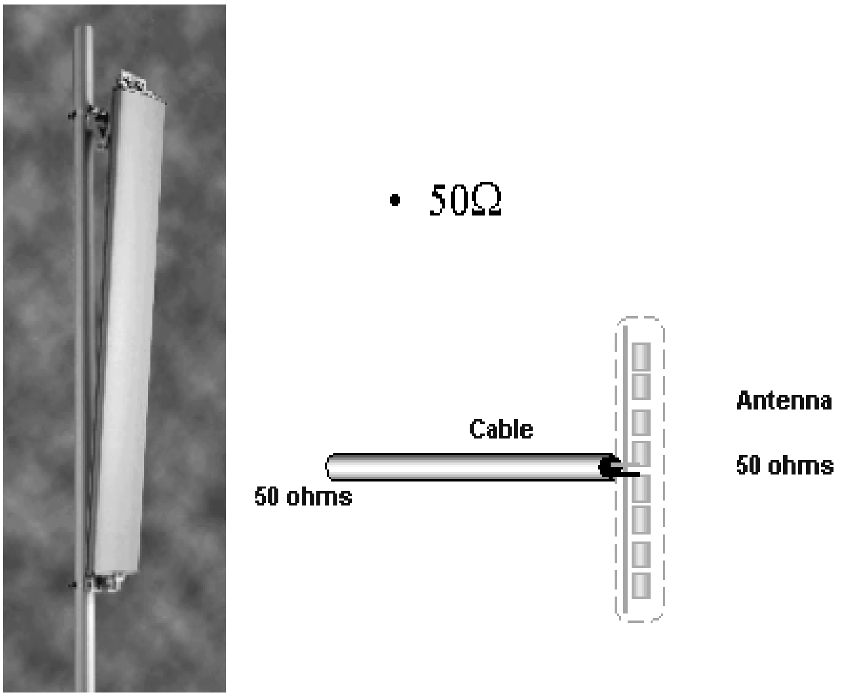


Figure 7: Impedance

1.3.5 VSWR :

Input impedance of the antenna must match the characteristic impedance of the transmission line. Otherwise, a reflected wave will generate and it will direct back towards the energy source. Forward transmitting wave and reflected wave will create a standing wave. The ratio between the maximum and minimum voltage of this standing wave is defined as the Voltage Standing Wave Ratio (VSWR). The VSWR is basically a measure of input impedance mismatch between the transmitter and the antenna. The higher the VSWR, the greater is the mismatch. The minimum VSWR is unity, which corresponds to a perfect match.

VSWR = Vmax/ Vmin

1.4 MECHANICAL FEATURES OF ANTENNA:

Antennas are always mounted at exposed sites. As a result the antenna must be designed to withstand the required mechanical loading. Vehicle antennas must withstand a high wind velocity, vibrations, saloon washing and still fulfill a limited wind noise requirement. Antennas for portable radio equipment are often exposed to ill handling and sometimes even played with by the user. Base station antennas are exposed to high wind speed, vibrations, ice, snow, a corrosive environment and of course also extreme electrostatic loading via lightning.

1.5 OMNI DIRECTIONAL ANTENNAS

The horizontal radiation pattern covers 360 degrees and vertical half power beam width is 78 degrees. Hence there will be lot of waste of energy both upwards and downwards in the desired horizontal plane.

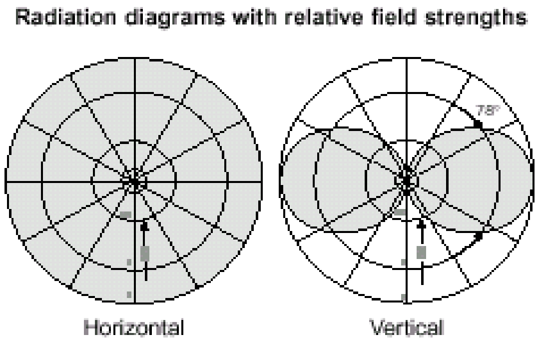


Figure 8: Omni directional Antennas

1.5.1 OMNI DIRECTIONAL ANTENNAS WITH GAIN

By connecting single and vertically stacked dipoles at a middle distance of one wavelength, the half power beam width can be reduced. As a result the radiated power in the horizontal plane is increased.

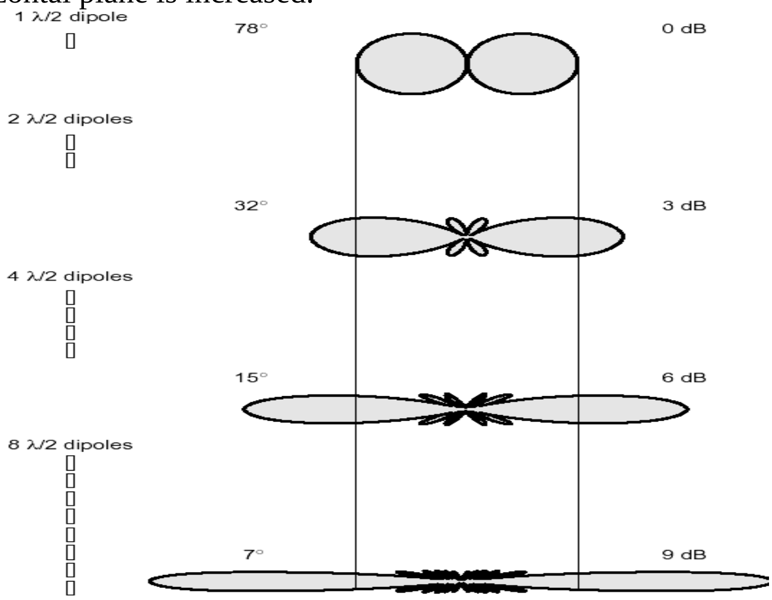


Figure 9: Omni Directional Antennas with Gain

This increase is called gain, which is nothing other than binding the radiated power in a defined direction. A doubling of the number of dipoles results in a gain increase of 3 dB (double the power).

1.6 DIRECTIONAL ANTENNAS

Directional antennas are provided with reflectors behind the radiating element. This focuses the energy in a desired direction avoiding transmission in the rear side of the antenna. The directional antennas are classified into the following types:

1. Grid Parabolic Reflector antennas
2. Parabolic Reflector antennas.
3. Cassegrain antennas.
4. Array antennas.

The first two types of antennas are mainly used in fixed point-to-point radio links and the grid types are employed up to 2GHz whereas the solid parabolic reflector antennas are used for higher frequencies. The connectivity between the antennas to the equipments is by coaxial cable up to 2GHz and for higher frequencies it is by hollow copper tube called wave-guide. The beam width of these antennas depends on the diameter of the antenna and frequency of operation. They produce very narrow beams.

Cassegrain antennas are associated with Satellite communication are comparatively larger which makes them to be fixed on the ground or roof tops and orient themselves towards the satellite by operating gear arrangement either manually or using motors.

Array antennas are more predominantly used in broadcasting and mobile communications. There are two types

(i)End Fire Arrays, (ii) Panel Antennas

1.6.1 END-FIRE ARRAYS

Directional antennas whose mechanical features are parallel to the main radiation beam are called "End-fire Arrays". Examples: Yagi antennas, logarithmic periodic (log-per) antennas Yagi antennas are very common due to their simple and cheap method of construction. The gain and bandwidth of Yagi antennas are electrically coupled with one other which is an electrical disadvantage, ie. one criterion is weighed off the other. The mechanical concept is not suitable for extreme climatic conditions.

1.6.2 PANEL ANTENNAS-BROADSIDE ARRAYS

Panel antennas are made up of several dipoles mounted in front of a reflector so that gain can be achieved from both the horizontal and vertical plane. This type of antenna is very well suited for antenna combinations.

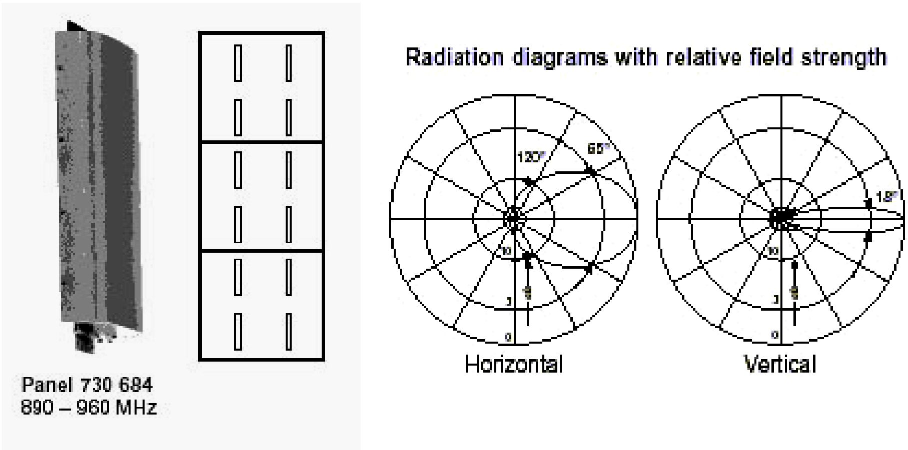


Figure 10: Panel Antennas-Broadside Arrays

1.7 ANTENNA SYSTEMS

Special applications, which cannot be realized by using a single antenna, are very often achieved via antenna combinations. The combination is made up of several single antennas and a distribution system (power splitter and connecting cable). Very often a combination is designed in order to achieve a higher gain. Many different antennas are also used to achieve a wide range of horizontal radiation characteristics by varying the number of antennas, the azimuth direction, the spacing, the phase and the power ratio.

1.8 DIVERSITY

Diversity is used to increase the signal level from the mobile to the base station.

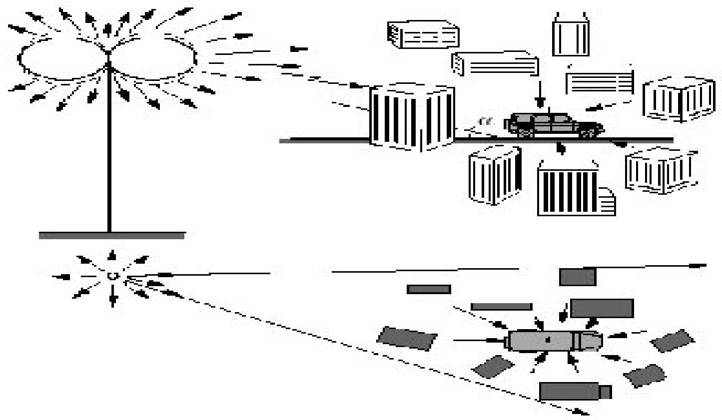


Figure 11: Diversity

The problem with this path is the fact that the mobile telephone only works with low power and a short antenna. Diversity is applied on the reception side of the base station.

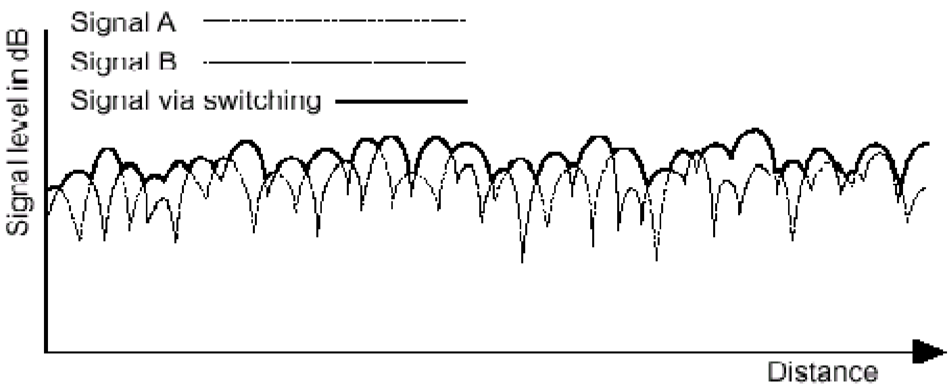


Figure 12: Diversity Gain

1.8.1 SPACE DIVERSITY:

This system consists of two reception antennas spaced a distance apart. One antenna has a certain field strength profile with maxima and minima from its coverage area, the other antenna has a completely different field strength profile although only spaced a few meters away. Ideally the minima of one antenna will be completely compensated by the maxima of the other. The improvement in the average signal level achieved with this method is called diversity-gain.

1.8.2 POLARIZATION DIVERSITY

The reflections, which take place within urban areas, are not all of the same polarization, i.e. Horizontal components also exist. Furthermore a mobile telephone is never held exactly upright which means that all polarizations between vertical and horizontal are possible. It is therefore logical that these signals be also used. Space diversity uses 2 vertically polarized antennas as reception antennas and compares the signal level. Polarization diversity uses 2 orthogonally polarized antennas and compares the resulting signals.

1.8.3 HORIZONTAL AND VERTICAL POLARIZATION

The dipoles of both antenna systems are horizontally and vertically polarized respectively. A spatial separation is not necessary which means that the differently polarized dipoles can be mounted in a common housing. Sufficient isolation can be achieved even if the dipoles are interlocked into one unit so that the dimensions of a dual-polarized antenna are not greater than that of a normal polarized antenna.

A minimum horizontal spacing is only required between the antennas, the antennas can also be mounted one above the other on the same mast. This makes the complete sector very compact, thereby easing permission procedures.

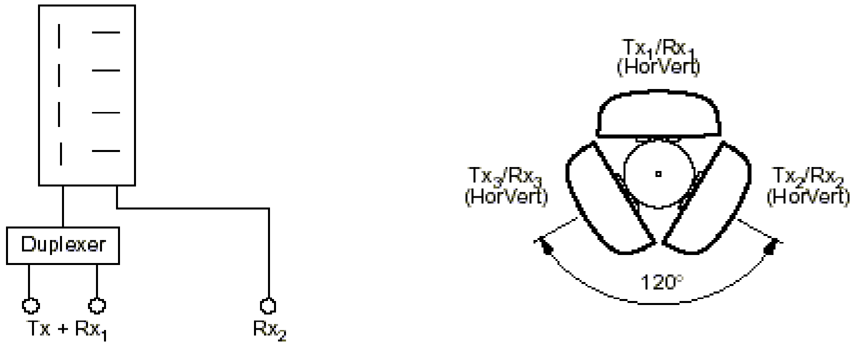


Figure 13: Horizontal and Vertical Polarization

1.8.4 POLARIZATION +45°/-45°

It is also possible to use dipoles at +45°/-45° instead of horizontally and vertically (0°/90°) placed.

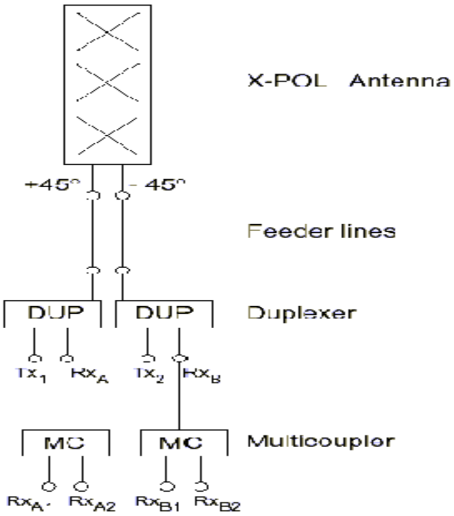


Figure 14: Polarization +45°/-45°

One now has two identical systems, which are able to handle both horizontally and vertically polarized components.

1.8.5 ANTENNA DOWN TILT

Mechanical Down Tilt

Physically tilt the antenna. The pattern in front goes down, and behind goes up popular for sectorization and special omni applications.

Electrical Down Tilt

- (fixed and adjustable)
- Incremental phase shift is applied in the feed network
- the pattern “droops” all around, like an inverted saucer
- common technique when down tilting Omni cells

1.9 INSTALLATION OF ANTENNA SYSTEM

Before installing the primary antenna feeder system, the qualifications of the installation should be checked upon personnel who are to work at heights, and then the installation environment, safety measures, installation tools and system components need preparations and checks to ensure a successful installation.

1.9.1 INSTALLATION PERSONNEL

The antenna feeder system should be installed by the installation personnel under the supervision of an Installation Supervisor.

The installation supervisor should be familiar with the materials, tools and installation operations, and is responsible for organizing and coordinating installation personnel as well as assigning suitable works to suitable persons in the principle of "safety first", and especially the works on towers. The installation supervisor is also responsible for truthfully recording engineering data.

The installation personnel should be skillful, and those who work at heights are required to have obtained relevant certificates, be in good health, suffer no acrophobia, follow the safety regulations and have purchased personal insurance. In addition, they are prohibited from drinking alcohol when working.

1.9.2 CHECK THE INSTALLATION ENVIRONMENT

Check the outdoor lightning ground wire to make sure that whether it is well grounded and its cross-section area is more than 50mm2. Check the distances between the antenna lightning rod, lightning grounding point or outdoor cabling rack and pole as well as the firmness and wind-resistance capacity of the pole to make sure that if they meet design requirements. In addition, prepare necessary tools and materials for the installation and determine the route for the primary feeder cables through negotiation with the user.

The equipment supplier should propose the requirements for the installation of the antenna support in terms of the structure and dimensions of the antenna, and the network operator is responsible for installing the antenna support based on the requirements.

The network operator is also responsible for installing the outdoor cabling rack, lightning rod, lightning grounding point and outdoor lightning ground wire. Moreover, the network operator is required to drill an opening on a wall or roof for the installation of the feeder cable window as part of the installation environment.

Reiterate safety precautions to the installation personnel. The outdoor installation should be conducted in the daytime on sunny days without strong wind. Obvious signs should be set up at the installation site to warn irrelevant people away from the site. The installation personnel working on the ground are obligated to warn irrelevant people, and especially children, away from the site. On the tower all the materials and tools, such as tools and metal parts not in use for a while, which might fall off to cause casualties, must be put in a canvas tool bag, and the bag must be sealed up immediately after tools are taken out of it.

Check Safety Measures

> 🔔 Note:
>
> The installation personnel working on a tower must wear safety belts, and those working on the ground must wear safety helmets. Do not wear loose clothes or slippery shoes when working on a tower.

1.9.3 PREPARE INSTALLATION TOOLS

1. Measurement tools: Compass, multi-meter, inclinometer and tape measure.
2. Communication tools: Two cell phones.

3. Hoisting tools: Pulley block and rope for hoisting primary feeder cables.

4. Special-purpose tools: Primary feeder cable cutter and special-purpose tools used to assemble primary feeder cable connectors.

5. General–purpose tools: Adjustable spanners, sharp nose pliers, diagonal pliers, electrician knife, files and hacksaws.

6. Safety protection tools: Safety belt (used by installation personnel working out of the tower platform), safety helmet, safety rope, dungaree, RF protective suit, canvas tool bag, gloves, multi-purpose power socket.

7. Other tools: Trestle ladder and the wooden wheel axis for uplifting the primary feeder cables (which can be borrowed from the user).

1.9.4 COMPOSITION AND INSTALLATION REQUIREMENTS OF THE ANTENNA FEEDER SYSTEM

Composition of the Antenna Feeder System

The antenna feeder system is composed of antennas, antenna jumpers, primary feeder cables, lightning arresters, cabinet-top jumpers and grounding parts. (See Fig.15)

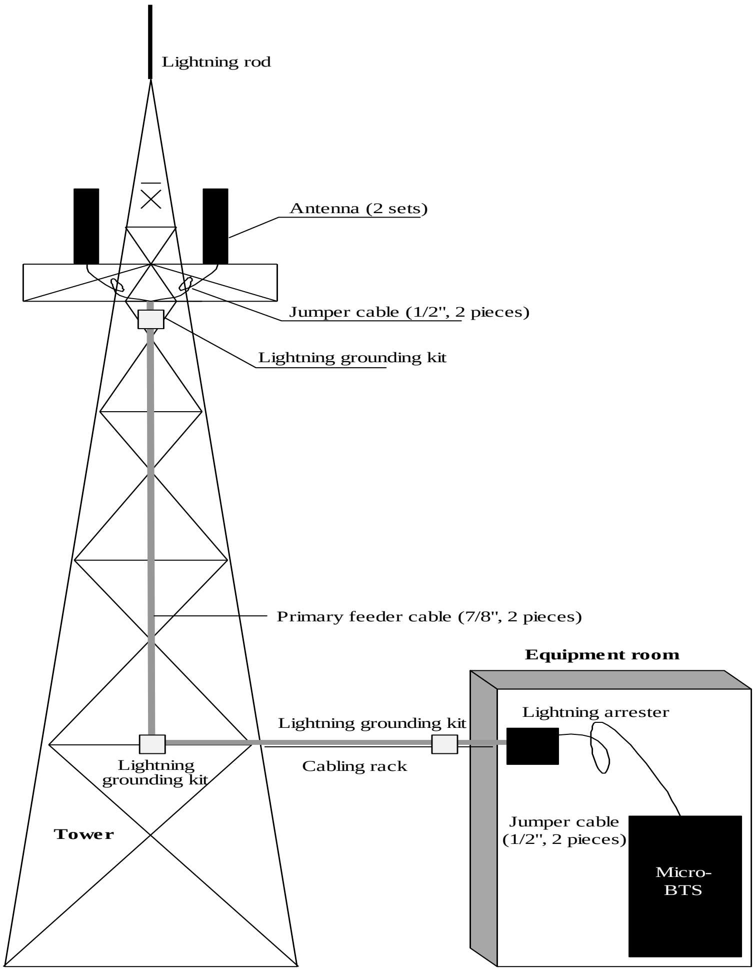


Figure 15: Typical Structure of an Antenna Feeder System

1.9.5 SPECIFICATIONS FOR THE ANTENNA INSTALLATION

Antenna height: - It is determined by the network planning.

Azimuth angle of antenna:-It is determined by the network planning.

Pitch angle of antenna: - It is determined by the network planning, usually within an adjustable range of 0~ 10 degrees.

Antenna direction: - It is determined by the azimuth angle of the antenna. Two antennas of the same sector must point to the same direction.

Distance between diversity antennas :- If two antennas of the same sector are diversity receiving antennas, they should be of the same vertical height (H), and the horizontal distance (d) between them should be as long as possible. Refer to the following inequality for "d". d≥10λ~20λ (or H/d=11), wherein, "d" is the horizontal distance between diversity antennas and "H" is the height of the antennas to the ground. If the carrier is 1.9GHz, "d" should be greater than 1.5m. If the carrier is 800MHz, "d" should be greater than 3.5m.

1.9.6 TOWER MOUNTED AMPLIFIER

Most base stations (BTS) can transmit a signal to a mobile device further and stronger than they can receive the signals coming back from it. This is known as link imbalance and is made worse by the feeder loss between the base station and the antennas.

This imbalance can be as high as 20% or more, so system designers need to correct the balance in order to improve coverage. The simplest solution is the addition of a Tower Mounted Amplifier (TMA). A TMA installed directly beneath a base station antenna can increase the sensitivity of the base station and increase its range by up to 40%, correcting the link imbalance and almost doubling its reception coverage area. A low loss filter and low noise amplifier within the TMA help to select and amplify the received signal. In effect, the Tower Mounted Amplifier works as a powerful "hearing aid" for the base station.

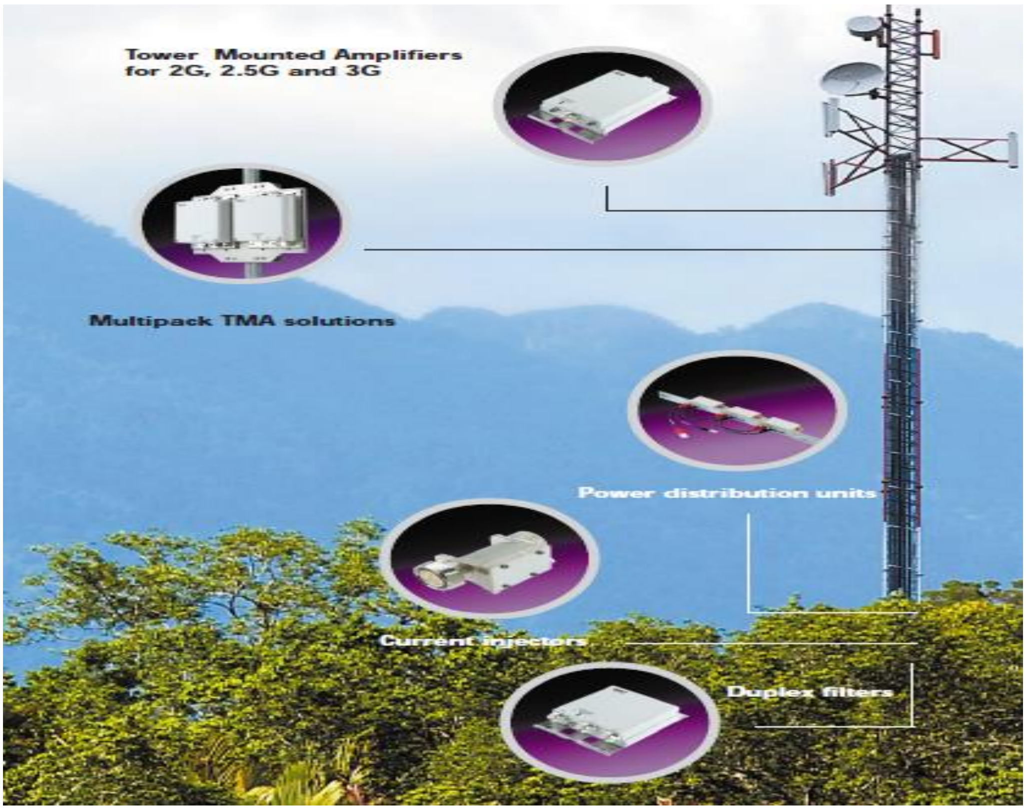


Figure 16: Tower Mounted Amplifier

1.10 REMOTE ELECTRICAL TILT (RET) SYSTEM

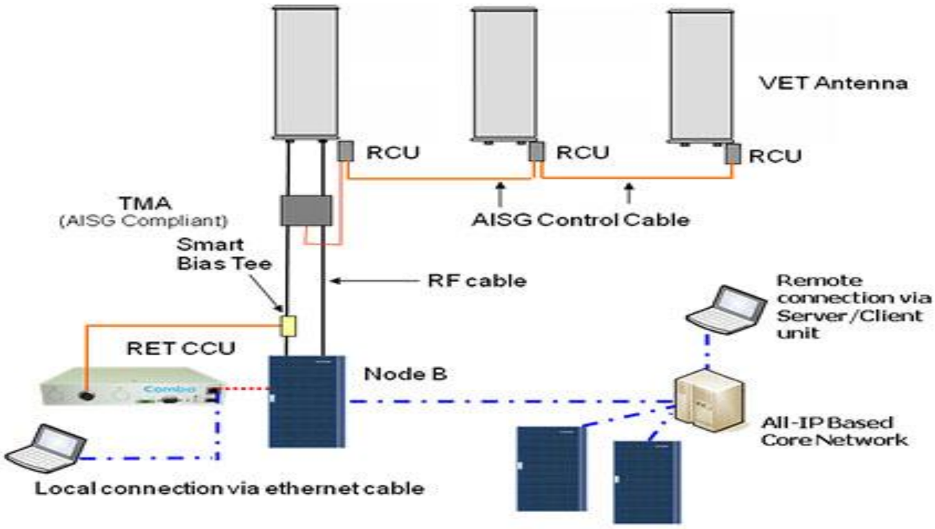


Figure 17: Remote Electrical Tilt (RET) System

1.11 TYPES OF TOWERS

Telecom towers are broadly classified on the basis of their placement as Ground-based and Roof-top.

Ground-Based Tower:

Erected on the ground, ground-based towers (GBTs) are taller (typically 200 to 400 feet) and are mostly used in rural and semi-urban areas because of the easy availability of real-estate space there. GBTs involve a capital expenditure in the range of Rs. 2.4 to 2.8 million, depending on the height of the tower.

Roof-Top Tower (RTT):

Roof-top towers (RTTs), which are generally placed on the roofs of high-rise buildings, are shorter (than GBTs) and more common in urban and highly populated areas, where there is paucity of real-estate space. Typically, these involve a capital expenditure of Rs. 1.5 to 2 million.

It is the height of a telecom tower that determines the number of antennas that can be accommodated, which in turn determines the capacity of the towers, apart from factors such as location and geographical conditions (wind speeds, type of terrain, etc.). Hence, typically, while GBTs can accommodate up to six tenants, RTTs can accommodate two to three tenants.

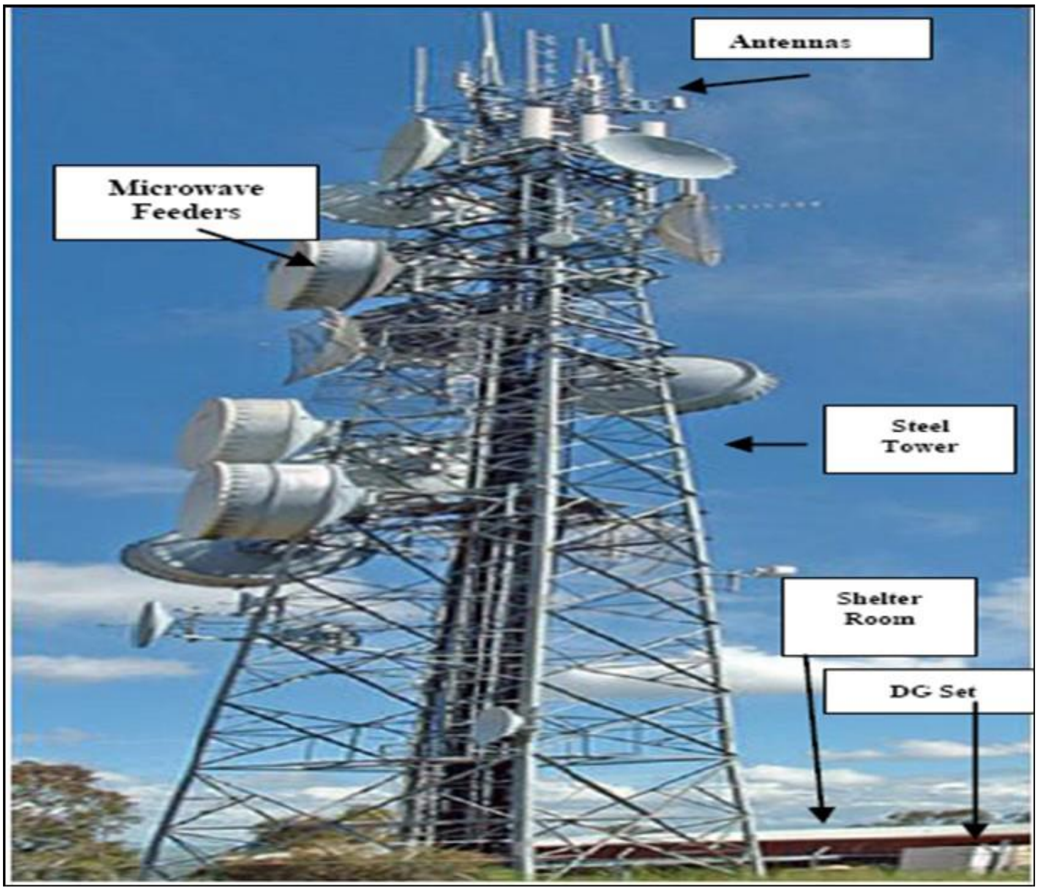


Figure 18: Types of Tower

1.12 GSM INTRODUCTION AND ARCHITECTURE

- GSM stands for Global System for Mobile Communication.
- GSM is a 2nd Generation Digital Cellular Communication System.
- GSM is the most widely accepted standard in telecommunications and it is implemented globally.
- GSM is the name of a standardization group established in 1982 to create a common European mobile telephone standard but it has been rapidly accepted worldwide.
- GSM is a circuit-switched system that divides each 200 kHz channel into eight 25 kHz time-slots. GSM operates on the mobile communication bands 900 MHz and 1800 MHz in most parts of the world. In the US, GSM operates in the bands 850 MHz and 1900 MHz
- GSM makes use of narrowband Time Division Multiple Access (TDMA) technique for transmitting signals.
- GSM was developed using digital technology. It has an ability to carry 64 kbps to 120 Mbps of data rates.
- GSM provides basic to advanced voice and data services including roaming service. Roaming is the ability to use your GSM phone number in another GSM network.

1.13 GSM SPECIFICATIONS:

Frequency Bands :

- Standard or primary GSM 900 Band :For Standard GSM 900 Band, the system is required to operate in the following frequency band:
- 890 - 915 MHz: Uplink (Mobile transmit, Base Station receive)
- 935- 960 MHz: Downlink (Base Station transmit, Mobile receive)
- DCS1800 Band: For DCS 1800 :The system is required to operate in the following band:
- 1710 - 1785 MHz: Uplink (Mobile transmit, Base Station receive)
- 1805 - 1880 MHz: Downlink (Base Station transmit, Mobile receive)

Bandwidth and Duplex Spacing :

Bandwidth for GSM 900 band is 25 Mhz and 75 Mhz for GSM 1800 Band. Duplex spacing i.e separation between Uplink and Downlink frequency for GSM 900 band is 45 Mhz and 95 Mhz for GSM 1800 Band.

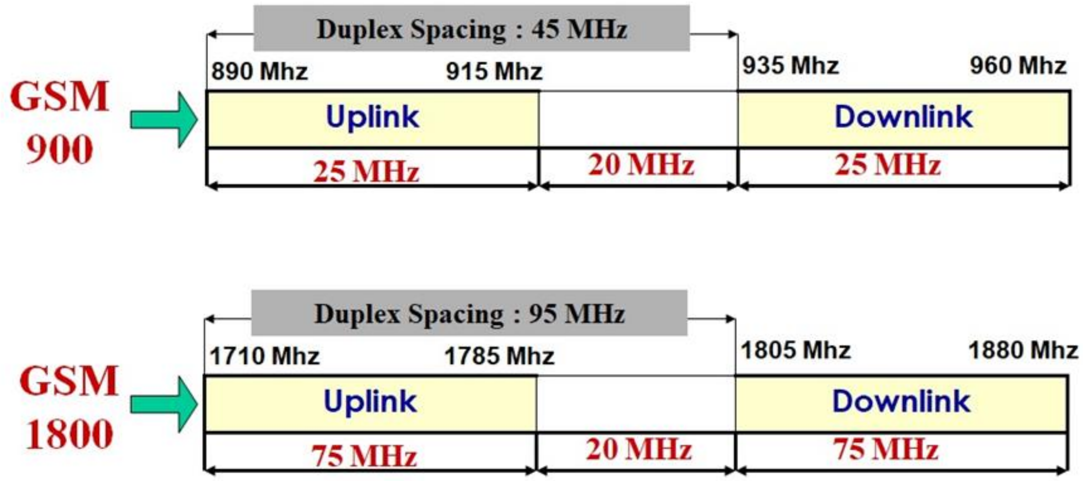


Figure 19: Bandwidth and Duplexing Spacing

Channel Arrangement :

900 MHz Band: 25 MHz bandwidth divided into 125 carrier frequencies of 200 kHz each. 125 carriers available in each direction. First carrier not used to avoid interference with other band.124 RF channels is used.

1800 MHz Band: 75 MHz bandwidth divided into 375 carrier frequencies of 200 kHz each. First carrier not used to avoid interference with other band. 374 RF channels are used.

ARFCN No: Absolute Radio Frequency Channel Number (ARFCN) is a code that specifies a pair of physical radio carriers used for transmission and reception on the air interface, one for the uplink signal and one for the downlink signal. One or more ARFCN are allocated to a cell/sector

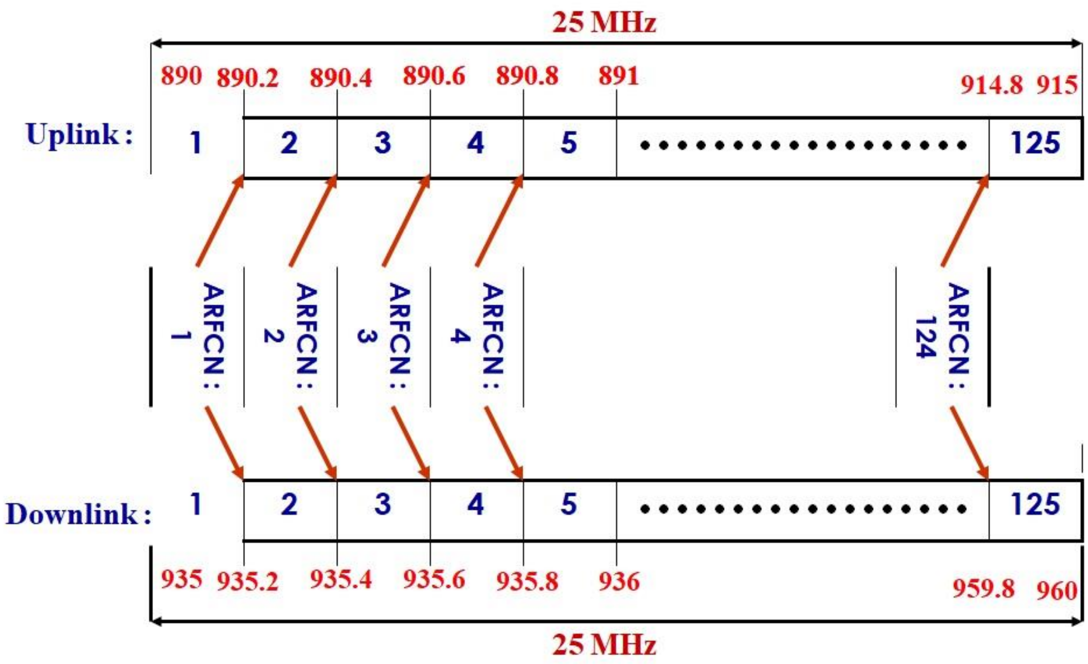


Figure 20: ARFCN arrangement for GSM 900 Mhz band

Duplexing Method

Duplexing is the technique by which the send and receive paths are separated over the medium.

There are two types of duplexing:

A) Frequency Division Duplexing FDD

B) Time Division Duplexing TDD

A) Frequency Division Duplexing (FDD)

Different Frequencies are used for send and receive paths and hence there will be a Forward band and reverse band. Duplexer is needed if simultaneous transmission (send) and reception (receive) methodology is adopted. Frequency separation between forward band and reverse band is constant.

B) Time Division Duplexing (TDD)

TDD uses different time slots for transmission and reception paths. Single radio frequency can be used in both the directions instead of two as in FDD. No duplexer is required. Only a fast switching synthesizer, RF filter path and fast antenna switch are needed. It increases the battery life of mobile phones.

GSM system adopted Frequency Division Duplexing method. Separate frequencies are used for Uplink and Downlink.

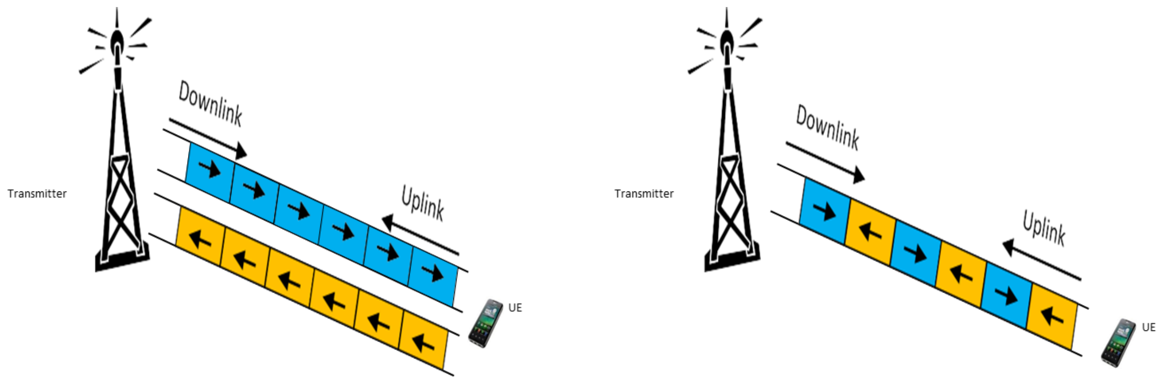


Figure 21: FDD and TDD

1.14 SUMMARY OF GSM SPECIFICATIONS :

	Standard or primary GSM 900 Band	1800 band
Uplink frequency	890-915 MHz	1710 - 1785 MHz
Downlink frequency	935-960 MHz	1805 – 1880 MHz
Duplex Distance	45 MHz	95 MHz
Carrier separation	200 KHz	200 KHz
Frequency Channels	124	374
Voice coder bit rate	13 Kbps	13 Kbps
Modulation	GMSK	GMSK
Air transmission Rate	270.8333 Kbps	270.8333 Kbps
Access Method	FDMA/TDMA	FDMA/TDMA
Speech Coder	RPE-LTP	RPE-LTP
Duplexing	FDD	FDD

Table 2. GSM Specifications

1.15 GSM NETWORK ARCHITECTURE:

A GSM network comprises of many functional units. The GSM network can be broadly divided into:

- The Mobile Station (MS)
- The Base Station Subsystem (BSS)
- The Network Switching Subsystem (NSS)
- The Operation Support Subsystem (OSS)

The architecture of the GSM network is presented in figure.

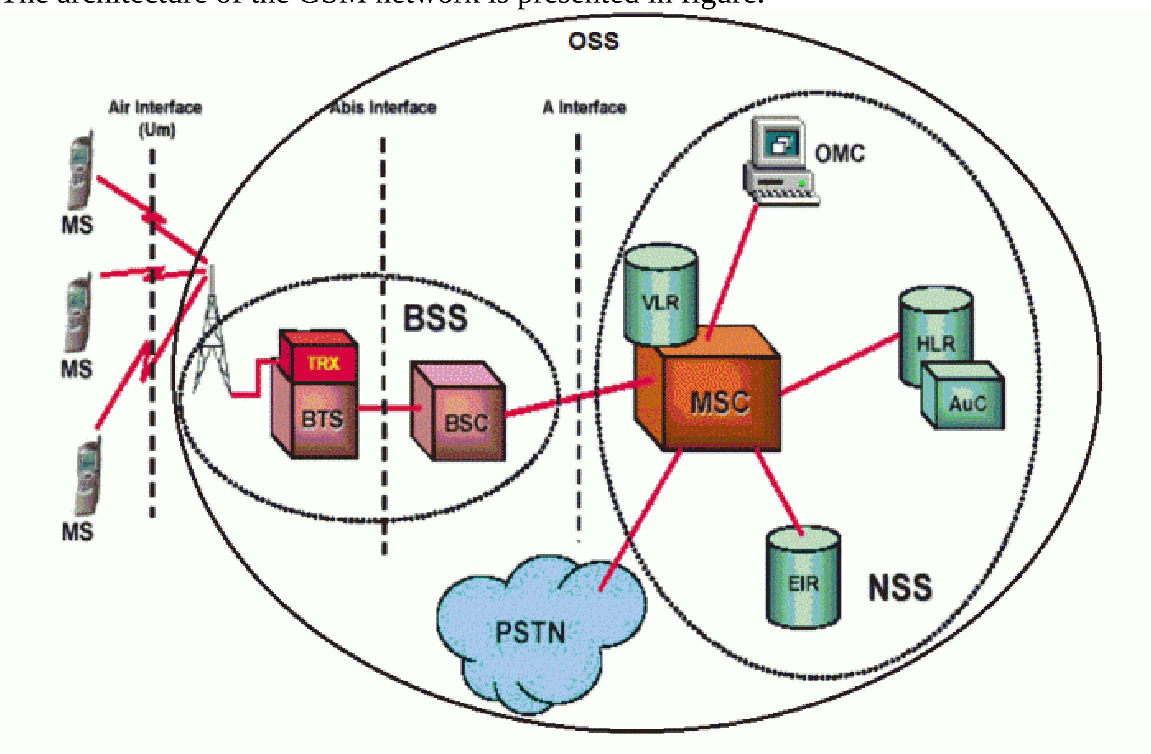


Figure 22: Architecture of GSM Network

1.16 GSM NETWORK AREAS

The GSM network is made up of geographic areas. These areas include cells, location areas (LAs), MSC/VLR service areas, and public land mobile network (PLMN) areas.

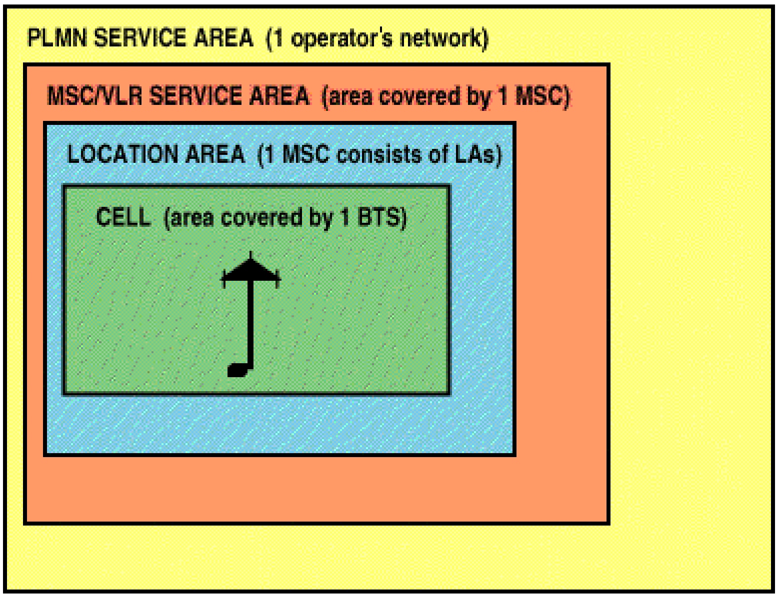


Figure 23: GSM Network Areas

Cell:

Cell is the basic service area; one BTS covers one cell. Each cell is given a Cell Global Identity (CGI), a number that uniquely identifies the cell.

Location Area:

A group of cells form a Location Area (LA). This is the area that is paged when a subscriber gets an incoming call. Each LA is assigned a Location Area Identity (LAI). Each LA is served by one or more BSCs.

MSC/VLR Service Area:

The area covered by one MSC is called the MSC/VLR service area.

PLMN:

The area covered by one network operator is called the Public Land Mobile Network (PLMN). A PLMN can contain one or more MSCs.

1.17 GSM ADDRESS AND IDENTITIES :

GSM treats the users and the equipment in different ways. Phone numbers, subscribers, and equipment identifiers are some of the known ones. There are many other identifiers that have been well-defined, which are required for the subscriber's mobility management and for addressing the remaining network elements. Vital addresses and identifiers that are used in GSM are addressed below.

International Mobile Station Equipment Identity (IMEI) :

The International Mobile Station Equipment Identity (IMEI) looks more like a serial number which distinctively identifies a mobile station internationally. This is allocated by the equipment manufacturer and registered by the network operator, who stores it in the Entrepreneurs-in-Residence (EIR). By means of IMEI, one recognizes obsolete, stolen, or non-functional equipment.

Following are the parts of IMEI:

- Type Approval Code (TAC): 6 decimal places, centrally assigned.
- Final Assembly Code (FAC): 6 decimal places, assigned by the manufacturer.
- Serial Number (SNR): 6 decimal places, assigned by the manufacturer.
- Spare (SP): 1 decimal place.

Thus, IMEI = TAC + FAC + SNR + SP. It uniquely characterizes a mobile station and gives clues about the manufacturer and the date of manufacturing.

International Mobile Subscriber Identity (IMSI)

Every registered user has an original International Mobile Subscriber Identity (IMSI) with a valid IMEI stored in their Subscriber Identity Module (SIM).

IMSI comprises of the following parts:

- Mobile Country Code (MCC): 3 decimal places, internationally standardized.
- Mobile Network Code (MNC): 2 decimal places, for unique identification of mobile network within the country.
- Mobile Subscriber Identification Number (MSIN): Maximum 10 decimal places, identification number of the subscriber in the home mobile network.

Mobile Subscriber ISDN Number (MSISDN)

The authentic telephone number of a mobile station is the Mobile Subscriber ISDN Number (MSISDN). Based on the SIM, a mobile station can have many MSISDNs, as each subscriber is assigned with a separate MSISDN to their SIM respectively.

Listed below is the structure followed by MSISDN categories, as they are defined based on international ISDN number plan:

- Country Code (CC): Up to 3 decimal places.
- National Destination Code (NDC): Typically 2-3 decimal places.
- Subscriber Number (SN): Maximum 10 decimal places.

Mobile Station Roaming Number (MSRN) :

Mobile Station Roaming Number (MSRN) is an interim location dependent ISDN number, assigned to a mobile station by a regionally responsible Visitor Location Register (VLA). Using MSRN, the incoming calls are channeled to the MS.

The MSRN has the same structure as the MSISDN.

- Country Code (CC): of the visited network.
- National Destination Code (NDC): of the visited network.
- Subscriber Number (SN): in the current mobile network.

Location Area Identity (LAI) :

Within a PLMN, a Location Area identifies its own authentic Location Area Identity (LAI). The LAI hierarchy is based on international standard and structured in a unique format as mentioned below:

- Country Code (CC): 3 decimal places.
- Mobile Network Code (MNC): 2 decimal places.
- Location Area Code (LAC): maximum 5 decimal places or maximum twice 8 bits coded in hexadecimal (LAC < FFFF).

Temporary Mobile Subscriber Identity (TMSI)

Temporary Mobile Subscriber Identity (TMSI) can be assigned by the VLR, which is responsible for the current location of a subscriber. The TMSI needs to have only local significance in the area handled by the VLR. This is stored on the network side only in the VLR and is not passed to the Home Location Register (HLR).Together with the current location area, the TMSI identifies a subscriber uniquely. It can contain up to 4 × 8 bits.

Local Mobile Subscriber Identity (LMSI)

Each mobile station can be assigned with a Local Mobile Subscriber Identity (LMSI), which is an original key, by the VLR. This key can be used as the auxiliary searching key for each mobile station within its region. It can also help to accelerate the database access. An LMSI is assigned if the mobile station is registered with the VLR and sent to the HLR. LMSI comprises of four octets (4x8 bits).

Cell Identifier (CI)

Using a Cell Identifier (CI) (maximum 2 × 8) bits, the individual cells that are within an LA can be recognized. When the Global Cell Identity (LAI + CI) calls are combined, then it is uniquely defined.

1.18 CONCLUSION

Antenna network plays very important role in wireless communication. GSM is a very successful technology due to its robust radio network design. By virtue of TDMA and frequency reuse the capacity of GSM systems has increased tremendously. But with the introduction of Data on mobile GSM has lost its shine as it delivers very less data rates

2 GSM/GPRS LOGICAL CHANNELS AND CALL PROCESSING

2.1 LEARNING OBJECTIVE

This chapter deals with Physical and logical channel of GSM and GPRS. This chapter gives basic idea about logical functions of GSM and GPRS Radio Channels. Also Call Management in GSM is discussed.

2.2 PHYSICAL AND LOGICAL CHANNEL

In GSM, a physical channel is a time slot in a TDMA Frame. The physical channel is the medium over which the information is carried. A physical channel may carry different messages, depending on the information that is to be sent. These messages are called Logical Channels.

One or more logical channels can be transmitted over a physical channel. Many types of logical channels exists, each designed to carry a different message to or from an MS. The type of logical channel is determined by the function of the information transmitted over it.

Different time slots will carry different logical channels, depending on the configuration of the BSS.

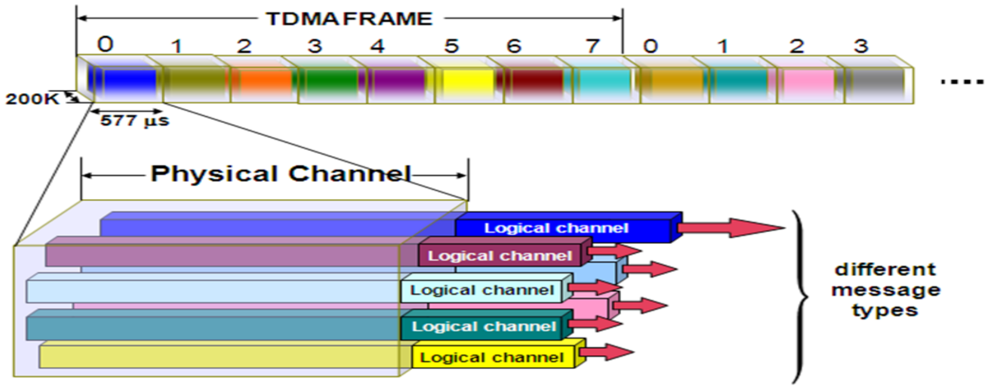


Figure 24: Physical and Logical Channel

Physical Channel = information container

Logical Channel = specification of the information global content

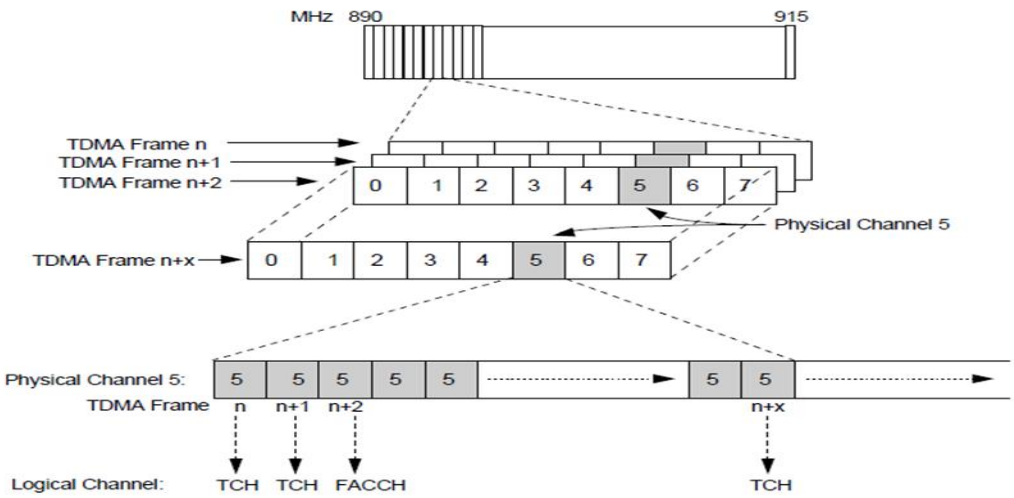


Figure 25: Mapping of logical channel to physical channel

2.3 TYPES OF LOGICAL CHANNELS:

There are different types of logical channels. The type of logical channel is determined by the function of the information transmitted over it.

The following types of logical Channels are defined:

- Traffic channels
- Broadcast channels
- Common control channels
- Dedicated control channels

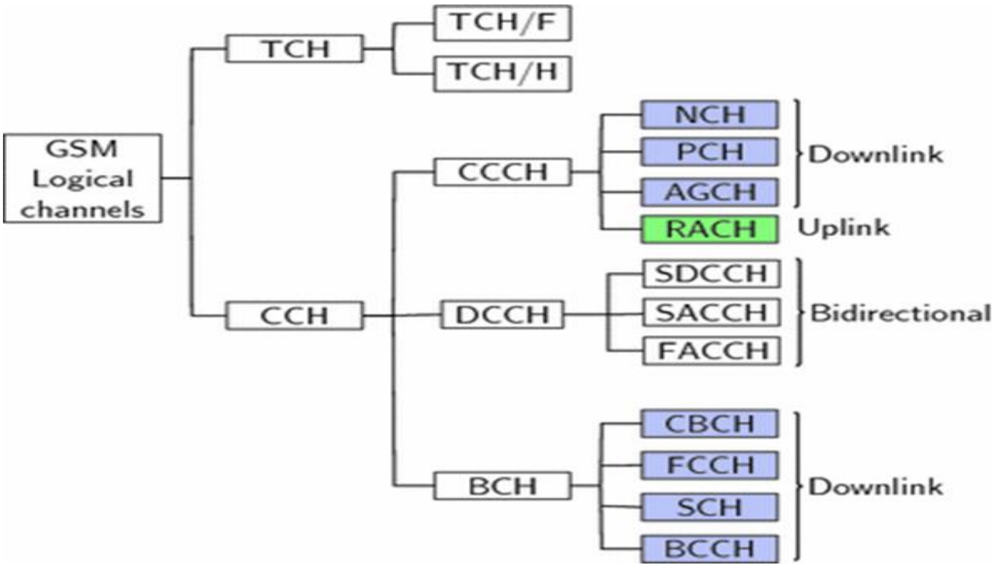


Figure 26: Types of Logical Channel in GSM

Note that the Traffic channel carries speech and data, and the other types carry control information (signaling).

2.3.1 TRAFFIC CHANNELS

The traffic channels are used to send speech or data services. There are two types of traffic channels. They are distinguished by their transmission rates. A TCH/F or a TCH/H may also be used to send signaling information (for example call forwarding and short messages). In that case a small portion of the time slot is used.

2.3.2 TCH/F (TRAFFIC CHANNEL FULL RATE)

The TCH/F carries information at a gross bit rate of 22.8 kbit/s (after channel coding). The net (or effective) bit rate at the TCH/F is for speech 13 kbit/s and for data 12, 6 or 3.6 kbit/s (before channel coding). The transmission rates of the data services allow services which are compatible to the existing, respectively, 9.6, 4.8 and 2.4 kbit/s PSTN and ISDN services.

2.3.3 TCH/H (TRAFFIC CHANNEL HALF RATE)

The TCH/H carries information at a gross bit rate of 11.4 kbit/s. The net bit rate at the TCH/H is for speech 5.6 kbit/s and for data 6 or 3.6 kbit/s.

2.3.4 TCH/EFR (ENHANCED FULL RATE)

The EFR provides a voice coding algorithm offering improved speech quality. The algorithm is fully compatible with a BSM speech quality. The algorithm is fully compatible with a GSM 13 Kbps speech channel. The main benefit will be improved voice quality which offers prospects to compete with PSTN networks. A TCH/F or a TCH/H may also be used to send signaling information (for example call forwarding and short messages).

2.3.5 BROADCAST CHANNELS

This channel carries system parameters needed to identify the network, synchronize time and frequency with the network, and gain access to the network. The broadcast channels are point-to-multipoint channels which are only defined for the downlink direction (BTS to the mobile station). They are divided into :

- Broadcast Control Channel (BCCH)
- Frequency Correction Channel (FCCH)
- Synchronization Channel (SCH)
- Cell Broadcast Channel (CBCH)

2.3.6 BCCH (BROADCAST CONTROL CHANNEL)

BCCH is transmitted by BTS at all times at constant power. Via BCCH MS is informed about the system configuration parameters needed to identify the network and gain access. These parameters include :

- Location Area Identity (LAI)
- List of the frequencies of neighboring cells, which should be monitored by the MS .
- List of frequencies used by the cell
- Cell Global Identity (CGI)
- Power control indicator(Max allowed power in Cell).
- Access parameters (Emergency call, call baring etc

2.3.7 FCCH (FREQUENCY CORRECTION CHANNEL)

To communicate with the BTS the mobile station must tune to the BTS. The FCCH transmits a constant frequency shift of the radio frequency carrier that can be used by the mobile station for frequency correction.

2.3.8 SCH (SYNCHRONIZATION CHANNEL)

The SCH is used to time synchronize the mobile stations. The data on this channel carries the TDMA frame number and the BSIC (Base Station Identity Code).

2.3.9 CBCH (CELL BROADCAST CHANNEL)

The CBCH is used for the transmission of generally accessible information (Short Message Service messages) in a cell, which can be polled by the mobile station.

2.3.10 COMMON CONTROL CHANNELS

Common control channels are specified as point-to-multipoint channels which only operate in one direction of transmission, either in the uplink or downlink direction. Used for signaling between the BTS and the MS and to request and grant access to the network. They are divided into :

- Paging Channel (PCH)
- Random Access Channel (RACH)
- Access Grant Channel (AGCH)

The PCH is used in the downlink direction for paging the mobile stations.

2.3.11 AGCH (ACCESS GRANT CHANNEL)

The AGCH is also used in the downlink direction. A logical channel for a connection is allocated via the AGCH if the mobile station has requested such a channel via the RACH.

2.3.12 RACH (RANDOM ACCESS CHANNEL)

The RACH is used in the uplink direction by the mobile stations for requesting a channel for a connection. It is an access channel that uses the slotted Aloha access scheme.

2.3.13 DEDICATED CONTROL CHANNELS

Dedicated control channels are full-duplex, point-to-point channels. They are used for signaling associated with calls and call-setup between BTS and certain MS. They are divided into :

Standalone Dedicated Control Channel (SDCCH)
Fast Associated Control Channel (FACCH)
Slow Associated Control Channel (SACCH)

2.3.14 SACCH (SLOW ASSOCIATED CONTROL CHANNEL)

The SACCH is a duplex channel which is always allocated to a TCH or SDCCH. The SACCH is used for transmission of signaling data, radio link supervision measurements, transmit power control and timing advance data. Note that the SACCH is only used for non-urgent procedures.

2.3.15 FACCH (FAST ASSOCIATED CONTROL CHANNEL)

The FACCH is used as a main signaling link for the transmission of signaling data (for example handover commands). It is also required for every call set-up and release. During the call the FACCH data is transmitted over the allocated TCH instead of traffic data; this is marked by a flag called a stealing flag. The process of stealing a TCH for FACCH data is called pre-emption.

2.3.16 SDCCH (STAND-ALONE DEDICATED CONTROL CHANNEL)

The SDCCH is a duplex, point-to-point channel which is used for signaling in higher layers. It carries all signaling between the BTS and the mobile station when no TCH is allocated. The SDCCHs are used for service requests (for example Short Message Service), location updates, subscriber authentication, ciphering initiation, equipment validation and assignment to a TCH. The net SDCCH bit rate is about 0.8 Kbps.

2.4 MULTIPLEXING LOGICAL CHANNELS ON TO PHYSICAL CHANNELS

Logical channels are transmitted on physical channels. The method of placing logical channels on physical channels is called mapping. Most logical channels take only one time slot to transmit. Some logical channels take more than one time slot. If so, the logical channel information is carried in the same time slot on consecutive TDMA frames. Several logical channels can share the same physical channel, making the use of time slots more efficient.

The GSM specifications 05.02 specify several combinations of channel types (the sequence of logical channels is fixed). The order of the logical channels depends on the channel combination.

2.5 MULTIFRAME, SUPERFRAME & HYPERFRAME CONCEPT

2.5.1 MULTIFARME

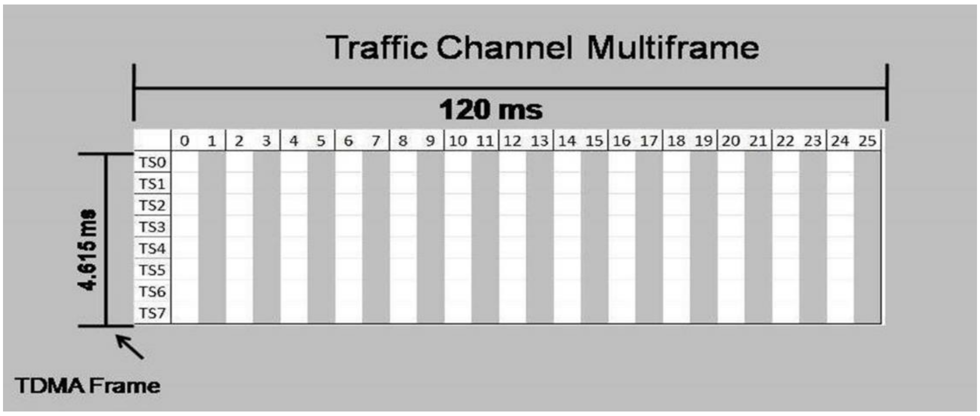
Logical Channel not required to be repeated in each frame. A Multiframe is composed of multiple TDMA frames. In a Multiframe all logic will be repeated once. There are two types of multiframes:

- Traffic Channel Multiframes
- Control Channel Multiframes

A TDMA frame consists of eight timeslots (physical channels). The length of a timeslot is 0.577 ms. The length of a TDMA frame is therefore 4.62 ms. Note: because data on a timeslot is transmitted in bursts, the length of a timeslot is often expressed in BP (Burst Period); 1 BP represents the length of 1 timeslot.

2.5.2 TRAFFIC CHANNEL MULTIFRAME

This multi-frame is defined as a succession of 26 TDMA frames. Used to carry TCH, SACCH and FACCH



26 TDMA frame, Duration: 4.615 * 26= 120 ms

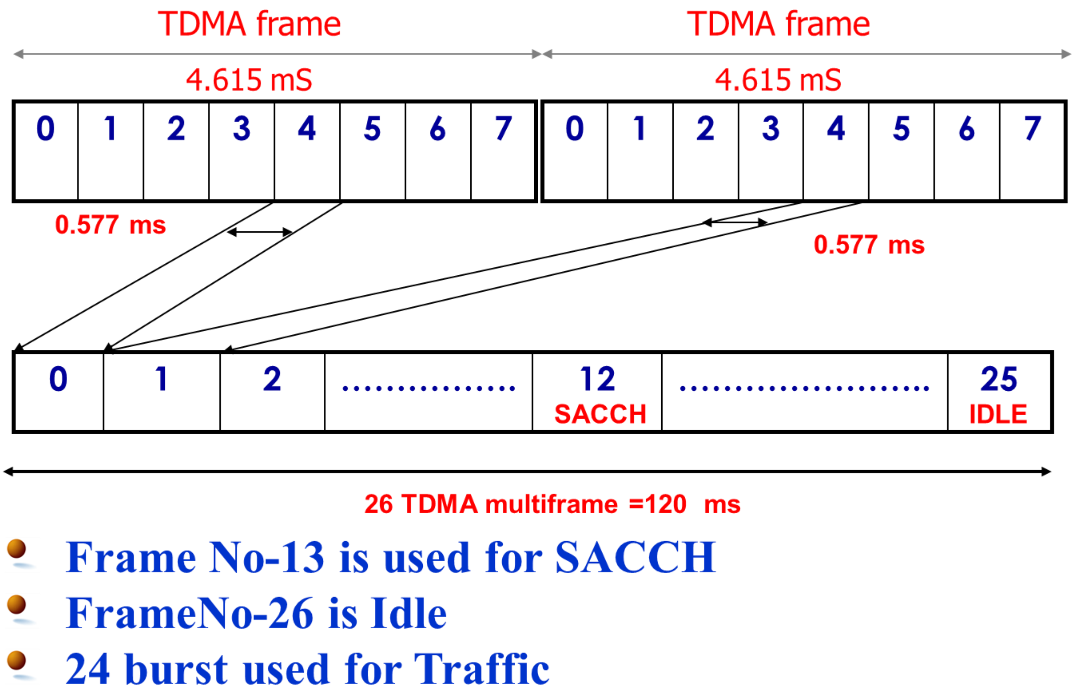


Figure 27: Traffic Channel Multiframe

2.5.3 CONTROL CHANNEL MULTIFRAMES

This multi-frame is defined as a succession of 51 TDMA frame , Duration : 4.615 * 51= 235.4 ms. Used to carry BCCH, CCCH, SDCCH and SACCH. 51 Frame structure occurs in several form depending on type of control channel and requirement.

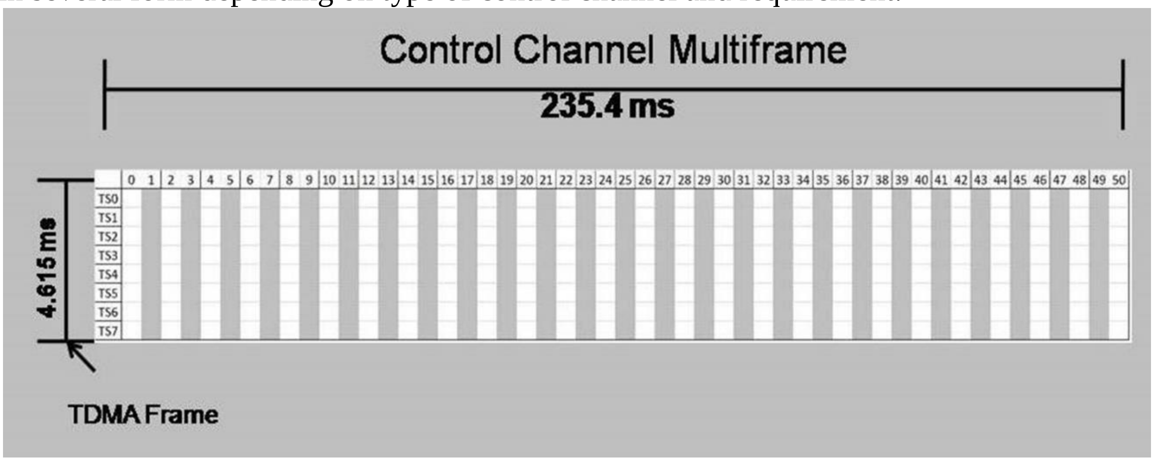


Figure 28: Control Channel Multiframe

2.5.4 SUPERFRAME

The super frame is a succession of 51 x 26 TDMA frames (6.12 sec), and corresponds to the smallest cycle for which the organization of all channels is repeated.

Control channel multiframe is not direct multiple of traffic channel multiframe.

Any given frame number will only occur simultaneously in both multiframe every 1326 TDMA Frame (26 * 31).26 no of Control Multiframe will form a Superframe also 51 no of Traffic Multiframe will form a Superframe. Timing of traffic channel multiframe is always moving in relation to that oh control multiframe – this enable MS to receive and decode BCCH from surrounding cells.

2.5.5 HYPER FRAME

Hyperframe consist of 2048 superframe. This is used in connection with ciphering and frequency hoping. Hyperframe duration = 3 hrs 28 min 53 sec. After this time the ciphering and frequency hoping algorithms are restarted.

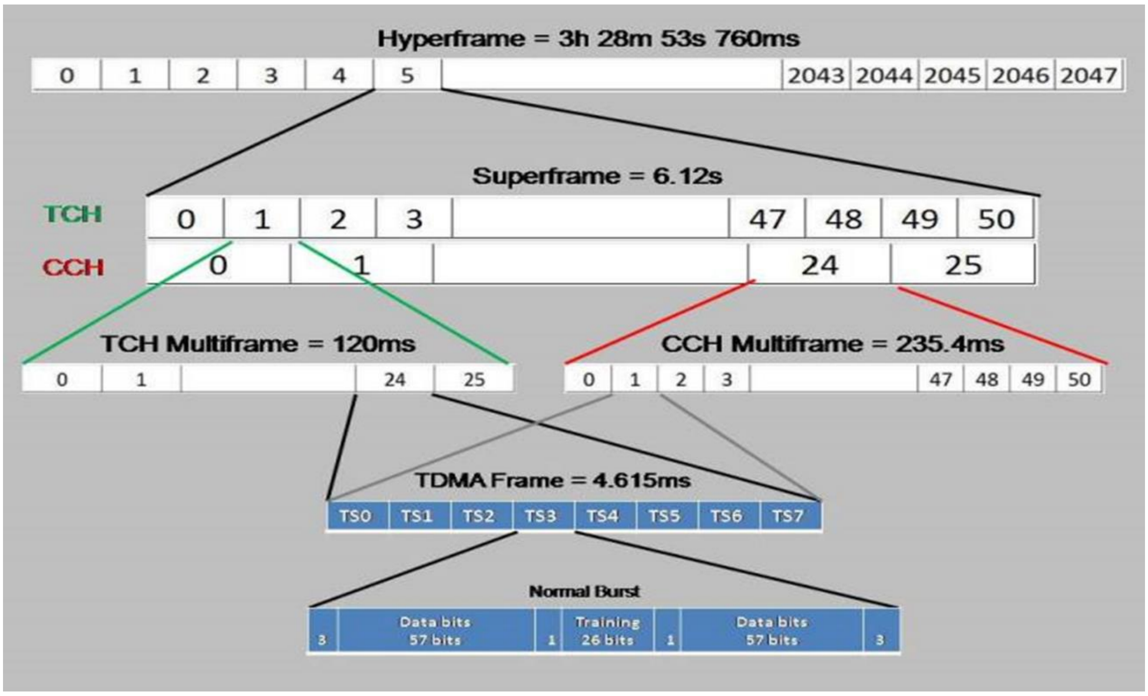


Figure 29: Hyperframe and Superframe

2.6 GPRS LOGICAL CHANNELS:

There is a variety of channels used within GPRS, and they can be set into groups dependent upon whether they are for common or dedicated use. Naturally the system does use the GSM control and broadcast channels for initial set up, but all the GPRS actions are carried out within the GPRS logical channels carried within the PDCH.

2.6.1 BROADCAST CHANNELS:

Packet Broadcast Control Channel (PBCCH): This is a downlink only channel that is used to broadcast information to mobiles and informs them of incoming calls etc. It is very similar in operation to the BCCH used for GSM. In fact the BCCH is still required in the initial to provide a time slot number for the PBCCH. In operation the PBCCH broadcasts general information such as power control parameters, access methods and operational modes, network parameters, etc, required to set up calls.

2.6.2 COMMON CONTROL CHANNELS:

- Packet Paging Channel (PPCH): This is a downlink only channel and is used to alert the mobile to an incoming call and to alert it to be ready to receive data. It is used for control signalling prior to the call set up. Once the call is in progress a dedicated channel referred to as the PACCH takes over.

- Packet Access Grant Channel (PAGCH): This is also a downlink channel and it sends information telling the mobile which traffic channel has been assigned to it. It occurs after the PPCH has informed the mobile that there is an incoming call.
- Packet Notification Channel (PNCH): This is another downlink only channel that is used to alert mobiles that there is broadcast traffic intended for a large number of mobiles. It is typically used in what is termed point-to-point multicasting.
- Packet Random Access Channel (PRACH): This is an uplink channel that enables the mobile to initiate a burst of data in the uplink. There are two types of PRACH burst, one is an 8 bit standard burst, and a second one using an 11 bit burst has added data to allow for priority setting. Both types of burst allow for timing advance setting.

2.6.3 DEDICATED CONTROL CHANNELS:

- Packet Associated Control Channel (PACCH): : This channel is present in both uplink and downlink directions and it is used for control signalling while a call is in progress. It takes over from the PPCH once the call is set up and it carries information such as channel assignments, power control messages and acknowledgements of received data.
- Packet Timing Advance Common Control Channel (PTCCH): This channel, which is present in both the uplink and downlink directions is used to adjust the timing advance. This is required to ensure that messages arrive at the correct time at the base station regardless of the distance of the mobile from the base station. As timing is critical in a TDMA system and signals take a small but finite time to travel this aspect is very important if long guard bands are not to be left.

2.6.4 DEDICATED TRAFFIC CHANNEL:

- Packet Data Traffic Channel (PDTCH): This channel is used to send the traffic and it is present in both the uplink and downlink directions. Up to eight PDTCHs can be allocated to a mobile to provide high speed data.

By organising the data to be sent into different channels, the data can be handled accordingly across the radio interface, and also, knowing the type of channel, the system is able to manipulate the data in the correct manner.

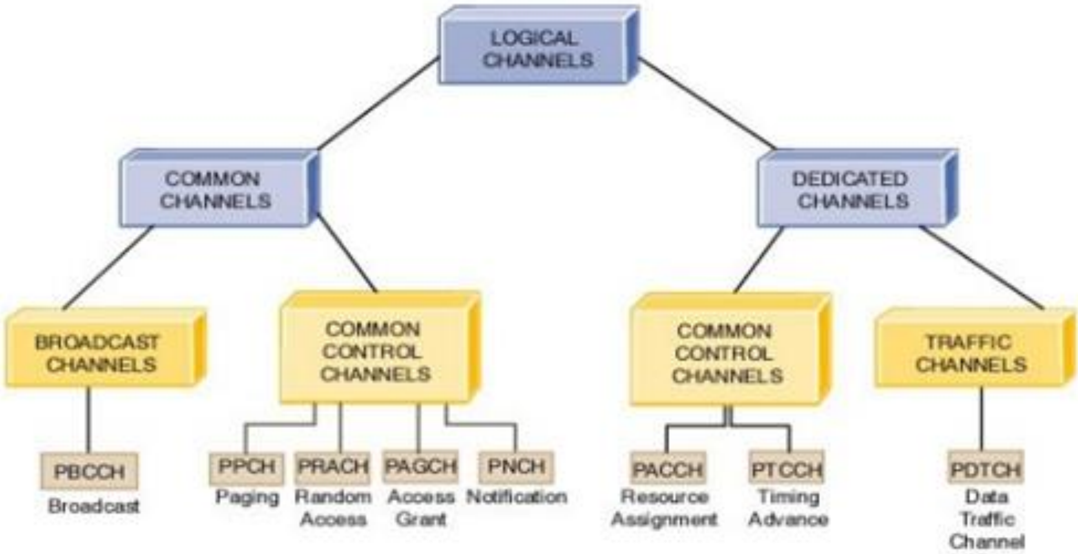


Figure 30: GPRS Logical Channel

2.7 CALL MANAGEMENT IN GSM:

2.7.1 MOBILE ORIGINATED CALL:

There are four distinct phase of a mobile originated call-

1. Setup phase.
2. Ringing phase.
3. Conversation phase.
4. Release phase.

Out of these phases the setup phase is the most important phase and includes authentication of the subscriber, Ciphering of data over radio interface, validation of mobile equipment, validation of subscriber data at VLR for requests service and assignment of a voice channel on A-interface by MSC. Whenever MS wants to initiate an outgoing call or want to send an SMS it requested for a channel to BSS over RACH. On receiving request from MS, BSS assigns a stand-alone dedicated control channel (SDCCH) to MS over access grant channel (AGCH). Once a SDCCH has been allocated to MS all the call set up information flow takes place over SDCCH.

MS now sends a Call Set up Request to the MSC/VLR certain check are performed at MSC/VLR like- whether the requested service is provisioned for the subscriber or not, whether the dialed digits are sufficient or not after this MSC sends Assignment command to the BSS which contains a free voice channel on A-interface On getting this message BSS allocates a free TCH to the MS and informs the MS to attach to it. MS on attaching to this TCH informs the BSS about it. On receiving a response from the BSS, MSC switches the speech path toward the calling MS. Thus at the end of Assignment the speech path is through from MS to MSC

Request for Service:

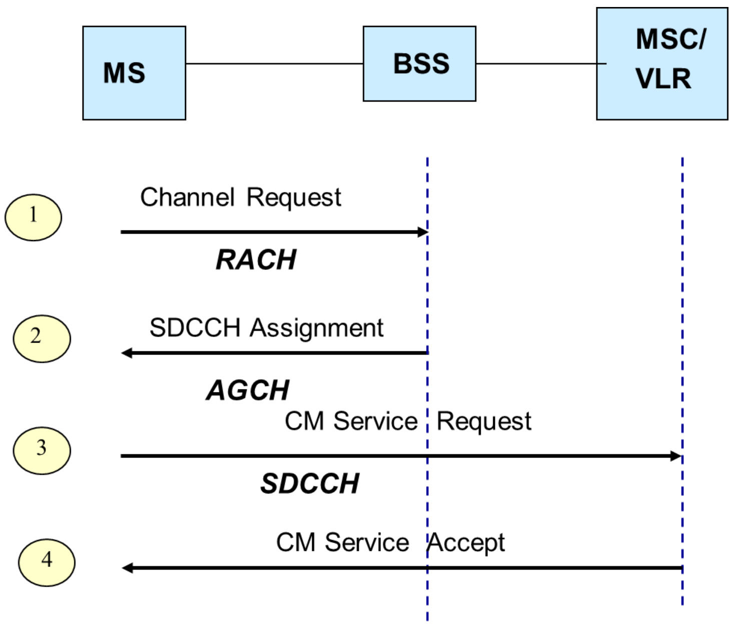


Figure 31: Request for Service

Equipment Validation:

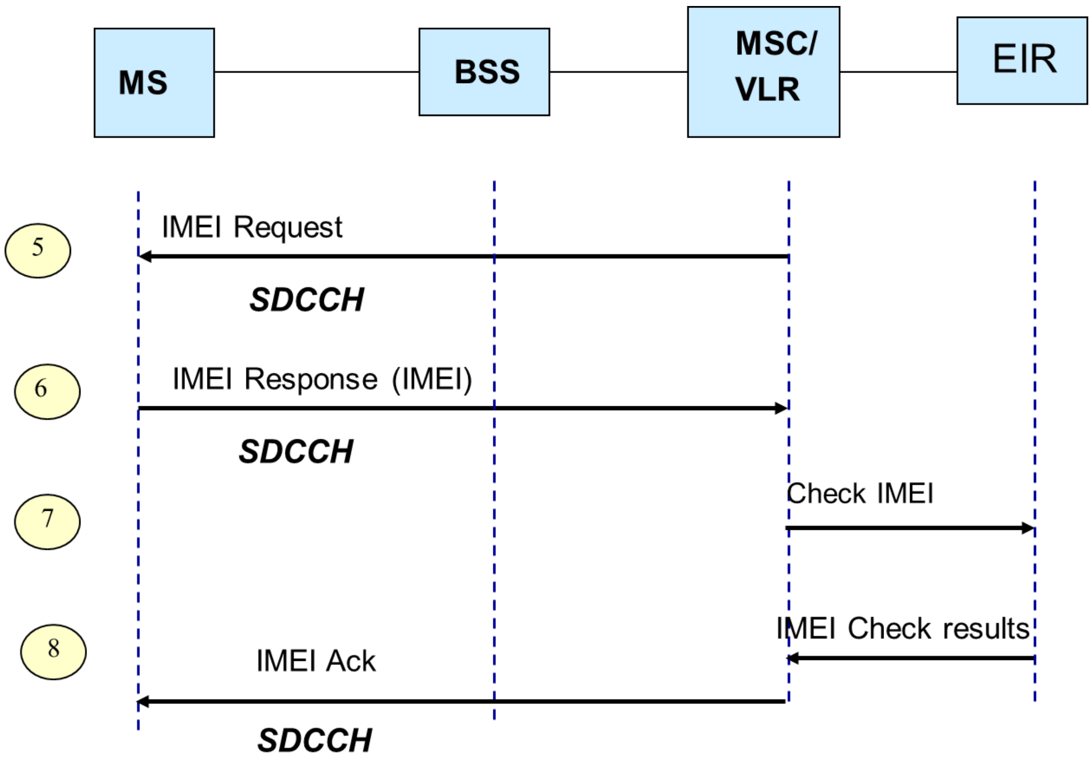


Figure 32: Equipment Validation

Call Setup:

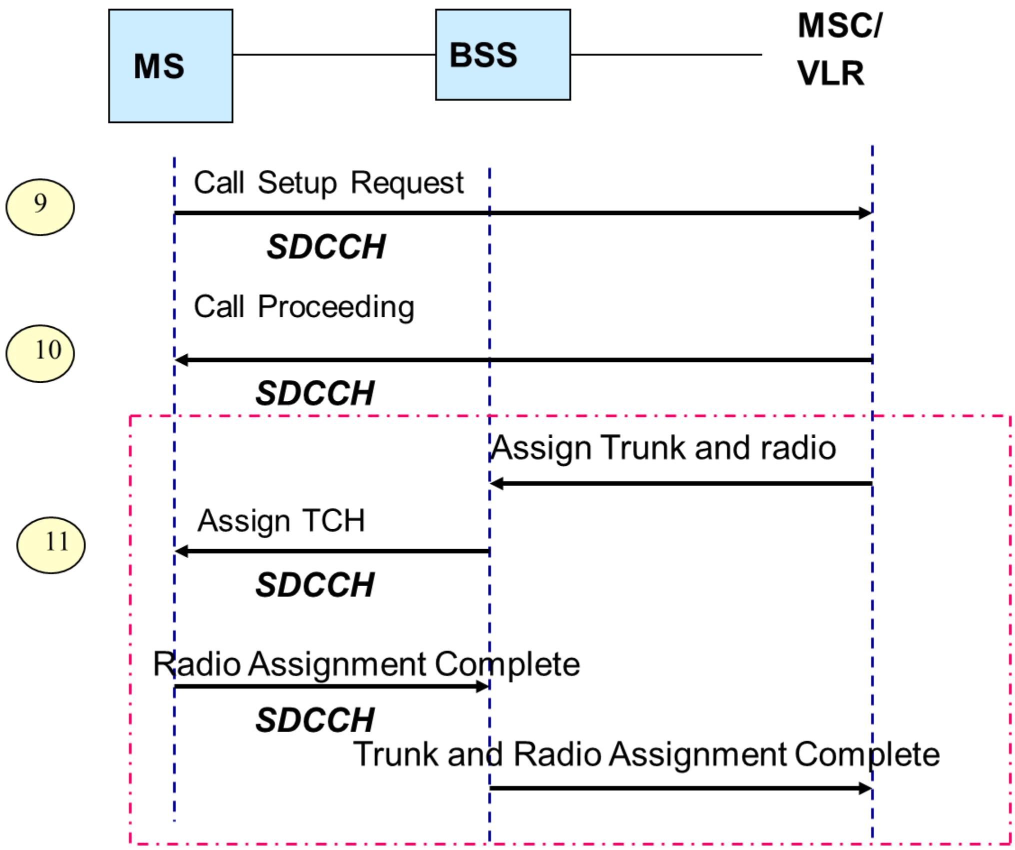


Figure 33: Call Setup

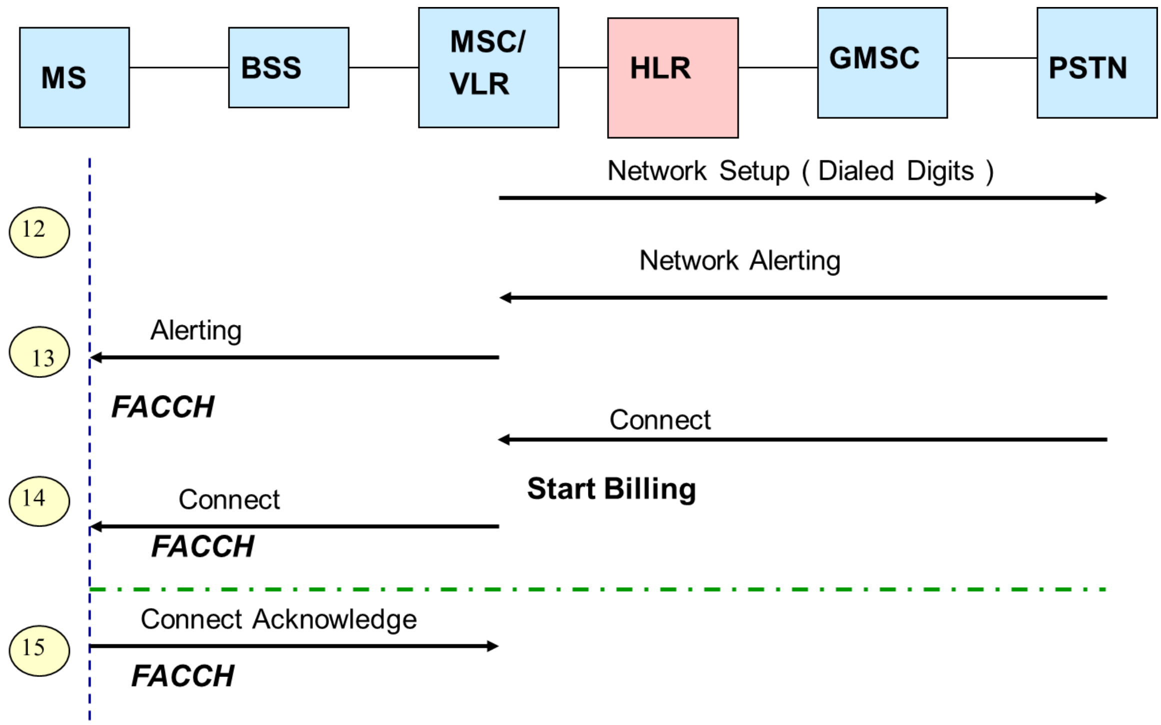


Figure 34: Call Setup

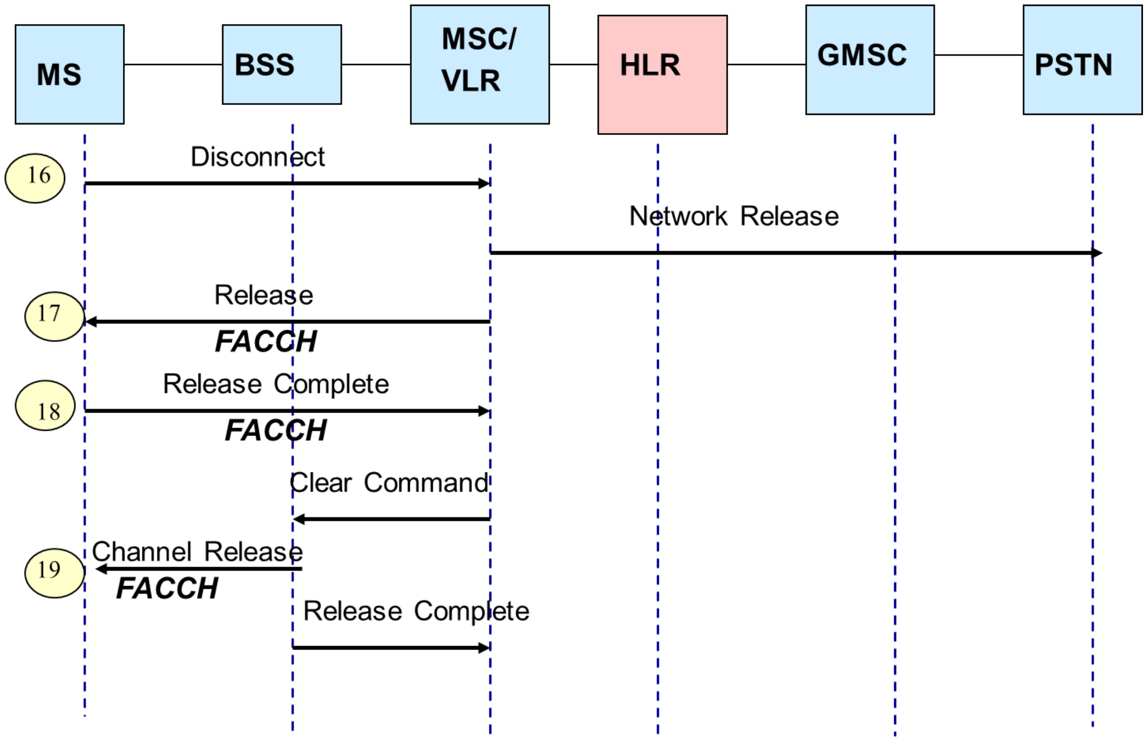


Figure 35: Call Setup

2.7.2 MOBILE TERMINATED CALL:

The different phases of a mobile terminated call are

- Routing analysis
- Paging.
- Call setup.
- Call release.

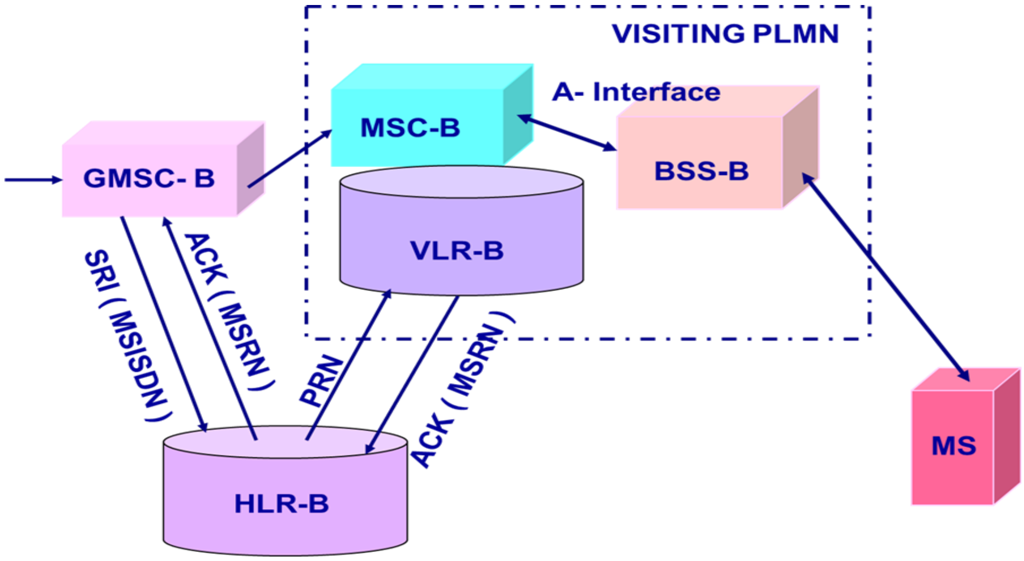


Figure 36: Mobile Terminated Call

The phases of mobile terminated (MT) call are similar to a mobile originated (MO) call except routing analysis and paging phase. Call to a mobile subscriber in a PLMN first comes to gateway MSC (GMSC). GMSC is the MSC, which is the capable of querying HLR for subscriber routing information. GMSC need not to be part of home PLMN, though it is normal practice to have GMSC as part of PLMN in commercially deployed networks.

GMSC Send / Routing / Info-Request (SRI request) is sent to HLR. SRI request contains MSISDN of the subscriber. HLR sends Provide / Roaming / Number-request (PRN request) to the VLR. VLR responds to PRN request with PRN response message, which carries an MSRN (mobile subscriber roaming number), which can be used for routing toward visiting MSC in the network. HLR returns MSRN to GMSC (MSC that queried HLR) in SRI response message. On getting MSRN the GMSC routes the call towards VMSC. The purpose of this entire exercise is to locate where the terminating mobile subscriber is.

VMSC uses the LAI provided by the VLR to determine which BSS"s should page the MS. MSC transmit a message to each of these BSS requesting that a page be performed.

Included in the message is the TMSI of the MS. Each of the BSS"s broadcasts the TMSI of the mobile in a page message on paging channel (PCH).When MS detects its TMSI broadcast on the paging channel, it responds with a channel request message over Random Access Channel (RACH). Now onward case is same as we have in MO call.

Routing Analysis :

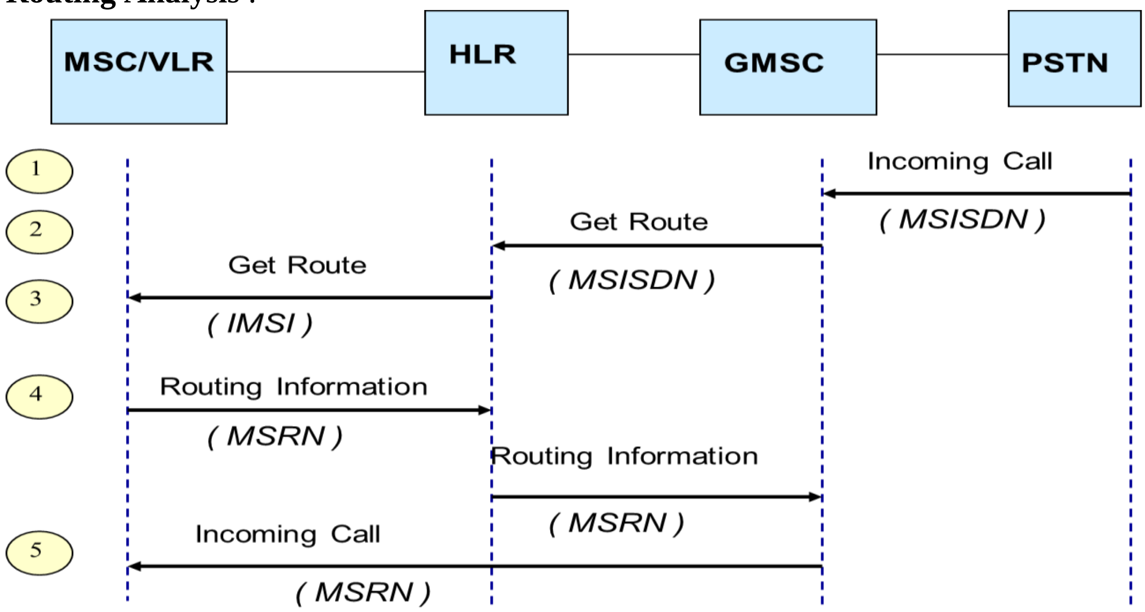


Figure 37: Roaming Analysis

Paging :

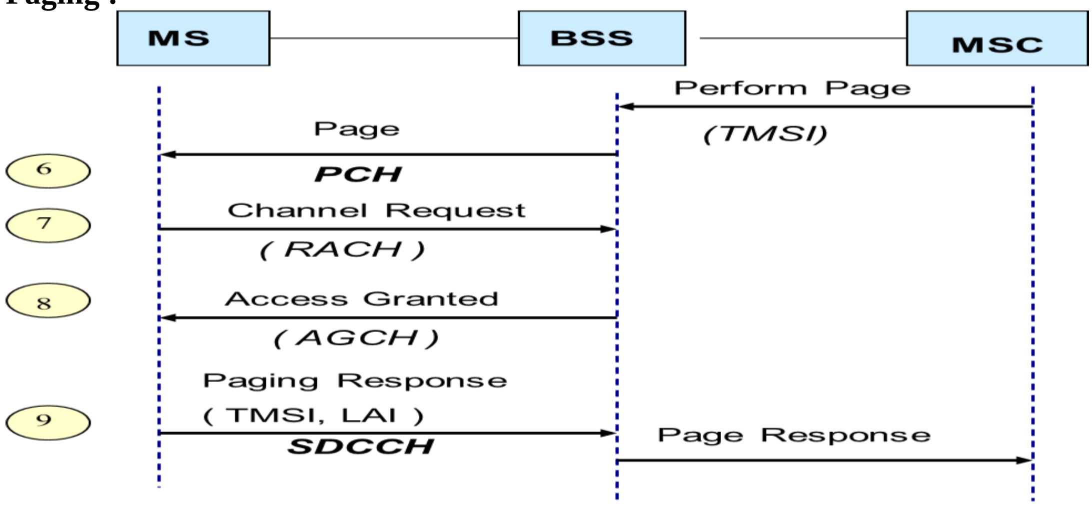


Figure 38: Paging

Call Setup- I :

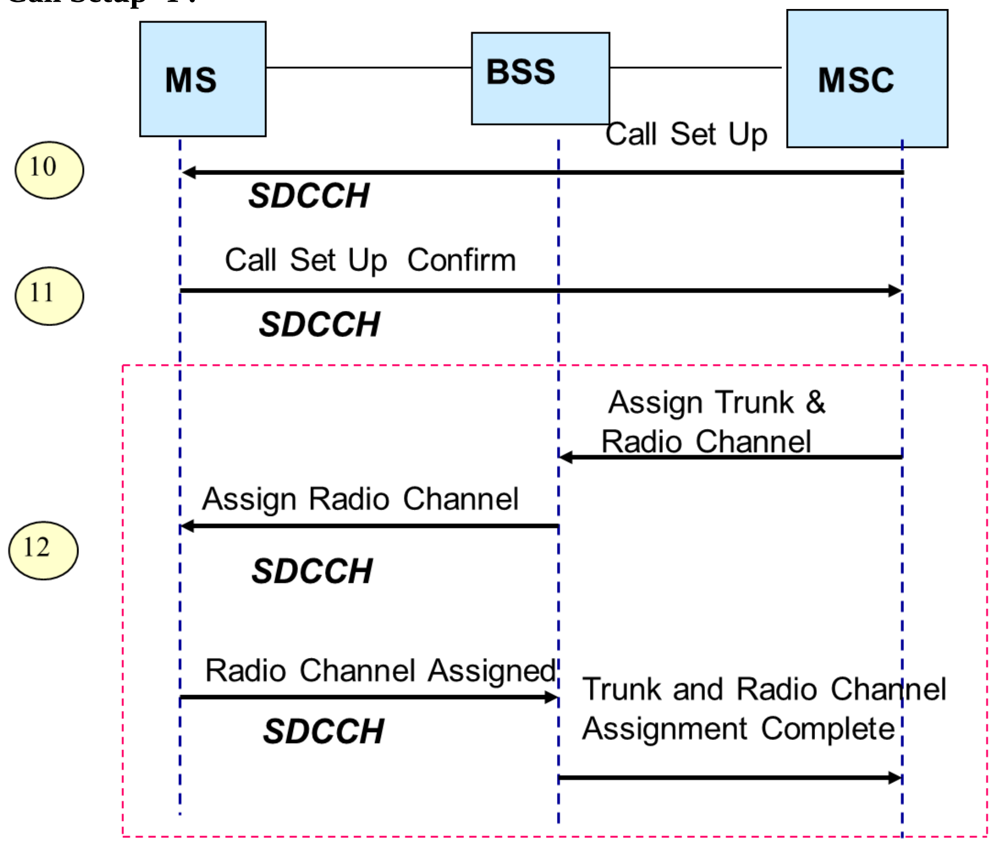


Figure 39: Call Setup

Call Setup-II :

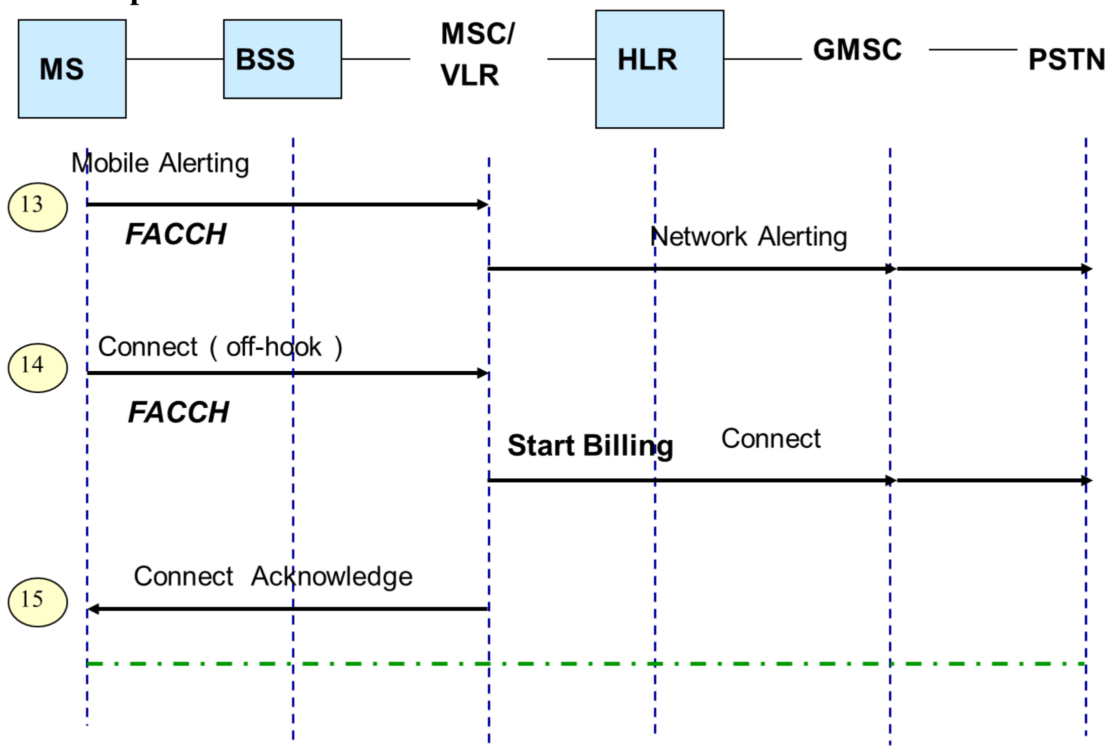


Figure 40: Call Setup

Call Release :

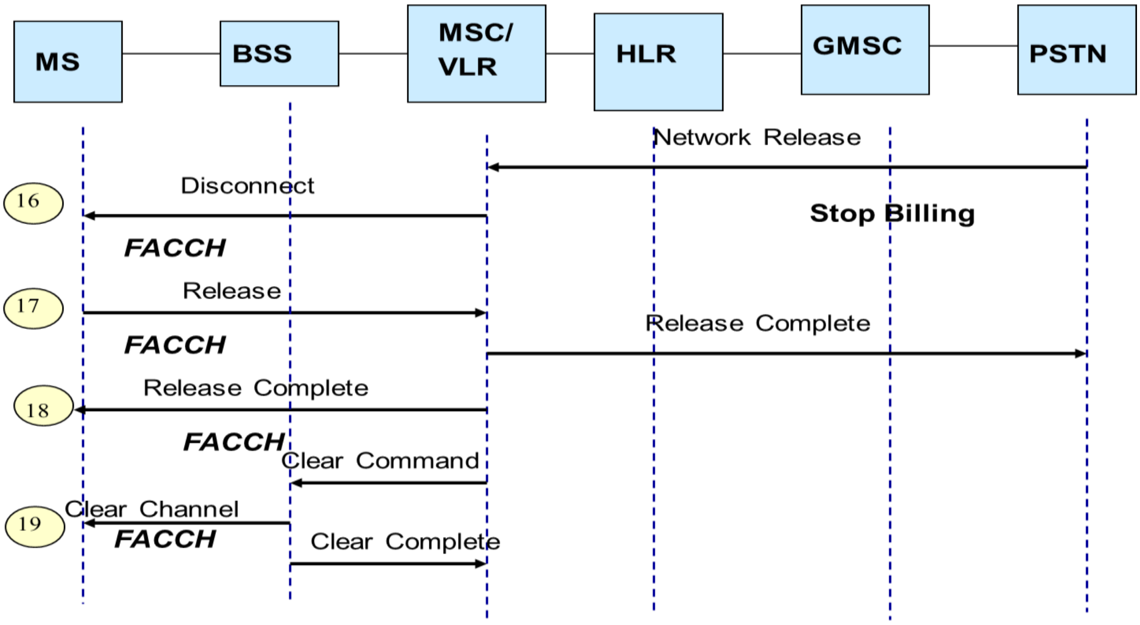


Figure 41: Call Setup

2.7.3 MOBILE TO MOBILE CALL:

The mobile-to-mobile call scenario is a combination of phases encountered in mobile originated (MO) and mobile terminated (MT) call.

The Mobile-to-mobile call is established using the same phases as seen earlier. The originating mobile part where the phases are the same as those of a mobile-to-land call, except that the call setup phase is partially performed. This means that only the call setup with Mobile is done. The terminating mobile part consist of the same phases as the land-to-mobile call scenario except again that the call setup phase performs only call setup with mobile. The figure below shows the channel assignment during the call.

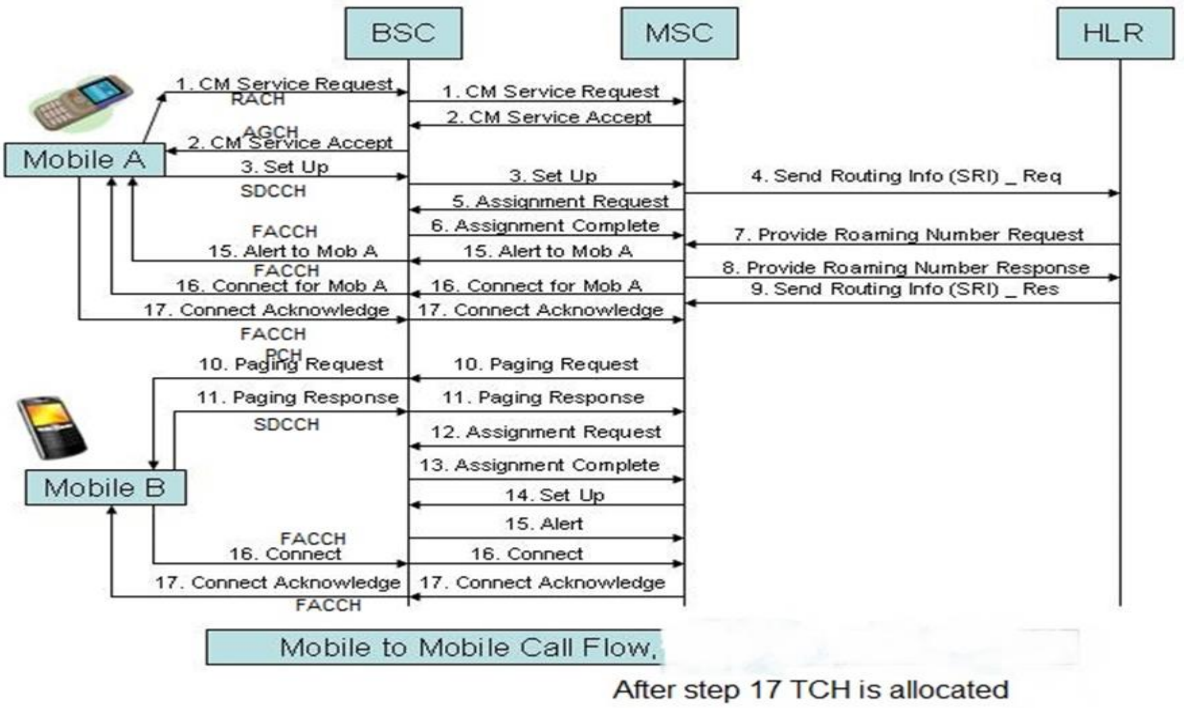


Figure 42: Mobile to Mobile Call

2.8 CONCLUSION

GSM is very successful technology due to its robust radio network design. By virtue of TDMA and frequency reuse the capacity of GSM system is increased tremendously. But with the introduction of Data on mobile GSM has lost its shine as it deliveries very less data rates. Thus, GSM has been migrated to newer technologies such as GPRS and EDGE

3 3G RADIO NETWORK – WCDMA

3.1 LEARNING OBJECTIVE

After completion of this chapter you will come to know about 3G Radio Network. WCDMA Technology is explained in this chapter along with basic CDMA technology and various codes used in 3G.

3.2 INTRODUCTION

3G refers to the 3rd generation of mobile telephony (that is cellular) technology. The 3rd generations the name suggests, follow two earlier generations. The 1st generation (1G) began in the early80's with commercial development of advanced mobile phone service (AMPS) cellular networks. Early AMPS network used frequency division multiplex access (FDMA) to carry analog voice over channels in the 800MHZ frequency band. The 2nd generation (2G) emerged in the 90's when mobile generators deployed two competing digital voice standards. In the North America, some operators adopted IS-95, which uses CDMA to multiplex up to 64 calls per channel in the 800MHZ band. Across the world, many operators adopted the global system for mobile communication (GSM) standard, which used the time division multiple accesses (TDMA) technique to multiplex up to 8 calls per channel in the 900MHZ and 1800MHZ spectrum bands.

The international telecommunication union (ITU) defined the 3rd generation (3G) of mobile telephony standards IMT-2000 to facilitate growth, increase bandwidth and support more diverse applications. Some of the limitations of 2Gsystems, it's only voice oriented, it has limited data capabilities, no worldwide (WW) roaming and incompatible system in different countries. Despite the extension of 2G system i.e. 2.5G such as GPRS and EDGE, which provides the enhanced facilities and much improved data rates, but there was still incompatibility issues and WW-roaming problems. Therefore, there was a need of a system that could provide more advanced services. Some of the features of the 3G systems are:

- Bit rates up to 2Mbps
- Variable bit rate to offer bandwidth on demand
- Multiplexing of services with different Qos requirements on a single connection
- Quality requirements from 10% frame error rate to 10-6 bit error rate.
- Co-existence with different systems and inter-system handovers for coverage enhancement sand loading balancing.
- Uplink and downlink asymmetry e.g. web browsing causes more loading to downlink than to uplink.
- High spectrum efficiency
- Co-existence of FDD (Frequency division duplex) and TDD (time division duplex) modes

3.3 3G STANDARDS AND WCDMA RELEASES

Universal Mobile Telecommunication System (UMTS) is the standard for European 3G based WCDMA systems which turned out to be the preferred solution for countries with 2G because of its high data capability. The 3rd Generation Partnership Project (3GPP) manages the UMTS and has assumed responsibility for the continued standardization of GSM since July 2000. If we recall the first commercial UMTS network was deployed in 2001 by NTT Do Como in Japan after since then other countries soon took the same step in deploying the network including Germany, UK, France etc. During the development of the UMTS specifications for the WCDMA systems within the3GPP, it went through a series of phases and continuous update for instance the first UMTS specification released which is known as the 3GPP *Release-99* which was functionally frozen in December 1999, which then implemented similar services with those of GSM phase 2+(GPRS/EDGE). However the 3G network might still offer additional services which are not available on the GSM platform e.g. video call. In the second phase brought about the3GPP *Release- 4* which would introduce mainly an all IP-Core Network which would allow for the separation of call signalling and control from all actual connections i.e. within the core network the flow of data will pass through a media gateway (MGW) which would in turn maintain the connection and perform other switching functions this approach was known as *Soft Switching,* however release-4 became frozen in march 2001because of newer releases to be introduced. After a while there was another release termed as the 3GPP *Release 5* which introduced the IP Multimedia Subsystem (IMS) which would unify and perform all IP based multiservice i.e. a combination of more than one service on a physical channel to a user e.g. voice & video or image. The introduction of HSDPA and wide band AMR services are evolution of the Air Interface in order to enhance the speed of the data rate, which was done by integrating the voice data on the dedicated channel and data on the downlink shared channel are all multiplexed and carried on the same carrier which allows for speed up to 14.Mbps .

However release 5 specifications were soon frozen in 2002, nevertheless subsequent releases within the specifications occur mainly with the transport technology; basically the changes are made to improve the flexibility and efficiency of the operating network.

3.4 CODE DIVISION MULTIPLE ACCESS AND WCDMA

Code Division Multiple Access (CDMA) is a multiple access technology where the users are separated by unique codes, which means that all users can use the same frequency and transmit at the same time. With the fast development in signal processing, it has become feasible to use the technology for wireless communication, also referred to as WCDMA and CDMA2000. In cdma One and CDMA2000, a 1.25 MHz wide radio signal is multiplied by a spreading signal (which is a pseudo-noise code sequence) with a higher rate than the data rate of the message. The resultant signal appears as seemingly random, but if the intended recipient has the right code, this process is reversed and the original signal is extracted. Use of unique codes means that the same frequency is repeated in all cells, which is commonly referred to as a frequency re-use of 1.

WCDMA is a step further in the CDMA technology. It uses a 5 MHz wide radio signal and a chip rate of 3.84 Mcps, which is about three times higher than the chip rate of CDMA2000 (1.22 Mcps). The main benefits of a wideband carrier with a higher chip rate are:

- Support for higher bit rates
- Higher spectrum efficiency
- Higher QoS

Further, experience from second-generation systems like GSM and cdma One has enabled improvements to be incorporated in WCDMA. Focus has also been put on ensuring that as much as possible of WCDMA operators' investments in GSM equipment can be reused. Examples are the re-use and evolution of the core network, the focus on co-siting and the support of GSM handover. In order to use GSM handover the subscribers need dual mode handsets.

3.5 WCDMA CONCEPTS

Wideband Code Division Multiple Access is used for transmission and reception in release 99. It concentrates on the air interface's physical layer, and the procedures used in higher layers. The action takes place in the air interface's transport protocols. In the transmitter, the radio link control and medium access control protocols handle tasks such as retransmissions and control of the transmitted data rate. The physical layer then manipulates the data in three stages. In the first stage, the data are processed one bit at a time, to carry out tasks such as error correction coding. In the second stage, the coded bits are divided into shorter units called chips, and the chips are processed at a time using the techniques of CDMA. Finally, the chips are converted from digital to analogue form for transmission over the air interface.

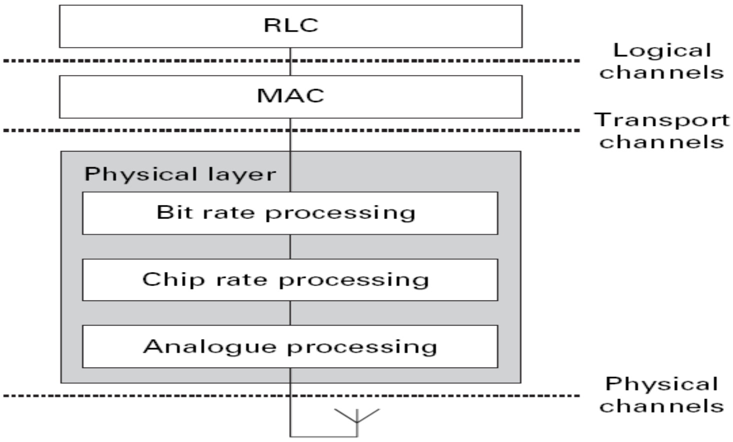


Figure 43: Architecture of the air interface's transport protocols

When the data enter the physical layer, the data rate is typically 12.2 kbps. Using error correction coding and another process called rate matching; the bit rate processor increases the bit rate by a factor between 2 and 3, to 30 kbps. The chip rate processor then divides each coded bit into 128chips, to produce a chip rate of 3.84 million chips per second(Mcps). The same chip rate is used throughout UMTS FDD mode, but the other numbers can vary from one data stream to another, and between the uplink and downlink.

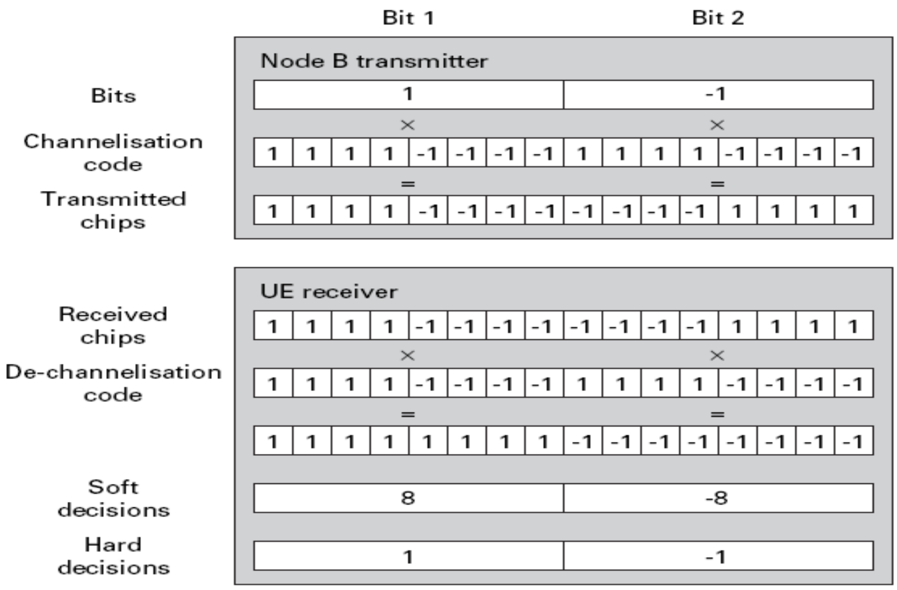


Figure 44: Downlink channelisation and de-channelisation, from a Base Station to a single mobile.

Figure shows the chip rate processing that is carried out on the downlink, in a network containing one mobile and one cell. At the top of the figure, the base station's chip rate transmitter is handling a stream of bits that it wishes to send to the mobile. The base station assigns the mobile a code that is known either as a channelisation code or a spreading code: this is made of chips and has a length equal to the bit duration, so that the code is repeated every bit. It then multiplies the symbol representations of the bits and chips together, and sends the resulting chips to the analogue processor for transmission.

The bits and chips both have values of 0 and 1, but we have represented them using binary phase shift keyed (BPSK) symbols of +1 and –1. In UMTS FDD mode, the chip rate is fixed at 3.84 Mcps, so the chip duration is about 0.26µs. The number of chips per bit is called the spreading factor: in this example, the spreading factor is 8. The bit rate equals the chip rate divided by the spreading factor, so here the bit rate is 480kbps. Note that error correction has already been applied to these bits, so the underlying information rate is typically one third to one half.

If we ignore problems like noise and propagation loss, then the mobile's chip rate processor receives an exact replica of the transmitted chips. We now assume that the base station has previously told the mobile about the channelisation code that it will use, so that the mobile can use this information to undo the effect of channelisation. It does this by multiplying the incoming chips by the channelisation code. The mobile now has to convert the chips into bits, which it does by adding together the chips that comprise each bit. The result is a set of soft decisions, each of which has a sign corresponding to the mobile's best estimate of the transmitted bit, and a magnitude corresponding to the mobile's confidence in that estimate. Finally, the mobile converts the soft decisions into hard decisions by taking the sign and it recovered the original bits.

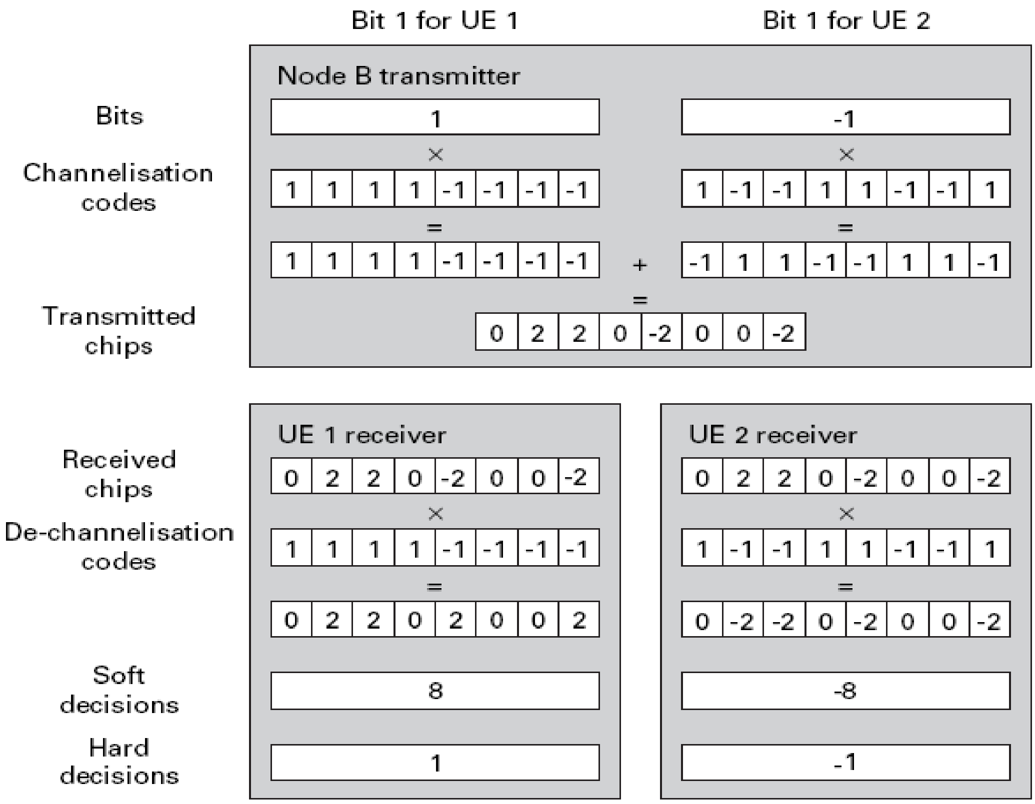


Figure 45: Downlink channelisation &de-channelisation, from a base station to two mobiles.

Figure shows what happens if there are two mobiles in the cell. Here, the base station assigns a different channelization code to the second mobile, with the condition that the two codes must be orthogonal: if we multiply them together chip-by-chip and add up the results, the total must be zero. The base station multiplies the incoming bits by the irrespective channelization codes as before, and then adds the two streams together, chip-by-chip. The transmitted chip stream contains signal levels of +2, 0 and –2, where each chip has contributions for both of the two mobiles. The receive processing is unchanged: each mobile multiplies the incoming stream of chips by its own channelization code, adds together the chips that comprise each bit, and calculates a set of hard decisions. In the figure, the two mobiles have successfully recovered the bits that were intended for them, despite the fact that the transmitted stream contained information for both mobiles. This works because the two channelization codes are orthogonal.

The complete processing procedures of a WCDMA system is shown in figure below Source coding can increase the transmission efficiency of the input service signal. Error detection and correction capabilities are introduced through channel coding to make the transmission more reliable. Multi- level spreading is done to increase the capability of overcoming interference. Through the modulation technique, the signals are then converted to radio signals from digital form for transmission through the channel. At the receiver, reverse of all these processes are carried out to recover the information signal back.

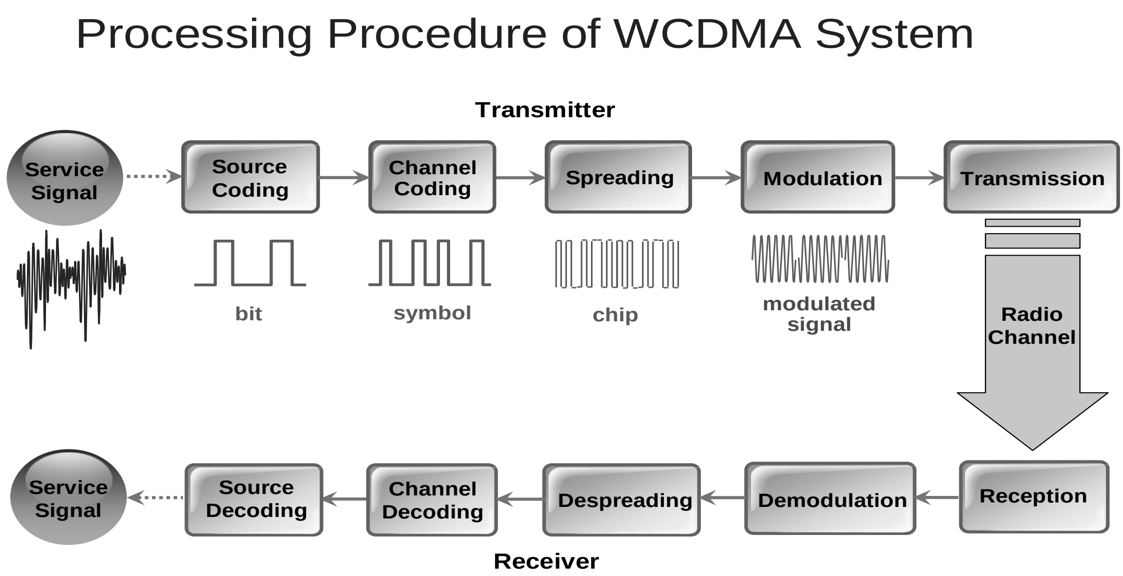


Figure 46: A WCDMA System

3.6 WCDMA CODES

Two categories of codes used with UMTS WCDMA systems are Channelisation codes and scrambling codes. Channelisation codes are orthogonal codes, based on Orthogonal Variable Spreading Factor (OVSF) technique. The codes are fully orthogonal, i.e., they do not interfere with each other, if they are time synchronized. Thus, channelisation codes can separate the transmissions from a single source. In the downlink, it can separate different users within one cell/sector. The OVSF channelisation codes are picked from the code tree shown in Figure We can think of the figure as a family tree in which each channelisation code has two children, one made by repeating it, and the other by repetition and inversion. The codes on each spreading factor are all mutually orthogonal, while codes on different spreading factors are orthogonal too, so long as they are not ancestors or descendants of each other.

The number of orthogonal codes available is equal to the spreading factor i.e. eight orthogonal codes at a spreading factor of eight. The spreading factors are implicitly restricted to integer powers of 2: in release 99, we only use spreading factors from 4 to 512 on the downlink, and 4 to 256 on the uplink. The channelisation code tree can only accommodate a limited number of mobiles, so we want to re-use it in every cell. This causes a problem if two nearby cells are transmitting on the same frequency and the same channelisation code, because of cross-talk between the two transmissions. This problem can be solved by introducing a second set of codes, known as scrambling codes, and labeling each nearby cell with a different scrambling code.

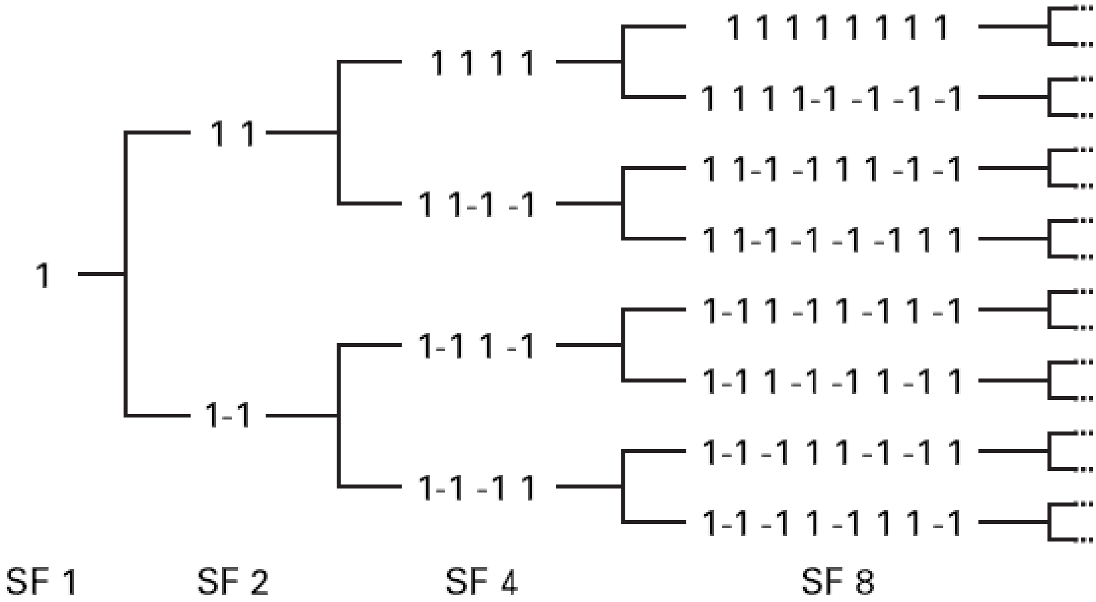


Figure 47: WCDMA Code Tree

3.7 CHANNELISATION CODES USED BY UMTS (ADAPTED FROM 3GPP TS 25.213.)

The scrambling codes are made of chips, but they have a much longer repetition period than the channelisation codes: 10ms, which is 38400 chips. In UMTS, there are enough scrambling codes to label 512 different cells. This number is large enough that cells on the same scrambling code are a large distance apart, and the cross-talk between them is minimal. Ideally, the scrambling codes would be orthogonal to each other, but here all the orthogonal codes are used in making the tree of channelisation codes. So codes are created using a pseudo-random number generator, which makes the scrambling codes uncorrelated. If we multiply two scrambling codes together and add up the results as before, then the total is zero on the average, but it is not identically zero.

The effect of using uncorrelated codes is shown in figure which has four cells with different scrambling codes, each transmitting to a different mobile. In this figure, the spreading factor is four, so take the first four chips from each scrambling code. Here each mobile receives a signal from its corresponding Node B, and interference from the other three. The channelisation codes are left out for clarity: Choose channelisation codes of 1111 throughout, which would leave all the other numbers unchanged. Also assume that each mobile receives equally strong signals from the four cells; this is a rather artificial situation, but it serves to illustrate the point. Each cell applies its scrambling codes by a chip-by-chip multiplication, and the process is reversed in the mobile receiver. Because the scrambling codes are uncorrelated and not orthogonal, the mobiles receive some interference from neighboring cells.

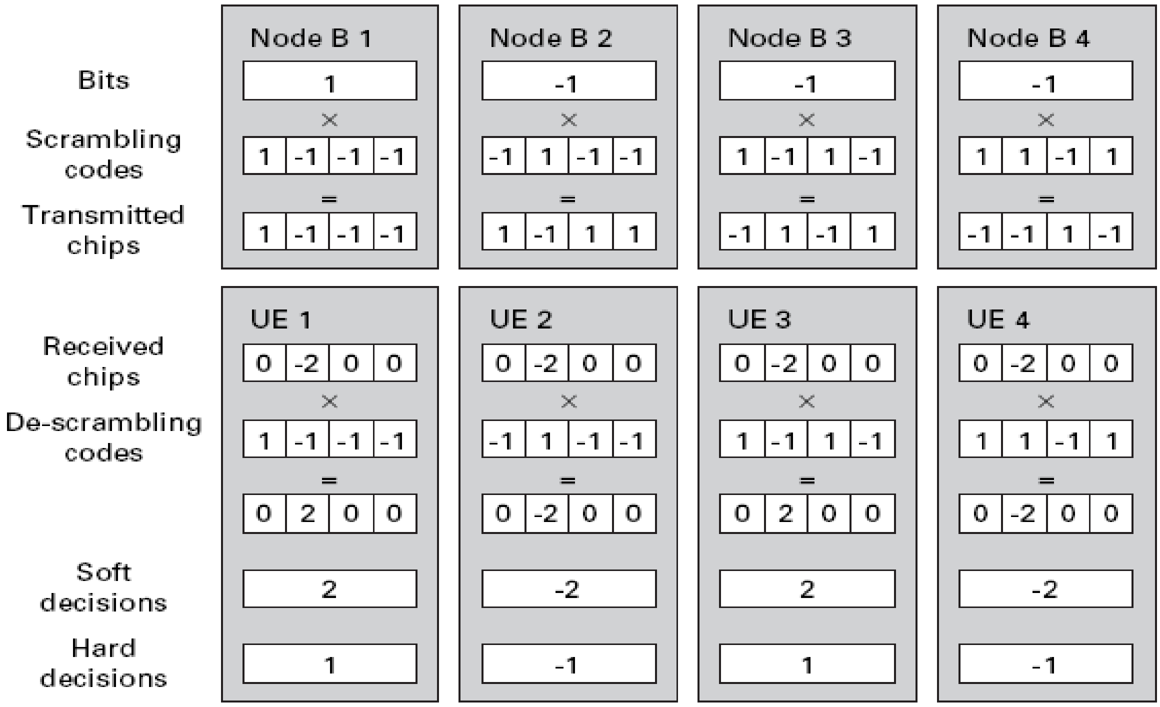


Figure 48: Scrambling and de-scrambling on the downlink.

This perturbs the soft decisions away from their expected values, and occasionally causes errors in the hard decisions. The receiver can correct most of these errors later on using error correction and retransmissions, but some of them will leak through and degrade the performance of the application. The interference and the resultant errors are a very important issue in UMTS, and will ultimately limit the capacity of the system.

In the uplink, the processing steps are exactly the same, but the channelisation and scrambling codes are used differently. The reason is that, in FDD mode, the transmissions from different mobiles are not time synchronised in any way. This simplifies the design of the system, but it has a disadvantage: it is impossible to distinguish the mobiles by the use of different channelisation codes, because those codes are only orthogonal if they are time synchronised with each other. Instead, the network distinguishes different mobiles by assigning different scrambling codes to them, which ever cell they are in. The channelisation codes are only used for two purposes: to set the data rate by means of the spreading factor, and to distinguish different transmissions from a single mobile.

3.8 WCDMA RADIO ACCESS NETWORK

The main purpose of the WCDMA Radio Access Network is to provide a connection between the handset and the core network and to isolate all the radio issues from the core network. The advantage is one core network supporting multiple access technologies. The WCDMA Radio Access Network consists of two types of nodes:

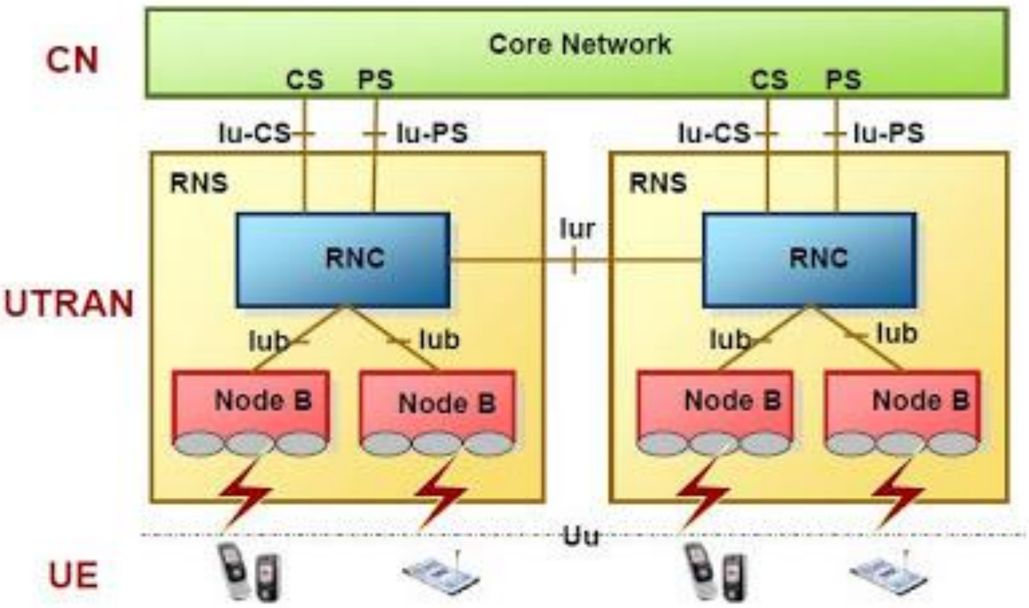


Figure 49: WCDMA Radio Access Network

3.9 RADIO BASE STATION (NODE B)

The Radio Base Station handles the radio transmission and reception to/from the handset over the radio interface (Uu). It is controlled from the Radio Network Controller via the Iub interface. One Radio Base Station can handle one or more cells.

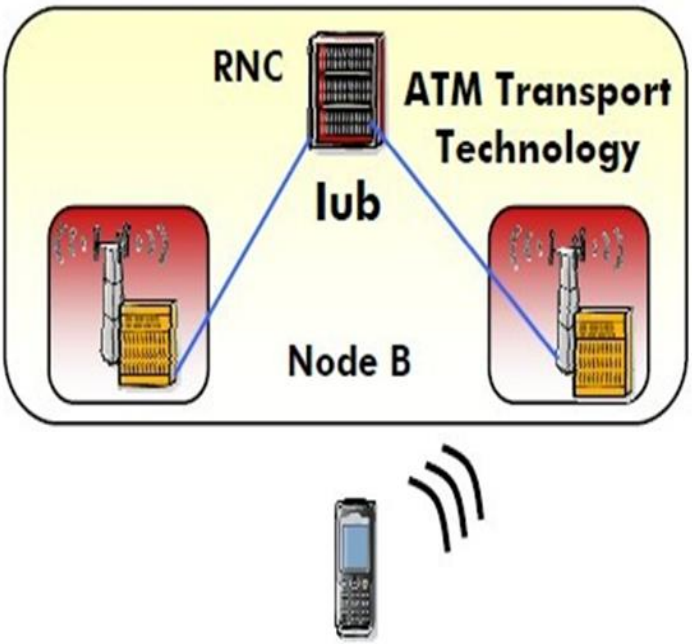


Figure 50: WCDMA Node B

3.9.1 FUNCTIONS OF NODE B:

- Radio transmission and reception handling
- Involved in the mobility management
- Involved in the power control
- Modulation / Demodulation
- Closed loop power control

3.10 RADIO NETWORK CONTROLLER (RNC)

The Radio Network Controller is the node that controls all WCDMA Radio Access Network functions. It connects the WCDMA Radio Access Network to the core network via the Iu interface. There are two distinct roles for the RNC, to serve and to control. The Serving RNC has overall control of the handset that is connected to WCDMA Radio Access Network. It controls the connection on the Iu interface for the handset and it terminates several protocols in the contact between the handset and the WCDMA Radio Access Network. The Controlling RNC has the overall control of a particular set of cells, and their associated base stations.

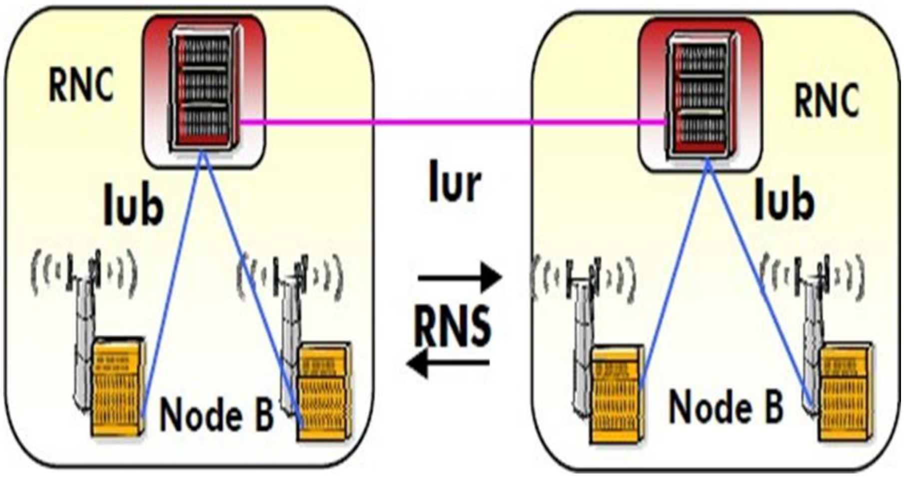


Figure 51: Radio Network Controller

Main Functions of this Intelligent part of UTRAN System includes;

- Radio resource management (code allocation, Power Control,
- congestion control, admission control)
- Call management for the users
- Connection to CS and PS Core Network
- Radio mobility management

When a handset must use resources in a cell not controlled by its Serving RNC, the Serving RNC must ask the Controlling RNC for those resources. This request is made via the Iur interface, which connects the RNCs with each other. In this case, the

Controlling RNC is also said to be a Drift RNC for this particular handset. This kind of operation is primarily needed to be able to provide soft handover throughout the network.

3.11 RADIO ACCESS BEARERS

The main service offered by WCDMA RAN is the Radio Access Bearer (RAB). To establish a call connection between the handset and the base station a RAB is needed. Its characteristics are different depending on what kind of service/information to be transported. The RAB carries the subscriber data between the handset and the core network. It is composed of one or more Radio Access Bearers between the handset and the Serving RNC, and one Iu bearer between the Serving RNC and the core network. 3GPP has defined four different quality classes of Radio Access Bearers:

- Conversational (used for e.g. voice telephony) – low delay, strict ordering
- Streaming (used for e.g. watching a video clip) – moderate delay, strict ordering
- Interactive (used for e.g. web surfing) – moderate delay
- Background (used for e.g. file transfer) – no delay requirement

3.12 RADIO NETWORK FUNCTIONALITY

For optimal operation of a complete wireless system i.e. from handset to radio access network (RAN) several functions are needed to control the radio network and the many handsets using it. All functions described in this section, except for Handover to GSM, are essential and therefore necessary for a WCDMA system.

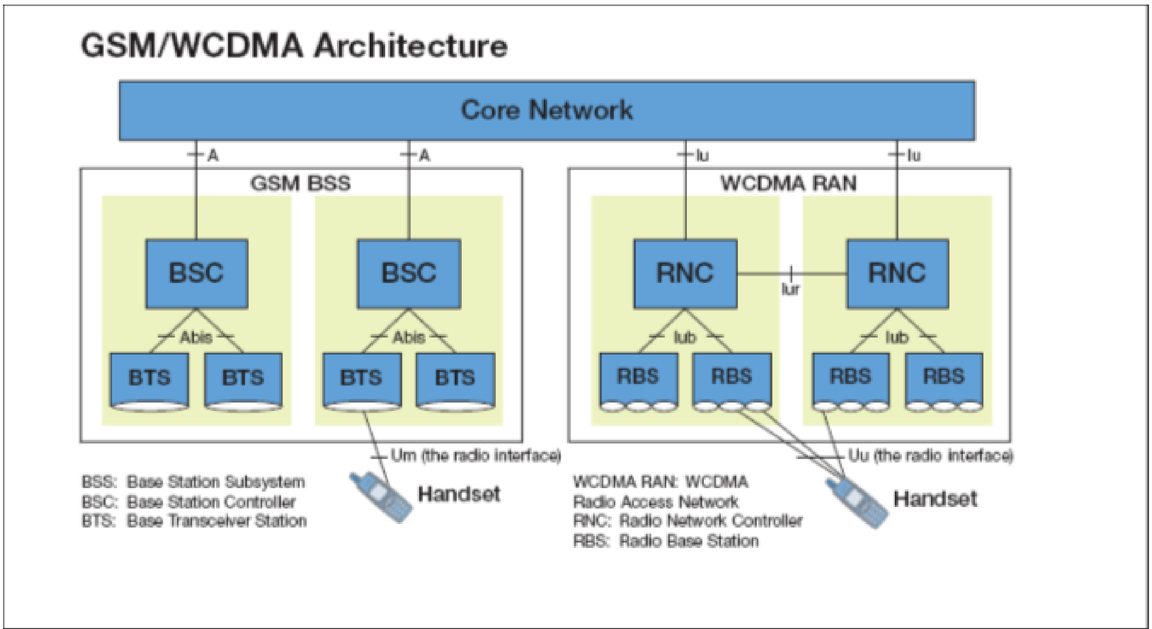


Figure 52: WCDMA Architecture

3.12.1 POWER CONTROL

The power control regulates the transmit power of the terminal and base station, which results in less interference and allows more users on the same carrier. Transmit power regulation thus provides more capacity in the network. With a frequency re-use of 1, it is very important to have efficient power control in order to keep the interference at a minimum. For each subscriber service the aim is that the base station shall receive the same power level from all handsets in the cell regardless of distance from the base station. If the power level from one handset is higher than needed, the quality will be excessive, taking a disproportionate share of the resources and generating unnecessary interference with the other subscribers in the network. On the other hand, if power levels are too low this will result in poor quality. In order to keep the received power at a suitable level, WCDMA has a fast power control that pdates power levels 1500 times every second. By owing that the rapid change in the radio channel is handled. To ensure good performance, power control is implemented in both the up-link and the down-link, which means that both the output powers of the handset and the base station are frequently updated. Power control also gives rise to a phenomenon called “cell breathing”. This is the trade-off between coverage and capacity, which means that the size of the cell varies depending on the traffic load. When the number of subscribers in the cell is low (low load), good quality can be achieved even at a long distance from the base station. On the other hand, when the number of users in the cell is high, the large number of subscribers generates a high interference level and subscribers have to get closer to the base station to achieve good quality.

3.12.2 SOFT AND SOFTER HANDOVER

With soft handover functionality the handset can communicate simultaneously with two or more cells in two or more base stations. This flexibility in keeping the connection open to more than one base station results in fewer lost calls, which is very important to the operator. To achieve good system performance with a frequency re-use of 1 and power control, soft and softer handover is required. Soft and softer handover enables the handset to maintain the continuity and quality of the connection while moving from one cell to another. During soft or softer handover, the handset will momentarily adjust its power to the base station that requires the smallest amount of transmit power and the preferred cell may change very rapidly. The difference between soft and softer handover is that during soft handover, the handset is connected to multiple cells at different base stations, while during softer handover, the handset is connected to multiple cells at the same base station. A drawback with soft handover is that it requires additional hardware resources on the network side, as the handset has multiple connections. In a well-designed radio network, 30–40 % of the users will be in soft or softer handover.

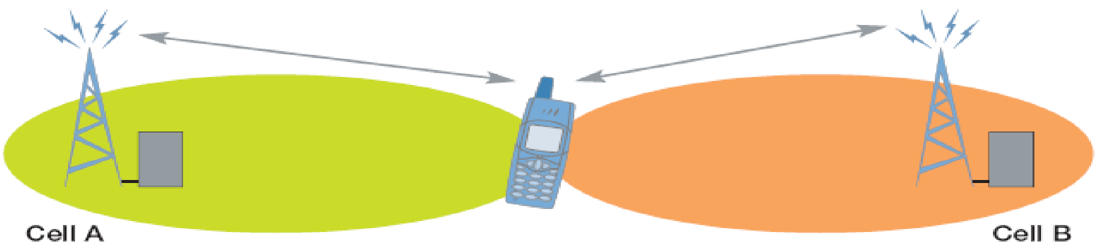


Figure 53: Soft and Softer Handover

3.12.3 HANDOVER TO GSM (INTER-SYSTEM HANDOVER)

When WCDMA was standardized a key aspect was to ensure that existing investments could be re-used as much as possible. One example is handover between the new (WCDMA) network and the existing (GSM) network, which can be triggered by coverage, capacity or service requirements. Handover from WCDMA to GSM, for coverage reasons, is initially expected to be very important since operators are expected to deploy WCDMA gradually within their existing GSM network. When a subscriber moves out of the WCDMA coverage area, a handover to GSM has to be conducted in order to keep the connection. Handover between GSM and WCDMA can also have a positive effect on capacity through the possibility of load sharing. If for example the numbers of subscribers in the GSM network is close to the capacity limit in one area, handover of some subscribers to the WCDMA network can be performed. Another function that is related to inter-system handover is the compressed mode. When performing handover to GSM, measurements have to be made in order to identify the GSM cell to which the handover will be made. The compressed mode is used to create the measurement periods for the handset to make the required measurements. This is typically achieved by transmitting all the information during the first 5 milliseconds of the frame with the remaining 5 milliseconds being used for measurements on the other systems.

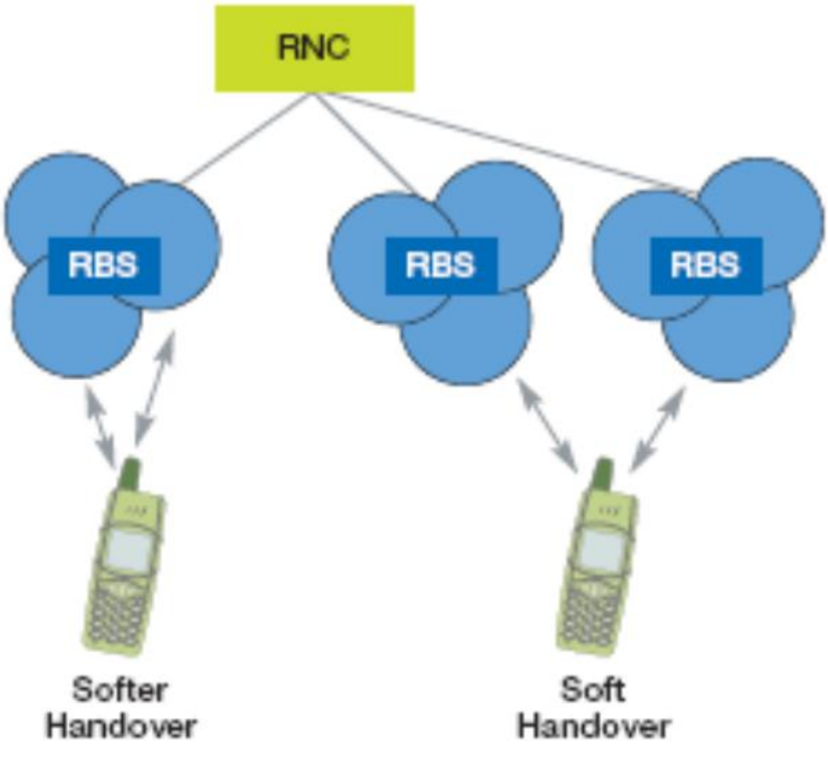


Figure 54: Inter System Handover

3.12.4 INTER-FREQUENCY HANDOVER (INTRA-SYSTEM HANDOVER)

The need for inter-frequency handover occurs in high capacity areas where multiple 5 MHz WCDMA carriers are deployed. Inter-frequency handover, which is handover between WCDMA carriers on different frequencies, has many similarities with GSM handover, for example the compressed mode functionality.

3.13 WCDMA CHANNELS

There are three types of WCDMA UMTS channels viz. logical channels (RLC layer), transport channels (MAC layer) and physical channels (PHY layer). Logical channels define what type of data is transferred. Transport channels define how and with which type of characteristics the data is transferred by the physical layer. Physical channel define the exact physical characteristics of the radio channel.

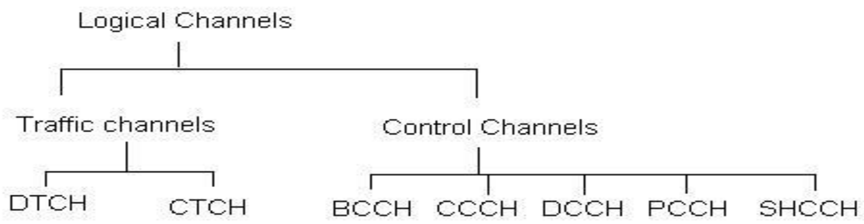


Figure 55: Logical Channels

The logical channels are distinguished by the different type of information they carry. The logical channels include:

- **Broadcast Control Channel (BCCH) (downlink):** This channel broadcasts information to UEs relevant to the cell, such as radio channels of neighboring cells, etc.

- **Paging Control Channel (PCCH) (downlink):** This channel is associated with the PICH and is used for paging messages and notification information.

- **Dedicated Control Channel (DCCH) (up and downlinks)**: This channel is used to carry dedicated control information in both directions.

- **Common Control Channel (CCCH) (up and downlinks):** This bi-directional channel is used to transfer control information.

- **Shared Channel Control Channel (SHCCH) (bi-directional):** This channel is bi-directional and only found in the TDD form of WCDMA / UMTS, where it is used to transport shared channel control information.

- **Dedicated Traffic Channel (DTCH) (up and downlinks):** This is a bidirectional channel used to carry user data or traffic.

- **Common Traffic Channel (CTCH) (downlink)**: A unidirectional channel used to transfer dedicated user information to a group of UEs.

There are different types of transport channels with different characteristics of the transmission as shown in figure. Common transport channels can be shared by multiple handsets (e.g. FACH, RACH, DSCH, BCH, PCH). Dedicated transport channels (DCH) are assigned to only one handset at a time.

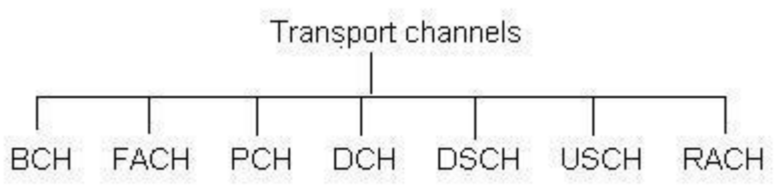


Figure 56: Transport channels

- **Broadcast Channel (BCH) (downlink):** This channel broadcasts information to the UEs in the cell to enable them to identify the network and the cell.
- **Forward Access Channel (FACH) (down link):** This is channel carries data or information to the UEs that are registered on the system. There may be more than one FACH per cell as they may carry packet data.
- **Paging Channel (PCH) (downlink):** This channel carries messages that alert the UE to incoming calls, SMS messages, data sessions or required maintenance such as re-registration.
- **Dedicated Transport Channel (DCH) (up and downlink):** This is used to transfer data to a particular UE. Each UE has its own DCH in each direction.
- **Downlink Shared Channel (DSCH) (downlink):** This channel can be shared by several users and is used for data that is "bursty" in nature such as that obtained from web browsing etc.
- **Uplink Common Packet Channel (CPCH) (uplink):** This channel provides additional capability beyond that of the RACH and for fast power control.
- **Uplink Shared Channel (USCH) (uplink):** It is used as shared channel carrying dedicated user data/control messages in the uplink.
- **Random Access Channel (RACH) (uplink):** This channel carries requests for service from UEs trying to access the system.

A frequency and a code characterize a physical channel (Refer figure below). The specifications include two modes: the FDD mode (Frequency Division Duplex) and the TDD mode (Time Division Duplex). The FDD mode is the mainstream mode that operators are now deploying in WCDMA. The TDD mode may eventually be deployed as well, as a complement to the FDD mode. The transmission functions of the physical layer include channel coding and interleaving, multiplexing of transport channels, mapping to physical channels, spreading, modulation and power amplification, with corresponding functions for reception.

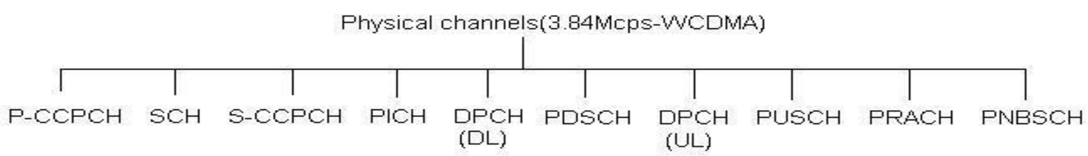


Figure 57: Physical channels

The 3G UMTS physical channels include:

- **Primary Common Control Physical Channel (PCCPCH) (downlink):** This channel continuously broadcasts system identification and access control information.
- **Secondary Common Control Physical Channel (SCCPCH) (downlink)**: This channel carries the Forward Access Channel (FACH) providing control information, and the Paging Channel (PACH) with messages for UEs that are registered on the network.
- **Physical Random Access Channel (PRACH) (uplink):** This channel enables the UE to transmit random access bursts in an attempt to access a network.
- **Dedicated Physical Data Channel (DPDCH) (up and downlink):** This channel is used to transfer user data.
- **Dedicated Physical Control Channel (DPCCH) (up and downlink):** This channel carries control information to and from the UE.
- **Physical Downlink Shared Channel (PDSCH) (downlink):** This channel shares control information to UEs within the coverage area of the node B.
- **Physical Common Packet Channel (PCPCH)**: This channel is specifically intended to carry packet data. In operation the UE monitors the system to check if it is busy, and if not it then transmits a brief access burst. This is retransmitted if no acknowledgement is gained with a slight increase in power each time. Once the node B acknowledges the request, the data is transmitted on the channel.
- **Synchronisation Channel (SCH)**: The synchronisation channel is used in allowing UEs to synchronize with the network.
- **Common Pilot Channel (CPICH)**: This channel is transmitted by every node B so that the UEs are able to estimate the timing for signal demodulation. Additionally they can be used as a beacon for the UE to determine the best cell with which to communicate.
- **Acquisition Indicator Channel (AICH)**: It is used to inform a UE about the Data Channel (DCH) it can use to communicate with the node B. This channel assignment occurs as a result of a successful random access service request from the UE.
- **Paging Indication Channel (PICH)**: This channel provides the information to the UE to be able to operate its sleep mode to conserve its battery when listening on the Paging Channel (PCH). As the UE needs to know when to monitor the PCH, data is provided on the PICH to assign a UE a paging repetition ratio to enable it to determine how often it needs to 'wake up' and listen to the PCH.

- **CPCH Status Indication Channel (CSICH)**: This channel, which only appears in the downlink carries the status of the CPCH and may also be used to carry some intermittent, or "bursty" data. It works in a similar fashion to PICH.
- **Collision Detection/Channel Assignment Indication Channel (CD/CA-ICH)**: This channel, in the downlink is used to indicate whether the channel assignment is active or inactive to the UE.

3.14 CONCLUSION

WCDMA is very successful technology due to its robust radio network design. By virtue of Code reuse the capacity of WCDMA system is increased tremendously. With introduction of HSPA and HSPA + , WCDMA has got add-on feature..

4 3G NETWORK ARCHITECTURE

4.1 LEARNING OBJECTIVE

After completion of this chapter student will able to understand UMTS Network and its functionalities

4.2 UMTS NETWORK COMPONENT

UMTS is regarded as a third generation (3G) wireless communication system based on WCDMA and is an evolved version of GSM GPRS and EDGE. The first release of the UMTS system was called release 99.

A UMTS network consists of three interacting domains:

- User Equipment (UE)
- UMTS Terrestrial Radio Access Network (UTRAN)
- Network (CN)

These three elements all have interfaces that connect to one element to the other which are denoted as Iu and Uu, the Iu is the interface between the core network and the UTRAN, while the Uu is the interface between the UTRAN and the User equipment,

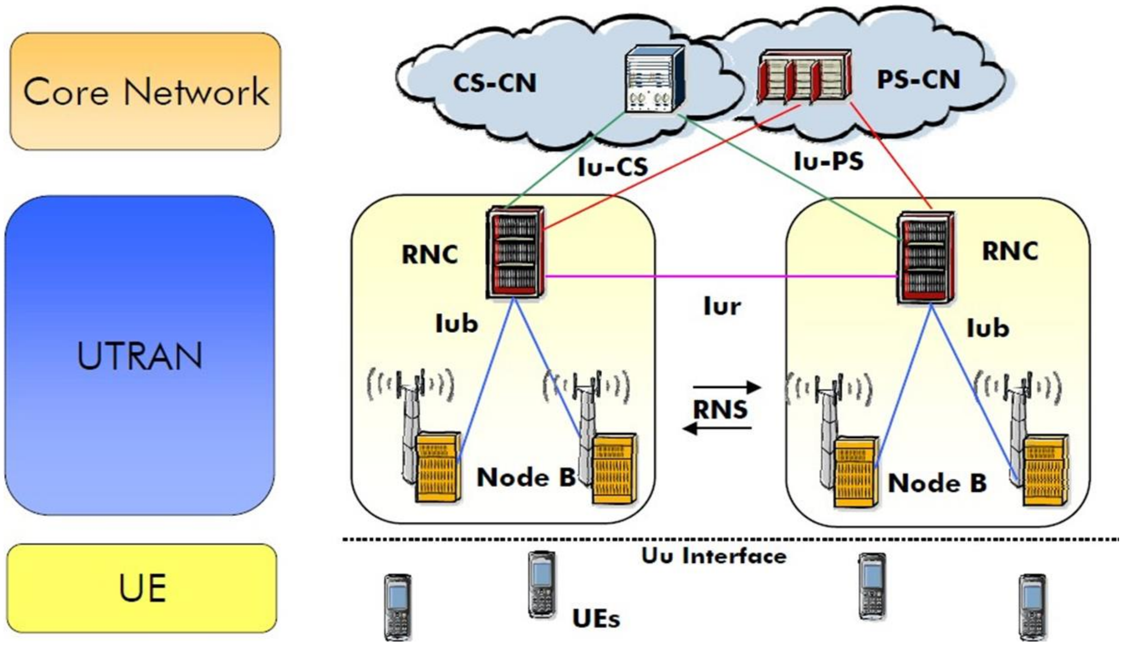


Figure 58: UMTS Release 99 Architecture

4.2.1 USER EQUIPMENT

The User Equipment or UE is the name given to what was previous termed as Mobile Station (MS) used to communicate with the node-B over the Uu interface. It consists of a UMTS subscriber Identity Module (USIM) which is basically a smart card or chip that performs authentication algorithms, stores the authentication and encryption keys and holds other information about the network operator.

UE have many different types of identities. Most of these UMTS identity types are taken directly from GSM specifications.

- International Mobile Subscriber Identity (IMSI)
- Temporary Mobile Subscriber Identity (TMSI)
- Packet Temporary Mobile Subscriber Identity (P-TMSI)
- Temporary Logical Link Identity (TLLI)
- Mobile station ISDN (MSISDN)
- International Mobile Station Equipment Identity (IMEI)
- International Mobile Station Equipment Identity and Software Number (IMEISV)

UMTS mobile station can operate in one of three modes of operation:

PS/CS mode of operation**:** The MS is attached to both the PS domain and CS domain, and the MS is capable of simultaneously operating PS services and CS services.

PS mode of operation: The MS is attached to the PS domain only and may only operate services of the PS domain. However, this does not prevent CS-like services to be offered over the PS domain (like VoIP).

CS mode of operation: The MS is attached to the CS domain only and may only operate services of the CS domain.

4.3 UMTS TERRESTRIAL RADIO ACCESS NETWORK (UTRAN)

The overall radio network access system of the UMTS is known as UMTS Terrestrial Radio Access Network (UTRAN).It provides and manages the air interface for the overall network.The UTRAN consist of multiple Radio Network Subsystems (RNSs) which is equivalent to the base station subsystem (BSS) in the GSM architecture. RNS consists two components:

- Node B
- Radio Network Controller (RNC)

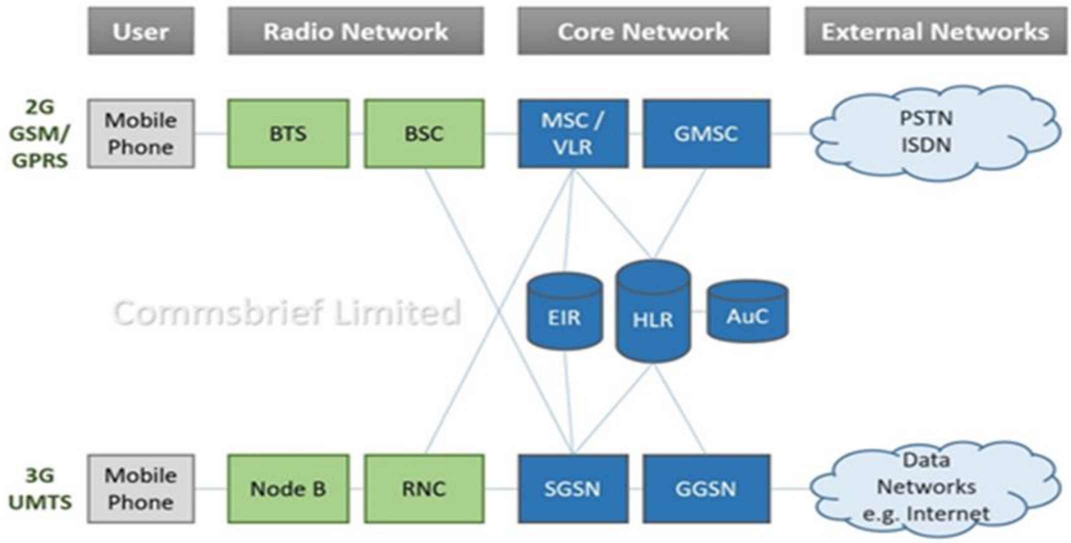


Figure 59: Architecture of GSM and UMTS

4.3.1 NODE B

The Node B is a UMTS base station which is equivalent to the BTSs in the GSM architecture. It controls one or more cells and transmits and receives radio signals to and from the mobiles that are in those cells; roughly it implements the physical layer of the air interface. Node B's are controlled by Radio Network Controllers (RNCs) via an interface known as the Iub interface.

4.3.2 RADIO NETWORK CONTROLLER (RNC)

The radio network controller is an intermediate component between the Node B and the core network. The RNC has three main functions, and an individual RNC can acquire up to three different names depending on which of these functions it is implementing. First, each Node B is controlled by a particular RNC, which is known as its controlling RNC (CRNC).A controlling RNC distributes downlink traffic to the Node Bs that it controls, collects traffic from them on the uplink, and exchanges signaling messages with them. Second, each mobile is controlled by a particular RNC, which is known as its serving RNC (SRNC). A serving RNC exchanges signaling messages with the mobiles that it serves, and acts as their sole point of contact with the core network. It also implements the layer 2 communications between the mobile and the network, for example by handling any retransmissions that are required over the air interface.

4.4 CORE NETWORK (CN)

The 3G UMTS core network architecture is a migration of that used for GSM with further elements overlaid to enable the additional functionality demanded by UMTS. The core network provides all the central processing and management for the system. The CN is similar to the network and switching subsystem (NSS) of the GSM architecture. The main function of the CN is to perform packet routing, connection of users, security, billing etc. The core network is the overall entity that interfaces to external networks including the public phone network and other cellular telecommunications networks.

The UMTS Core Network elements can be categorised into two domains depending on the type of traffic and functions they handle.

- **Circuit switched elements:** These elements are primarily based on the GSM network entities and carry data in a circuit switched manner, i.e. a permanent channel for the duration of the call.

- **Packet switched elements:** These network entities are designed to carry packet data. This enables much higher network usage as the capacity can be shared and data is carried as packets which are routed according to their destination.

4.4.1 CIRCUIT SWITCHED CORE NETWORK:

The circuit switched elements of the UMTS core network architecture include the following network entities:

Mobile Switching Centre (MSC):

The MSC is the interface between the Radio Access Network (RAN) and fixed networks. It provides mobility management, call control and switching functions to enable circuit-switched services to and from mobile stations.

Gateway MSC (GMSC):

The GMSC interfaces with the fixed networks, handles subscriber location information from the HLR and performs routing functions to and from mobile stations. GMSC functionality can be contained in all or some of the MSCs of the network, depending on network configuration.

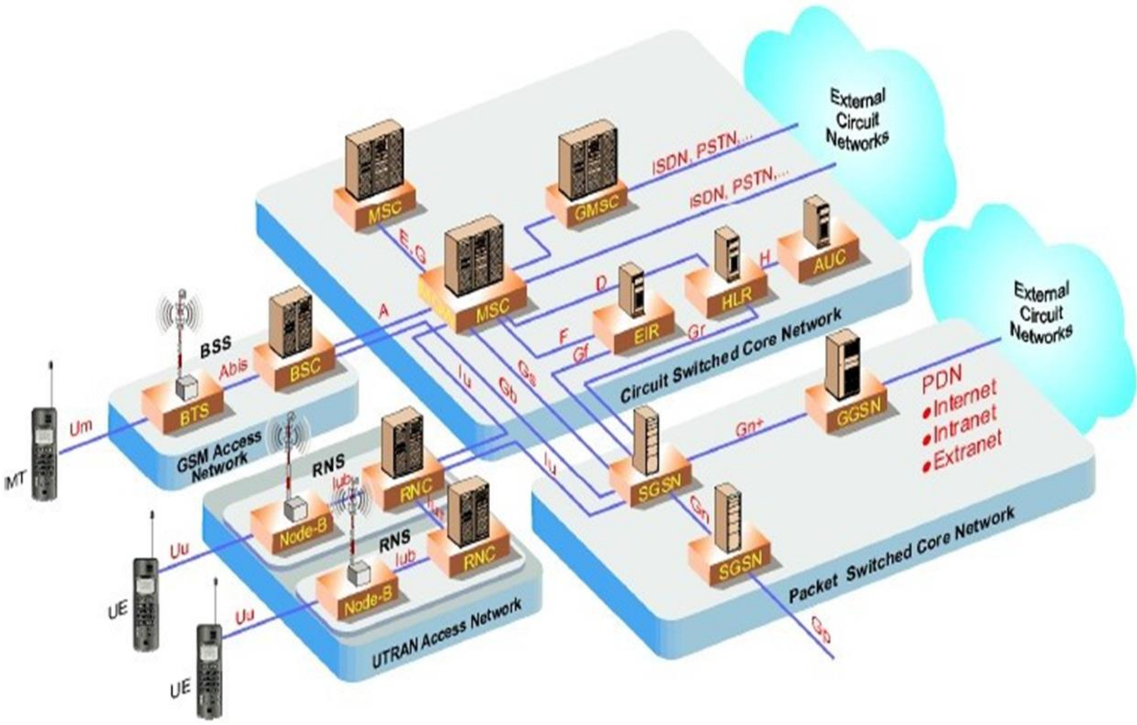


Figure 60: UMTS Network Elements

4.4.2 PACKET SWITCHED ELEMENTS

Packet Switched core network includes elements that support packet switching technology. Packet-switching technology routes packets of user data independently of one another. No dedicated circuit is established. Each packet can be sent along different circuits depending on the network resources available. The packet switched elements of the 3G UMTS core network architecture include the following network entities:

Serving GPRS Support Node (SGSN):

As the name implies, this entity was first developed when GPRS was introduced, and its use has been carried over into the UMTS network architecture. The SGSN provides a number of functions within the UMTS network architecture.

- **Mobility Management :**When a UE attaches to the Packet Switched domain of the UMTS Core Network, the SGSN generates MM information based on the mobile's current location.

- **Session Management:** The SGSN manages the data sessions providing the required quality of service and also managing what are termed the PDP (Packet data Protocol) contexts, i.e. the pipes over which the data is sent.

- **Interaction with other areas of the network:** The SGSN is able to manage its elements within the network only by communicating with other areas of the network, e.g. MSC and other circuit switched areas.

- **Billing:** The SGSN is also responsible billing. It achieves this by monitoring the flow of user data across the GPRS network. CDRs (Call Detail Records) are generated by the SGSN before being transferred to the charging entities (Charging Gateway Function, CGF).

Gateway GPRS Support Node (GGSN):

Like the SGSN, this entity was also first introduced into the GPRS network. The Gateway GPRS Support Node (GGSN) is the central element within the UMTS packet switched network. It handles inter-working between the UMTS packet switched network and external packet switched networks, and can be considered as a very sophisticated router. In operation, when the GGSN receives data addressed to a specific user, it checks if the user is active and then forwards the data to the SGSN serving the particular UE.

4.4.3 SHARED ELEMENTS

Some network elements, particularly those that are associated with registration are shared by both domains and operate in the same way that they did with GSM. The shared elements of the 3G UMTS core network architecture include the following network entities:

Home location register (HLR):

This database contains all the administrative information about each subscriber along with their last known location. In this way, the UMTS network is able to route calls to the relevant RNC / Node B. When a user switches on their UE, it registers with the network and from this it is possible to determine which Node B it communicates with so that incoming calls can be routed appropriately. Even when the UE is not active (but switched on) it re-registers periodically to ensure that the network (HLR) is aware of its latest position with their current or last known location on the network.

Visitor Location Register (VLR):

The VLR manages mobile subscribers in the home PLMN and those roaming in a foreign PLMN. The VLR exchanges information with the HLR.

Equipment identity register (EIR):

The EIR is the entity that decides whether given UE equipment may be allowed onto the network. Each UE equipment has a number known as the International Mobile Equipment Identity. This number, as mentioned above, is installed in the equipment and is checked by the network during registration.

Authentication centre (AuC):

The AuC is a protected database that contains the secret key also contained in the user's USIM card.

Equipment Identity Register (EIR):

The EIR stores information on mobile equipment identities.

SMS MSCs.:

SMS MSCs enable the transfer of messages between the Short Message Service Center and the PLMN.

4.5 ENHANCEMENT IN UMTS ARCHITECTURE IN FUTURE RELEASES

The first enhancement was the bearer independent circuit switched core network in release 4. In this architecture, the mobile switching centre is split in two. The circuit switched media gateway (CS-MGW) handles the traffic functions of the MSC, but uses different transport protocols that we will see in the next section. It also includes a media conversion function, which allows it to communicate with networks that are using other types of transport protocol. The MSC server combines the signalling functions of the MSC with those of the VLR, and also controls the CS-MGW over a signalling interface that lies between them. A GMSC server is built in the same way.

The main network enhancement in release 5 is the IP multimedia subsystem (IMS). This is an extra network which interfaces with the packet switched domain, and which provides users with real time packet switched services that cannot be supplied using the packet switched domain alone. The home subscriber server (HSS) was also introduced in release5, and combines the functions of the HLR and the AuC. The third release5 enhancement (not shown in the figure) is an architectural feature known as IuFlex. In earlier releases, each radio network controller was connected to just one MSC and one SGSN. IuFlex introduces a more flexible architecture in which each RNC can be connected to multiple MSCs and multiple SGSNs.

The main release 6 enhancement is wireless local area network (WLAN) interworking. This allows users to access the network operator's packet switched services using a wireless LAN. The services are supplied either by the IMS, or by data servers that are controlled by the network operator and directly connected to a GGSN. The connection uses some extra core network components that are not shown in the figure, known as the WLAN access gateway (WAG) and packet data gateway (PDG).

<table>
<tr><th colspan="2" rowspan="2">3GPP Release</th><th colspan="2">Radio Access Networks (RANs)</th><th colspan="3">Core Network</th></tr>
<tr><th>BSS elements</th><th>UTRAN elements</th><th>CSCN elements</th><th>PSCN elements</th><th>common elements</th></tr>
<tr><td colspan="2">R99</td><td rowspan="3">BSC
BTS</td><td rowspan="3">RNC
Node B</td><td>MSC
GMSC
IWF</td><td rowspan="3">SGSN
GGSN
BG</td><td rowspan="2">HLR
VLR
AuC
EIR
SMS MSCs</td></tr>
<tr><td rowspan="2">R00</td><td>R4 (NGN architecture)</td><td rowspan="2">R99 elements
+
MSC server
GMSC server
MGW</td></tr>
<tr><td>R5 (All-IP core network)</td><td>R99 and R4 elements
+
HSS
IM subsystem</td></tr>
</table>

Figure 61: 3GPP Releases

4.6 3GPP RELEASE 4 (R4) ARCHITECTURE

3GPP Release 4 implements the NGN architecture in the core network, separating the control and user planes. This enables a true separation of control and connection operations, and provides the independence of applications and services from basic switching and transport technologies. 3GPP Release 4 (R4) introduces the following new network elements in addition to R99 elements:

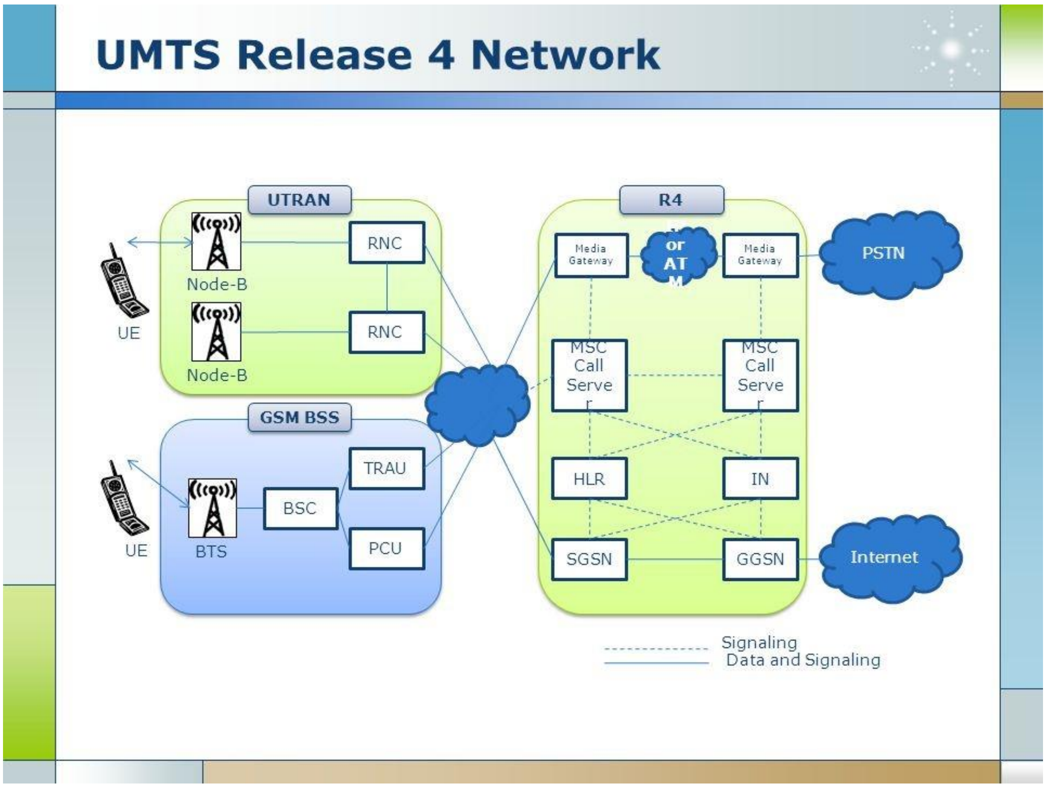


Figure 62: UMTS Release 4 Architecture

4.7 CORE NETWORK ELEMENTS

MSC server:

The MSC server provides call control and mobility management functions for an MSC. It also holds subscriber service data information and provides connection control for media channels in a CS-MGW.

GMSC server:

The GMSC server provides call control and mobility management functions for a GMSC.

Circuit-Switched-Media GateWay (CS-MGW):

The CS-MGW is an interface between the UTRAN and the Core Network. The CS- MGW supports both UMTS and GSM media. CS-MGW terminates bearer channels from circuit-switched networks and media streams from packet networks. It supports media conversion, bearer control and payload processing. See figure below for an illustration of 3GPP Release 4 network architecture.

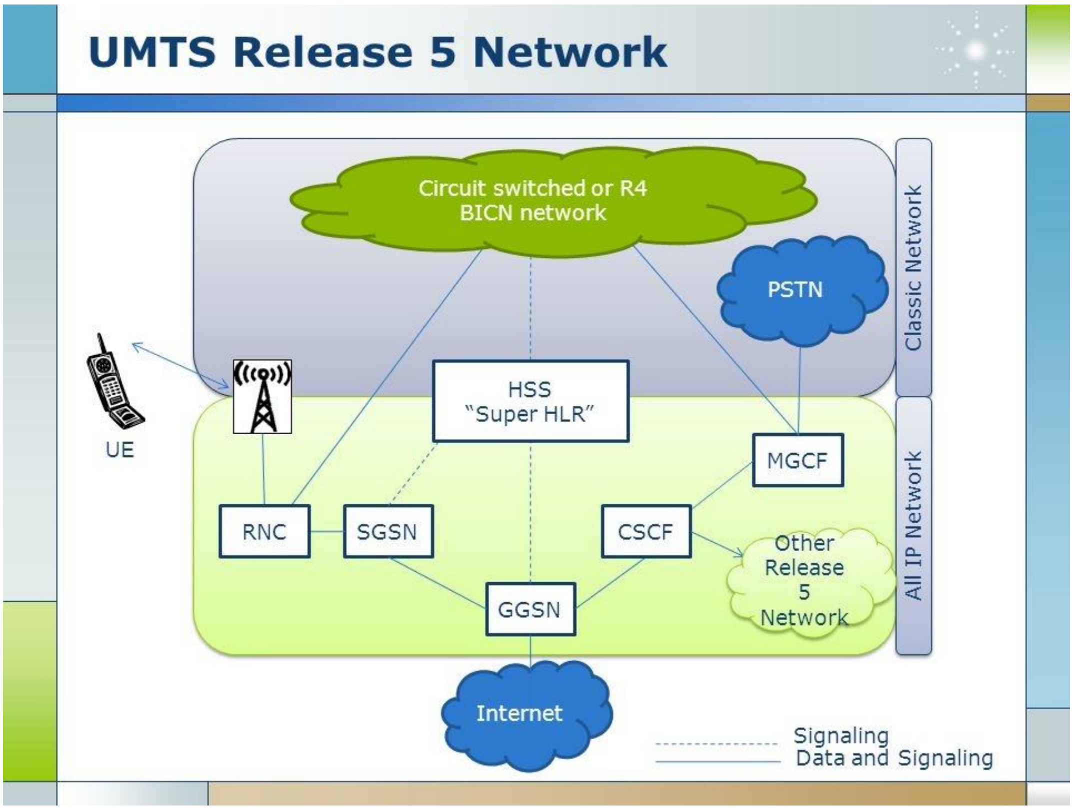


Figure 63: UMTS Release 5 Architecture

4.8 GPP RELEASE 5 (R5)

3GPP Release 5 implements a unified IP backbone infrastructure which enables high performance services and functions. 3GPP Release 5 (R5) introduces the following new network elements in addition to R99 and R4 elements:

Common Core Network elements:

- Home Subscriber Server (HSS)
- Internet protocol Multimedia (IM) subsystem.

The IM subsystem consists of all Core Network elements that use the services provided by the PSCN to offer multimedia services. The IM subsystem primarily includes the Call Server Control Function (CSCF), Media Gateway Control Function (MGCF) and the Multimedia Resource Function (MRF).

4.9 CONCLUSION

3G is very successful technology due to its robust radio network design. By virtue of CDMA and code reuse the capacity of 3G system is increased tremendously. But with the introduction of Data demand on mobile 3G has lost its shine as it deliveries very less data rates. Thus 3G has been migrated to newer technologies such as 4G and 5G.

5 UMTS (3G), HSPA AND HSPA+

5.1 LEARNING OBJECTIVE

After completion of this chapter participant will come to know the basics of UMTS (3G), HSPA and HSPA+. 3GGP guidelines also has been discussed in this chapter. Lastly how speed increases in HSPA+ and impact of modulation on speed has been discussed.

5.2 THIRD-GENERATION PARTNERSHIP PROJECT (3GPP)

The cellular technologies specified by 3GPP are the most widely deployed in the world, with the number of users passing 5 billion. Third Generation Partnership Project (3GPP) was formed by standards-developing organizations from all regions of the world. This solved the problem of trying to maintain parallel development of aligned specifications in multiple regions. The present organizational partners of 3GPP are ARIB (Japan), CCSA (China), ETSI (Europe), ATIS (USA), TTA (Korea) and TTC (Japan).

ETSI (European Telecommunications Standards Institute) in early 1998 had selected Wideband CDMA (WCDMA) as the technology for UMTS (Universal Mobile Telecommunications System) in the paired spectrum (FDD) and TD-CDMA (Time Division CDMA) for the unpaired spectrum (TDD). There was also a decision to harmonize the parameters between the FDD and the TDD components.

3GPP consists of several Technical Specifications Groups (TSGs), 3GPP TSG RAN is the technical specification group that has developed WCDMA, its evolution HSPA, as well as LTE, and is in the forefront of the technology.

The specifications of all releases can be updated after each set of TSG meetings, which occur 4 times a year. The 3GPP documents are divided into releases, where each release has a set of features added compared to the previous release. The features are defined in Work Items agreed and undertaken by the TSGs. The releases up to Release 7 and some main features of those are shown in Figure below. The date shown for each release is the day the content of the release was frozen. For historical reasons, the first release is numbered by the year it was frozen (1999), while the following releases are numbered 4, 5, etc. For the WCDMA Radio Access developed in TSG RAN, Release 99 contains all features needed to meet the IMT-2000 requirements as defined by ITU. There are circuit-switched voice and video services, and data services over both packet switched and circuit-switched bearers. The first major addition of radio access features to WCDMA is Release 5 with High Speed Downlink Packet Access (HSDPA) and Release 6 with Enhanced Uplink. With HSPA, UTRA goes beyond the definition of a 3G mobile system and also encompasses broadband mobile data. With the studies of an Evolved UTRAN (LTE) and the related System Architecture Evolution (SAE), further steps are taken in terms of broadband capabilities.

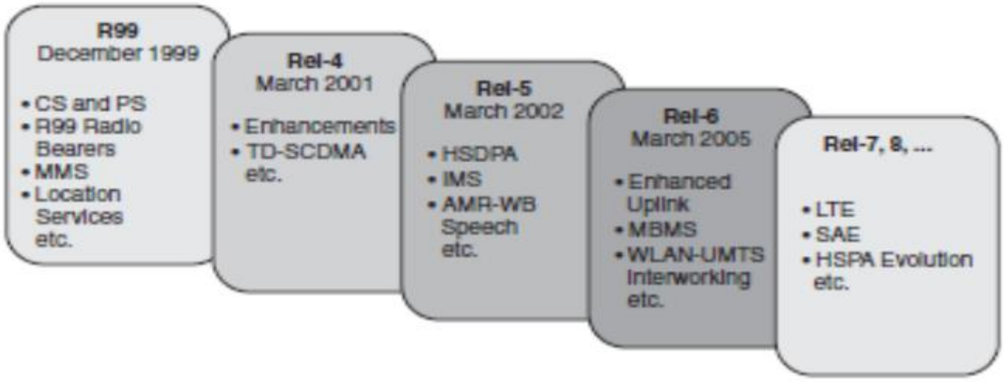


Figure 64: Releases of 3GPP specifications for UTRA

5.3 3GPP SPECIFICATIONS

3GPP specifications are the actual documents that define the system. At a high level, the specifications are organized into releases, each of which is a version of the system with a particular set of features. 3GPP maintains the specifications for all the releases of UMTS in parallel. This allows it to add new features to the system as part of each new release, while making the occasional technical correction to the older, more stable releases that are used by manufacturers. Each release is developed over a period of months or even years, but the most important event happens when the release is frozen. After it has been frozen, there are no more changes to a release's technical features, although some issues such as the details of the protocols and the conformance tests will usually lag behind. Technical corrections can of course continue for a long time after freezing. The first release of UMTS was release99, which was frozen in March 2000. This release specified a 3G telecommunication system based on the core network of GSM, but with a new air interface that used wideband code division multiple accesses (W-CDMA).The plan was then to have one release per year, using a numbering scheme of release00, release 01 and so on. However, it was soon realized that this was too ambitious, so the numbering scheme was changed to uncouple it from the calendar year, and the next release became known as release 4. Using this scheme, release99 is synonymous with release3, while the numbers1 and 2 are reserved for draft specifications.

5.4 HSPA AND HSPA+

High Speed Packet data Access (HSPA) has been an upgrade to WCDMA networks used to increase packet data performance. The introduction was done in steps; High Speed Down Link (DL) Packet data Access (HSDPA), was introduced in 3GPP Release 5, and Enhanced Up Link (UL), also referred to as High Speed UL Packet data Access (HSUPA), came in Release 6.

The combination of HSDPA and Enhanced UL is referred to as HSPA. HSPA evolution (also known as HSPA+ and evolved HSPA) came in Release 7 with further improvements in later releases.

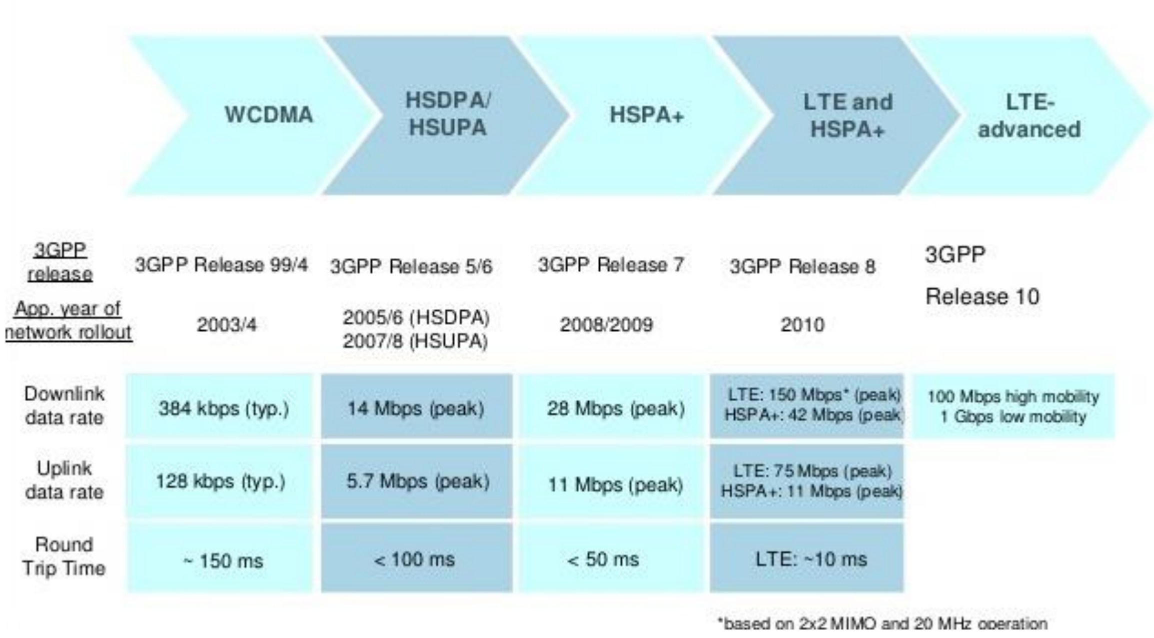


Figure 65: 3GPP UMTS evolution

5.4.1 HSDPA (RELEASE-5)

WCDMA 3GPP Release 5 extends the specification with, among other things, a new downlink transport channel that enhances support for interactive, background, and to some extent, streaming services, yielding a considerable increase in capacity compared to Release 99. It also significantly reduces delay and provides peak data rates of up to 14 Mbit/s. This enhancement commonly goes under the abbreviation HSDPA (High Speed Downlink Packet Access).

The new transport channel is called HS-DSCH (High Speed Downlink Shared Channel)

HS-DSCH transmission is based on Shared-Channel transmission, similar to release 99/4 Downlink Shared Channel (DSCH). However, HS-DSCH transmission supports several new features, not supported for DSCH.

HS-DSCH supports the use of higher order modulation. This allows for higher peak data rates and higher capacity.

HS-DSCH supports fast link adaptation and fast channel dependent scheduling. This means that the instantaneous radio-channel conditions can be taken into account in the selection of transmission parameters as well as in the scheduling decision and allows for higher capacity.

HS-DSCH supports fast hybrid ARQ (Automatic Repeat reQuest) with soft combining. This reduces the number of retransmissions as well as the time between retransmissions.

To support these features with minimum impact on the existing radio-interface protocol architecture, a new MAC sublayer, MAC-hs, is introduced for HS-DSCH transmission. To reduce the retransmission delay for hybrid ARQ and allow for as up-to-date channel-quality estimates as possible for the link adaptation and channel-dependent scheduling, MAC-hs is located in the Node B.

For the same reasons, HS-DSCH uses a shorter TTI (Transmission Time Interval) (2 ms) compared to release 99/4 transport channels.

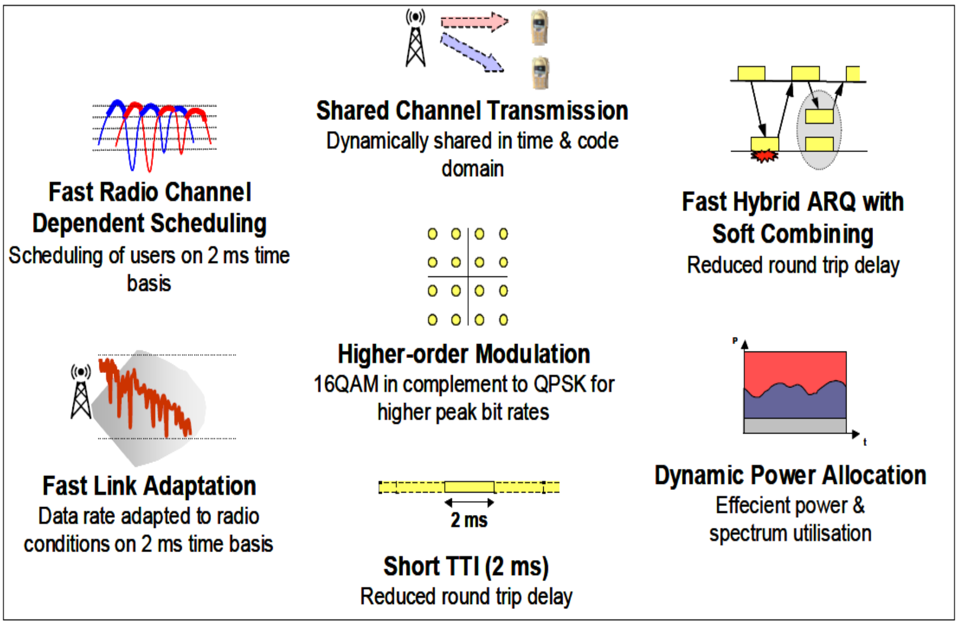


Figure 66: HSDPA Principle

Reduced transmission time interval (TTI) ~2ms

One reason for a shorter TTI is to reduce the air-interface delay by reducing the RTT (Round Trip Times). This will improve the end user performance .Short TTI is also necessary to benefit from other functionalities such as fast link adaptation, fast scheduling and fast hybrid ARQ. In earlier releases it was minimum 10 ms.

Shared Channel Transmission

HSDPA user data is carried on the new shared transport channel, High Speed-DL Shared Channel (HS-DSCH), which in turn is carried by one or more High Speed-Physical DL Shared Channel (HS-PDSCH), each using a channelization code with SF=16. The number of HS-PDSCH can range from 1 to a maximum of 15. In R99 the physical channel carrying user data can be allocated a channelization code with SF ranging from 4 to 512. R99 and HSDPA will use channelization codes from the same code tree, see figure below. Therefore all the DL channels within one cell are orthogonal at the point of transmission; at point of reception there will however be some interference, mainly due to multi-path fading.

A major feature in HSDPA is that the channelization codes can be shared not only through code multiplexing, as in R99, but also using time multiplexing. In time multiplexing one UE is allocated all the channelization codes available for HSDPA in one TTI and another UE may use all the resources in the next TTI. Through time multiplexing the radio resources may be more efficiently utilized than with code multiplexing since in each TTI the resources can be allocated to the UE experiencing the best radio channel. Of course if the data to be delivered does not require all available codes, then code multiplexing can be used.

The maximum channel rate for HSDPA is 14.4 Mbps, with a peak user data rate of 13.4 Mbps (on MAC level), compared with a maximum user data rate of 384 kbps for R99.

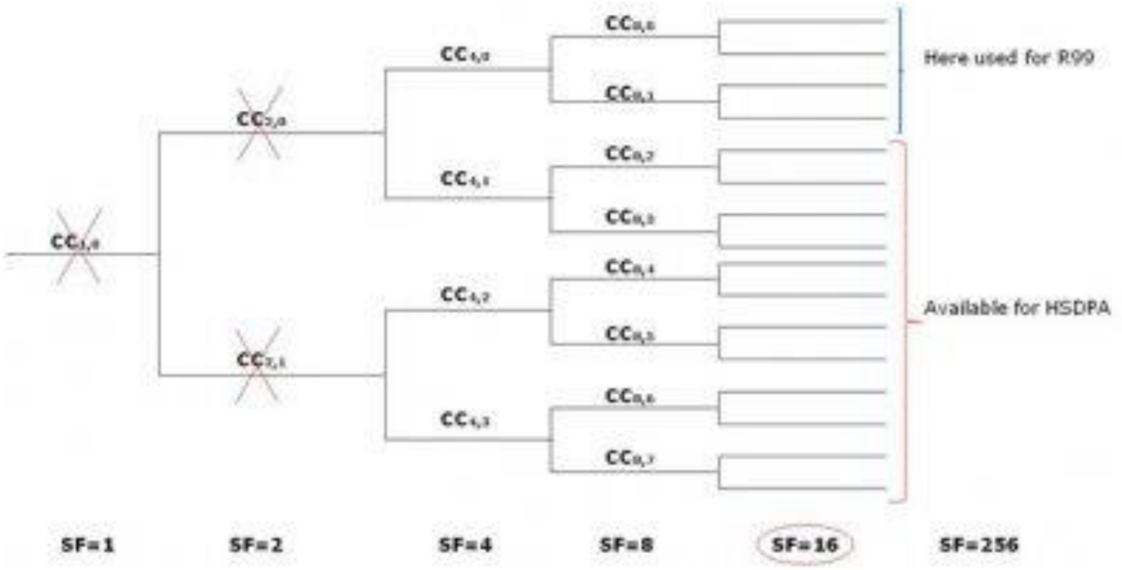


Figure 67: Channelization code tree, the code tree is shared between R99 and HSDPA services.

Higher Order Modulation

WCDMA release 99/4 uses QPSK data modulation for downlink transmission. To support higher data rates, higher-order data modulation, such as 16QAM, can be used. However, higher-order modulation is also less robust and typically requires higher energy per bit for a given error rate.

Fast Link Adaption

In a cellular system, the radio-channel conditions experienced by different downlink communication links will typically vary significantly, both in time and between different positions within the cell.

In WCDMA, power control is used to compensate for differences and variations in the instantaneous downlink radio channel conditions. From an overall system-throughput point of- view, power control is not the most efficient means to allocate available resources.

For services that do not require a specific data rate, such as many best-effort services, adjusting the data rate, while keeping the transmission power constant, can also control the energy per information bit. This can be referred to as rate control and rate adjustment. It is also often referred to as (fast) link adaptation, although, in principle, power control can also be seen as a kind of link adaptation.

There are different means by which the data rate can be adjusted to compensate for variations and differences in the instantaneous channel conditions.

By adjusting the channel-coding rate. The use of channel coding with higher coding rate allows for higher data rates at the expense of less robustness to channel impairments.

By adjusting the modulation scheme. The use of higher order modulation, such as 16QAM, allows for more bits per modulation symbol and thus for higher data rates. However, this is achieved at the expense of less robustness to channel impairments.

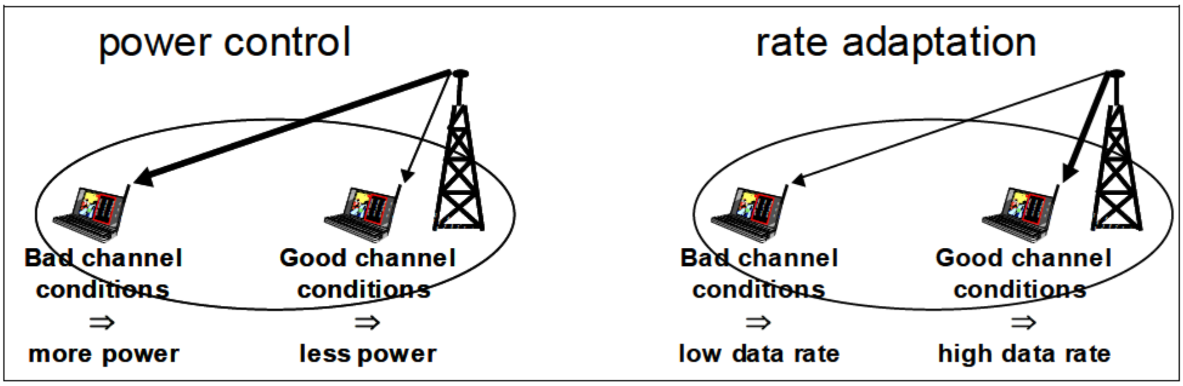


Figure 68: Power Control Vs Rate Adaptation

Fast Channel Dependent Scheduling

Fast Scheduling is about to decide to which terminal the shared channel transmission should be directed at any given moment. It's called channel-dependent scheduling because it's dependent on the instantaneous channel condition.

The trade-off is between the cell throughput and fairness against users. In some cases, there might be a particular user who is perhaps on the cell border which might not be allocated the radio resources because he does not have good enough C/I. Remember that we don't have SHO for dedicated shared channel.

Different scheduling algorithms used are:

- Round Robin: radio resources are allocated to communication links on a sequential basis, not taking into account the instantaneous radio-channel conditions experienced by each link.
- Proportional Fair: allocates the channel to the user with relatively best channel quality. It gives rather high throughput and is rather fair.
- Flexible Scheduler: five different levels of fairness; equal rate, low fairness, medium fairness, high fairness and max C/I. For maximum cell throughput, the radio resources should as much as possible is allocated to communication links with the best instantaneous channel conditions.

HARQ with Soft Combining

In a conventional ARQ scheme, received data blocks that cannot be correctly decoded are discarded and retransmitted data blocks are separately decoded, In case of hybrid ARQ with soft combining, received data blocks that cannot be correctly decoded are not discarded. Instead the corresponding received signal is buffered and soft combined with later received retransmissions of the same set of information bits. Decoding is then applied to the combined signal. In R99 it is possible to use retransmission, ARQ, on the RLC protocol layer, between UE and RNC, but in HSDPA Hybrid ARQ (HARQ) is introduced enabling retransmission on the physical layer between UE and NodeB.

The use of hybrid ARQ with soft combining increases the effective received Eb/I0 for each retransmission and thus increases the probability for correct decoding of retransmissions, compared to conventional ARQ.

Figure shows that Fast hybrid ARQ allows UEs to rapidly request retransmissions of erroneously received transport blocks.

The UE attempts to decode each transport block it receives, reporting to NODE-B its success or failure 5 ms after the reception of the transport block. The hybrid ARQ mechanism in NODE-B can rapidly respond to retransmissions requests. This leads to shorter Round Trip Times.

The UE employs soft combining, which is it combines soft information from previous transmission attempts with the current transmission to increase the probability of decoding the transport block. This reduces error rates for retransmissions.

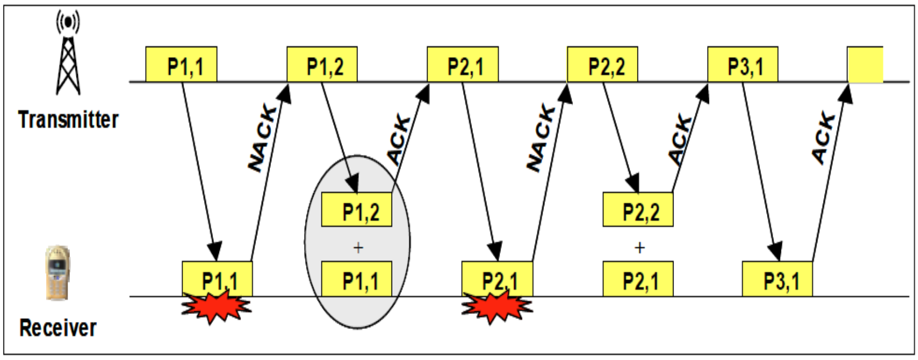


Figure 69: HARQ with Soft Combining

Dynamic Power Allocation

In HSDPA the resources shared between DL R99 transport channels and HSDPA transport channels are power and channelization codes. When HSDPA services are active, DL power from the NodeB – the sender is normally kept constant and shared between R99 channels and the new HSDPA specific channels, power not used for R99 can be used for HSDPA, see figure below. If there is no HSDPA traffic, then the power will fluctuate, depending on the R99.

The HS-DSCH does not employ fast power control to compensate for channel variations. Instead, to maximize user throughput in the downlink, it adjusts the data rate to match the instantaneous radio conditions and the available transmission power in the NodeB.

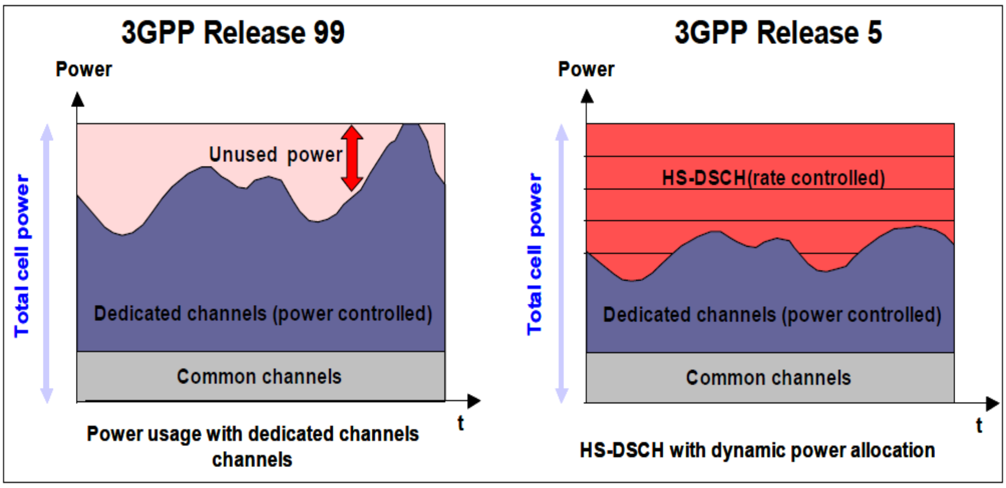


Figure 70: Power Allocation in R99 and Release5

HSDPA Channel Structure

In HSPDA one new transport channel and three new physical channels are implemented.

HS-DSCH - High-Speed Downlink Shared Channel: transport channel that carries the user data.

HS-PDSCH - High-Speed Physical Downlink Shared Channel: physical downlink channel that carries the user data and layer 2 overhead bits over the air interface.

HS-SCCH - High-Speed Shared Control Channel(s): physical downlink channel that carries control information how to decode the information on HS-PDSCH and which UE that shall decode it.

HS-DPCCH - High-Speed Dedicated Physical Control Channel: physical uplink channel to send ACK/NAK reports and channel quality reports.

Each connection also has an associated dedicated transport channel (A-DCH) allocated in the cell. The A-DCH will be mapped on physical channels DPDCH+DPCCH.

Downlink A-DCH is used for layer 3 control signalling.

Uplink A-DCH is used for layer 3 control signalling and user data.

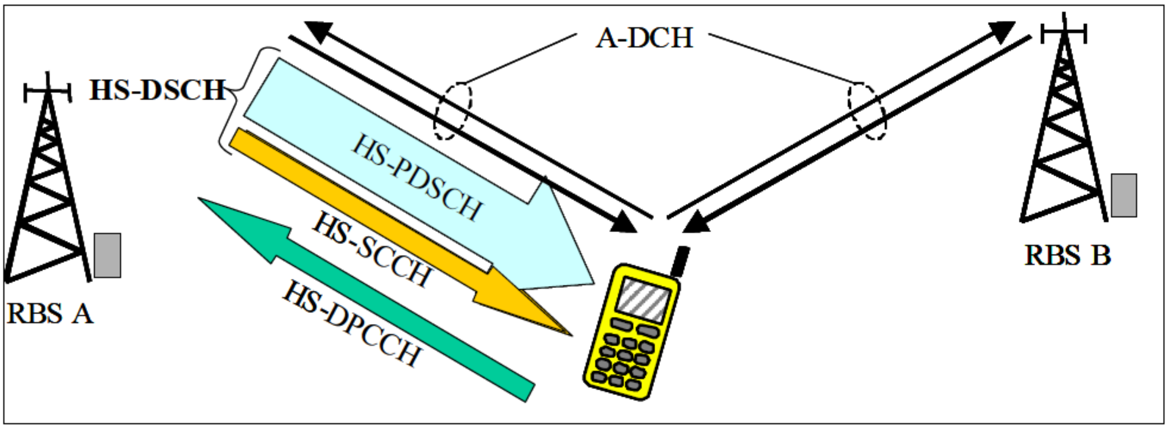


Figure 71: HSDPA Channels

5.4.2 EUL (ENHANCED UPLINK) OR HSUPA (RELEASE-6)

HSUPA (High Speed Uplink Packet Access), standardized in Release 6, constitutes a set of improvements to the uplink only, that optimizes uplink performance using the Enhanced Dedicated Channel (E-DCH). These improvements include higher throughputs, reduced latency, and increased spectral efficiency. HSUPA provides peak uplink data rate of 5.76Mbps. For applications like VoIP, improvements balance the capacity of the uplink with the capacity of the downlink. HSUPA achieves its performance gains through the following approaches:

New uplink and downlink physical channels and an enhanced dedicated physical channel in the uplink called E-DCH (Enhanced Uplink Dedicated Channel) are introduced. E-DCH provides improved uplink performance in terms of Increased data rates and increased capacity (up to 2 times the capacity of Release 99)

A short TTI, as low as 2 msec, which allows faster responses to changing radio conditions and error conditions.

Fast Node B-based scheduling, which allows the base station to efficiently allocate radio resources.

Fast Hybrid ARQ, which improves the efficiency of error processing and is implemented in Node B as compared to RNC for faster response.

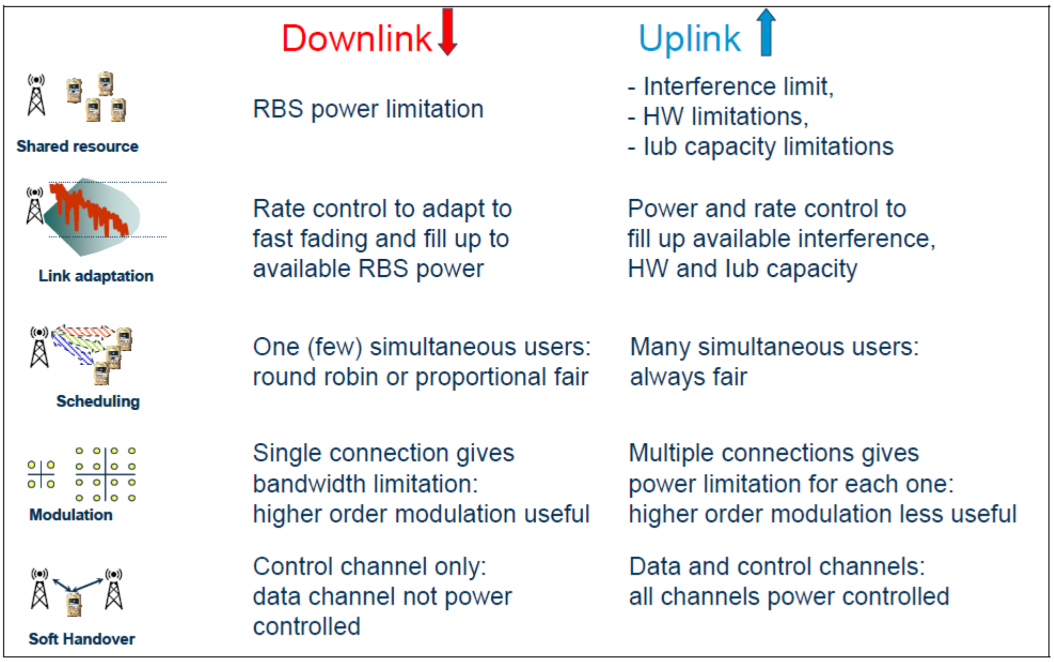


Figure 72: Comparison between HSDPA and HSUPA

The combination of TTI, fast scheduling, and Fast Hybrid ARQ also serves to reduce latency, which can benefit many applications as much as improved throughput. HSUPA can operate with or without HSDPA in the downlink, although it is likely that most networks will use the two approaches together. Beyond throughput enhancements, HSUPA also significantly reduces latency. In optimized networks, latency will fall below 50 msec, relative to current HSDPA networks at 70 msec.

HSUPA in tandem with HSDPA is known as HSPA. HSPA is an upgrade to UMTS networks that usually requires only new software and base station channel cards, instead of necessitating the replacement of major pieces of infrastructure. As a result, operators can deploy HSPA quickly and cost-effectively. HSPA is backward-compatible with UMTS, EDGE and GPRS. This design benefits customers when they travel to areas that haven't yet been upgraded to HSPA, as their HSPA-enabled handsets and modems will still provide fast packet-data connections.

5.4.3 HSPA+ (3GPP RELEASE-7 AND ONWARDS)

HSPA+ provides an evolution of High Speed Packet Access, from 3GPP Release-7 onwards with data rates up to 336Mbit/s to the mobile device (downlink) and 69 Mb/s from the mobile device (uplink) in 3GPP Release 11. The improved data rates support high bandwidth services like video streaming and the reduced latency improves the performance of real-time applications like VoIP.

Features in HSPA+

Higher Order Modulation: Higher order modulation is a way of increasing performance. HSPA uses 16 QAM on the downlink and QPSK on the uplink. But radio links can achieve higher throughputs by adding 64 QAM on the downlink and 16 QAM on the uplink and this has been added in HSPA+ with further increase in order of modulation in later releases.

MIMO: MIMO is a technique that employs multiple Tx antennas and multiple Rx antennas, often in combination with multiple radios and multiple parallel data streams. The transmitter sends different data streams over each antenna. Whereas multipath is a hurdle for other radio systems, MIMO exploits multipath, relying on signals to travel across different uncorrelated communications paths. This results in multiple data paths effectively operating somewhat in parallel and, through appropriate decoding, in a multiplicative gain in throughput.

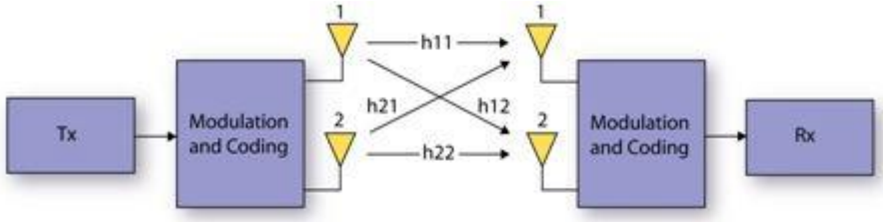


Figure 73: 2x2 MIMO

In 3GPP Release 7 MIMO cannot be used in combination with 64 QAM, but this feature is available in Release 8. Subsequently, in Releases-9, 10 and 11, 2X2 MIMO is combined with carrier aggregation to double the peak data rate.

Continuous Packet Connectivity: Continuous Packet Connectivity (CPC) enables efficient "always-on" service and enhanced uplink UL VoIP capacity, as well as reductions in call set-up delay for Push-to-Talk Over Cellular (PoC).

DUAL CARRIER HSPA+: Other functions have been added to HSPA+ in later releases for example in Release 8 Dual Cell-HSDPA (also referred to as Dual Carrier-HSDPA, DC-HSDPA), where carrier aggregation of two adjacent 5 MHz bands, covering the same area, is used to increase the performance. In Release 9 DC-HSUPA and DB-DC-HSDPA (where in the downlink the primary serving cell resides on a carrier in one frequency band and the secondary serving cell on a carrier in another frequency band. In the uplink transmission takes place only on one carrier, which can be configured by the network on any of the two frequency bands) is also introduced.

HSPA+ Architecture Evolution: The UMTS network is increasingly being used for IP based packet services and for better user experience it is important that the network latency should be reduced. A flat architecture improves the latency and also increases the user and control plane efficiency and this was introduced in 3GPP Release 7. In the figure below, the integrated RNC/NodeB architecture option for HSPA+ is compared to the traditional HSPA architecture and the architecture with One Tunnel Solution. Benefit of this new architecture option is that there are fewer nodes, which reduces latency, making it flatter and simpler. Finally, the integrated RNC/NodeB architecture is similar to the SAE/EPC architecture in 3GPP Release-8.

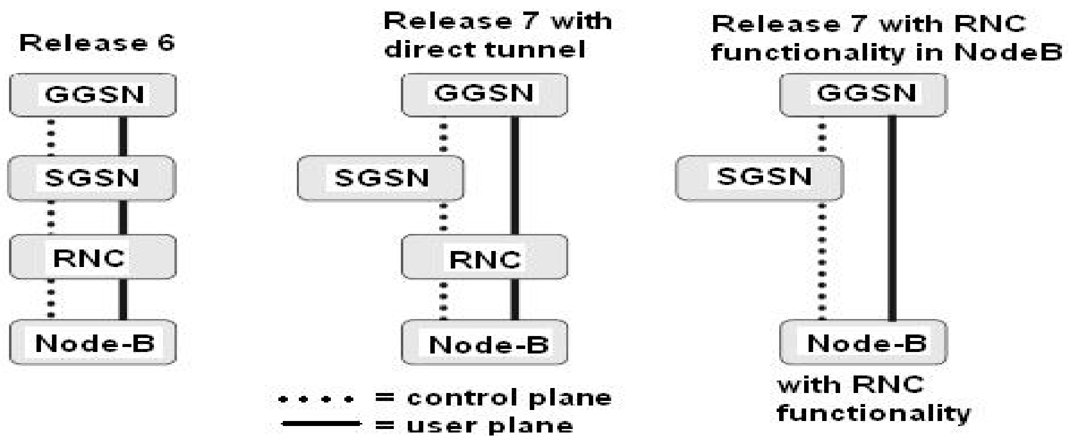


Figure 74: Evolution towards flat architecture

5.5 CONCLUSION

The following figure shows the improvement in data rate with respect to each release (Release-6 onwards) with combination of MIMO, QAM and multiple carriers.

Technology	Downlink (Mbps) Peak Data Rate	Uplink (Mbps) Peak Data Rate
HSPA as defined in Release 6	14.4	5.76
Release 7 HSPA+ DL 64 QAM, UL 16 QAM, 5/5 MHz	21.1	11.5
Release 7 HSPA+ 2X2 MIMO, DL 16 QAM, UL 16 QAM, 5/5 MHz	28.0	11.5
Release 8 HSPA+ 2X2 MIMO DL 64 QAM, UL 16 QAM, 5/5 MHz	42.2	11.5
Release 8 HSPA+ (no MIMO) Dual Carrier, 10/5 MHz	42.2	11.5
Release 9 HSPA+ 2X2 MIMO, Dual Carrier DL and UL, 10/10 MHz	84.0	23.0
Release 10 HSPA+ 2X2 MIMO, Quad Carrier DL, Dual Carrier UL, 20/10 MHz	168.0	23.0
Release 11 HSPA+ 2X2 MIMO DL and UL, 8 Carrier DL, Dual Carrier UL, 40/10 MHz	336.0	69.0

Table 3. Data Rate Vs Releases

From the above table we conclude that HSDPA/HSUPA/HSPA+ has significantly improved the data carrying performance of 3G networks

6 MIGRATION TO 4G AND INTRODUCTION TO 5G

6.1 LEARNING OBJECTIVE

In this chapter migration from 4G to 5G has been discussed along with various releases of 3GPP. LTE has been discussed in detail along with complete network architecture. Details of 5G have also been discussed.

6.2 UMTS EVOLUTION TO LTE:

The evolution of UMTS-HSPA happens in stages referred to as 3GPP Releases. A summary of the different 3GPP releases towards LTE is as follows:

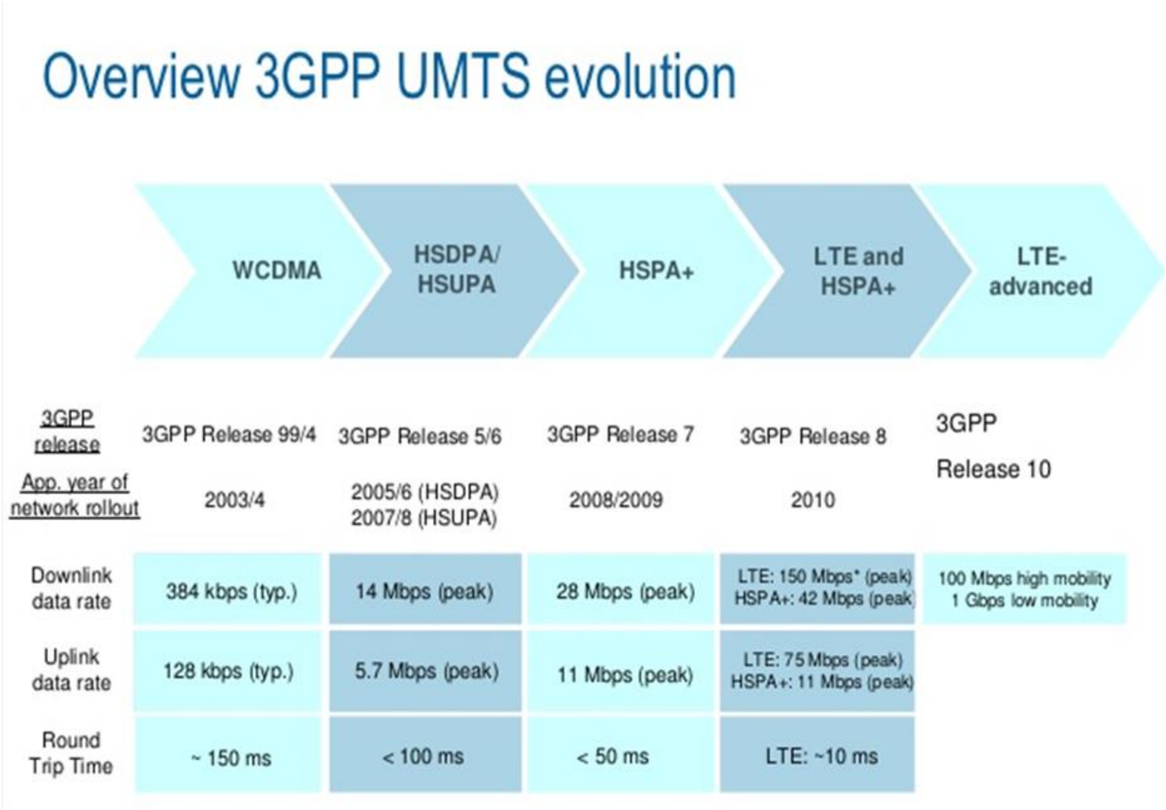


Figure 75: 3GPP UMTS Evolution

Release 99: First deployable version of UMTS. Enhancements to GSM data (EDGE). Majority of deployments today are based on Release 99.Provides support for GSM/EDGE/GPRS/WCDMA radio-access networks.

Release 4: Multimedia messaging support. First steps toward using IP transport in the core network.

Release 5: HSDPA. First phase of IMS. Full ability to use IP-based transport instead of just Asynchronous Transfer Mode (ATM) in the core network.

Release 6: HSUPA. Enhanced multimedia support through Multimedia Broadcast/Multicast Services (MBMS). Performance specifications for advanced receivers. WLAN integration option. IMS enhancements. Initial VoIP capability.

Release 7: Provides enhanced GSM data functionality with Evolved EDGE. Specifies HSPA Evolution (HSPA+), which includes higher order modulation and MIMO. Provides fine-tuning and incremental improvements of features from previous releases. Results include performance enhancements, improved spectral efficiency, increased capacity, and better resistance to interference. Continuous Packet Connectivity (CPC) enables efficient "always-on" service and enhanced uplink UL VoIP capacity, as well as reductions in call set-up delay for PoC. Radio enhancements to HSPA include 64 QAM in the downlink DL and 16 QAM in the uplink. Also includes optimization of MBMS capabilities through the multicast/broadcast, single-frequency network (MBSFN) function.

6.3 LTE

LTE (Long Term Evolution) is the project name given to development of a high performance air interface for cellular mobile communication systems. It is the last step toward the 4th generation (4G) of radio technologies designed to increase the capacity and speed of mobile telephone networks.

It was 3GPP release 8 when LTE was introduced for the very first time. All the releases following only enhanced the technology. Based on release 8 standardization, following were the main achievements.

- High peak data rates : Up to 300 Mbps in downlink and 75 Mbps in uplink when using 4x4 MIMO and 20 MHz bandwidth
- High spectral efficiency
- Flexible bandwidths: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz
- Short round trip time: 5 ms latency for IP packets in ideal radio conditions
- Simplified Architecture
- OFDMA in downlink and SC-FDMA in uplink
- All IP network
- MIMO Multiple Antenna Scheme
- Operation in paired (FDD) and unpaired spectrum (TDD)

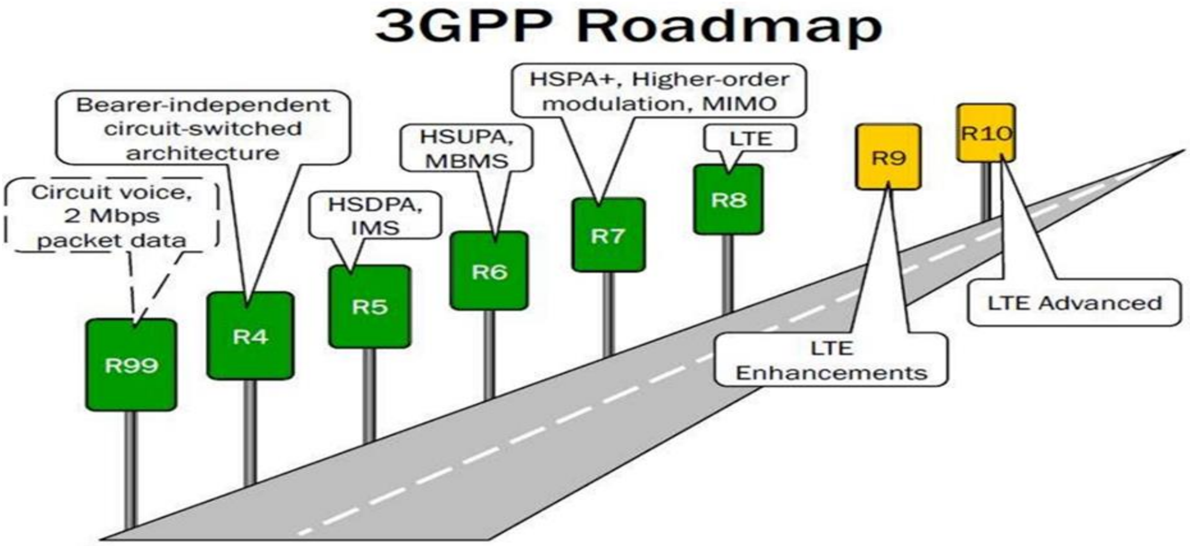


Figure 76: Evolution to LTE

6.4 LTE ENHANCEMENT:

The initial enhancements were included to LTE in release 9. These were in fact the improvements which were left behind from release 8 or perhaps provided some minor improvements. These improvements are listed below with brief description.

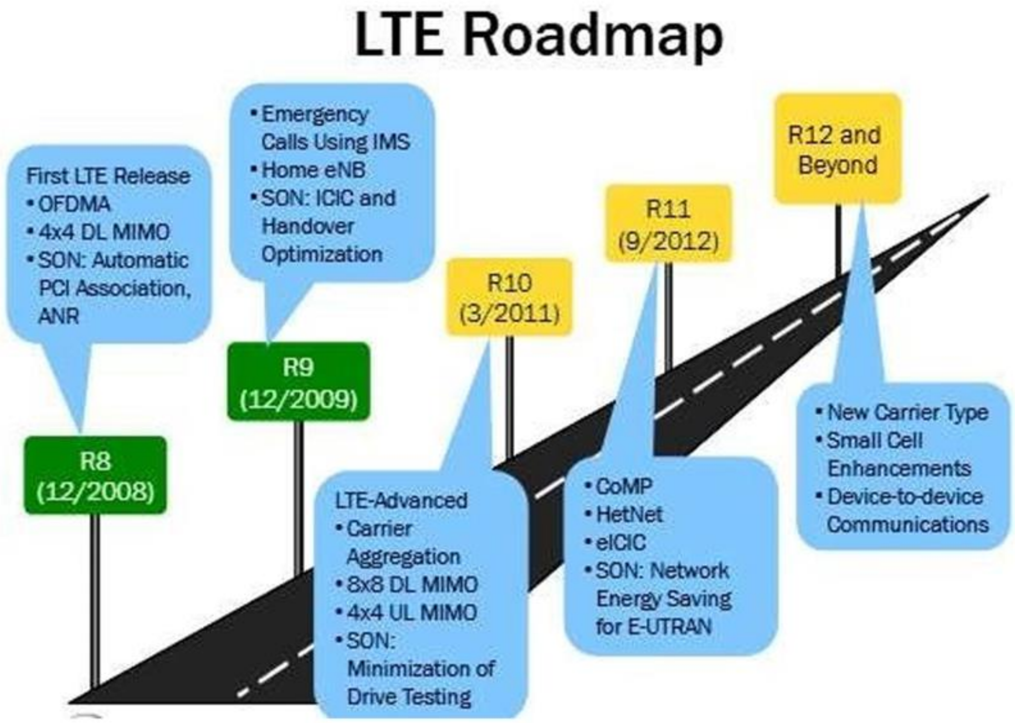


Figure 77: 3GPP LTE Enhancement

6.5 4G : LTE ADVANCED

The basic LTE, long term evolution cellular services were launched around 2010 with some advance deployments well before this. It was never envisaged that this initial form of LTE would provide the full performance intended. This required some additional elements that were in what was termed LTE Advanced.

LTE Advanced, LTE-A incorporated a number of new techniques that enabled the system to provide very much higher data rates, and also much better performance, particularly at cell edges and other areas where performance would not normally have been so good.

LTE Advanced took a few more years to fully develop and roll out across the networks, but when introduced it enabled its many advanced features to provide significant improvements over basic LTE.

6.5.1 FOLLOWING ARE SOME SIGNIFICANT IMPROVEMENTS IN RELEASE 10.

Enhanced Uplink multiple accesses: Release 10 introduces clustered SC-FDMA in uplink. Release 8 SC-FDMA only allowed carriers along contiguous block of spectrum but LTE-Advanced in release 10 allows frequency-selective scheduling in uplink

MIMO enhancements: LTE-Advanced allows upto 8x8 MIMO in downlink and on the UE side it allows 4X4 in uplink direction.

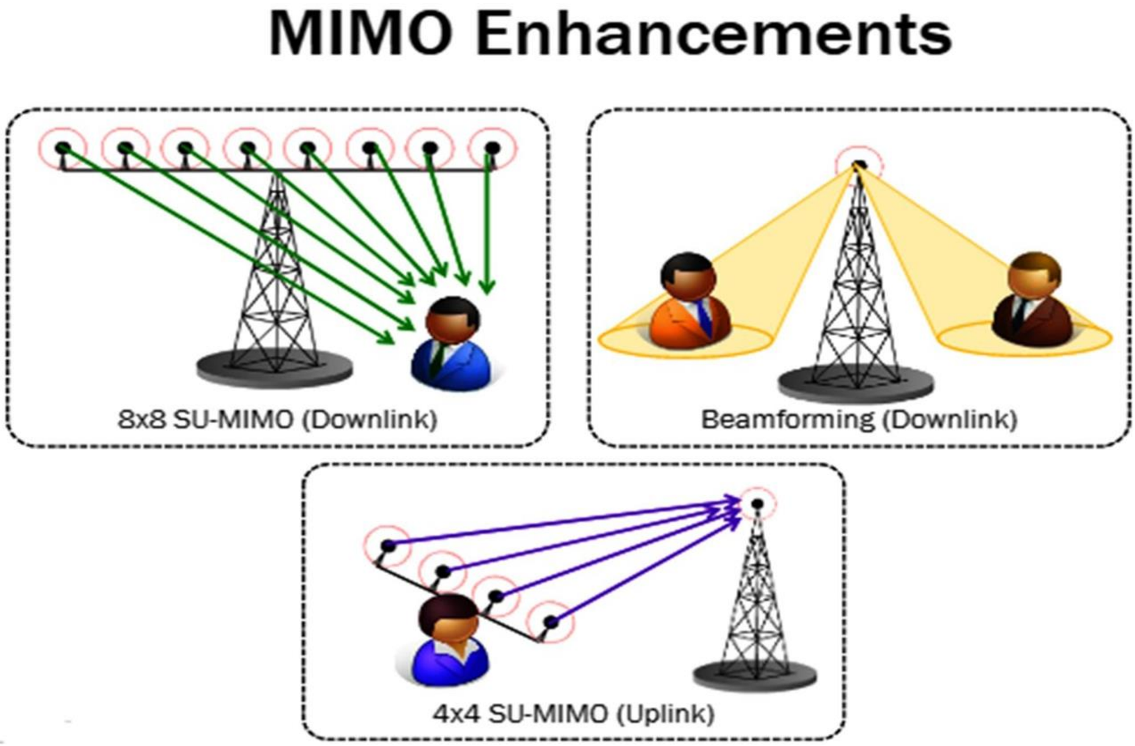


Figure 78: MIMO Enhancement

Relay Nodes: In order to decrease coverage loop holes, Relay nodes are one of the features proposed in release 10. The relay nodes or low power ends extending the coverage of main eNB in low coverage environment. The relay nodes are connected to Donor eNB (DeNB) through Un interface.

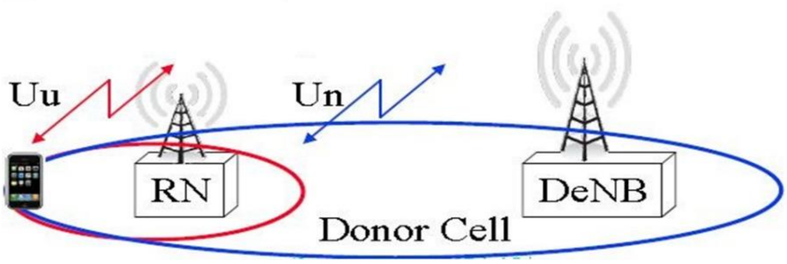


Figure 79: Relay Node

Carrier Aggregation (CA):

CA introduced in release 10 is a cost effective way for operators to utilize their fragmented spectrum spread across different or same bands in order to improve end user throughput as required by IMT-Advanced. Carrier Aggregation increases the channel bandwidth by combining multiple RF carriers. Each individual RF carrier is known as a Component Carrier.

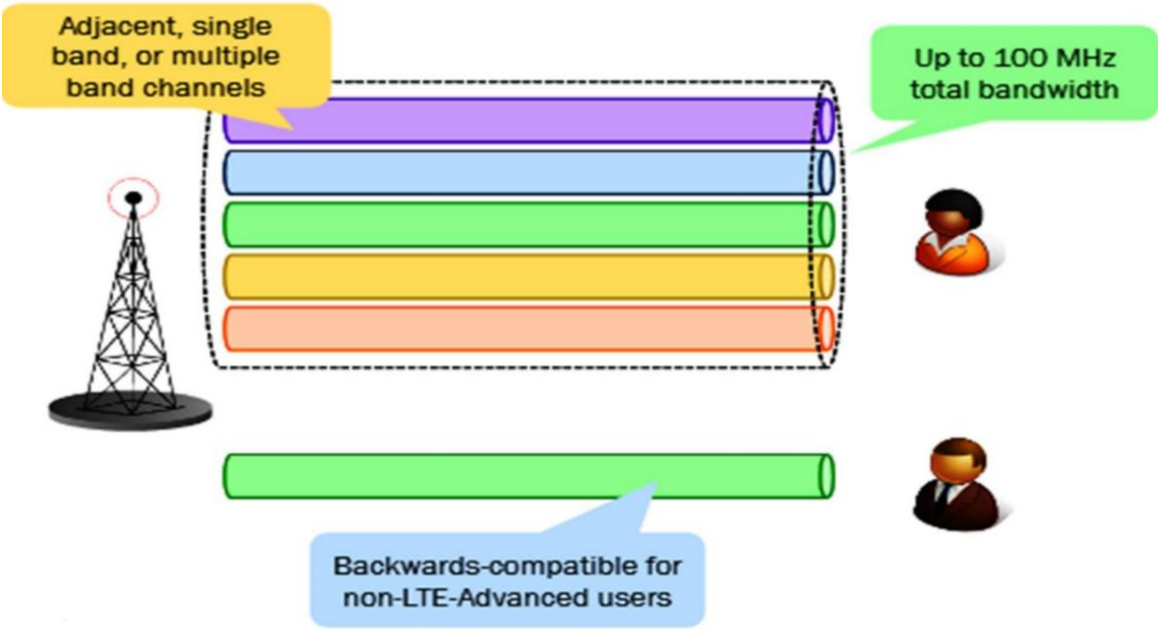


Figure 80: Carrier Aggregation

The release 10 version of the 3GPP specifications defines signalling to support up to 5 Component Carriers. i.e. a maximum combined channel bandwidth of 100 MHz. Component Carriers do not need to be adjacent and can be located in different operating bands. The release 10 version of the 3GPP specifications defines individual Component Carriers to be backwards compatible so they can be used by release 8 and release 9 devices.

Support for Heterogeneous Networks:

The combination of large macro cells with small cells results in heterogeneous networks. Release 10 intended to layout the detail specification for heterogeneous networks.

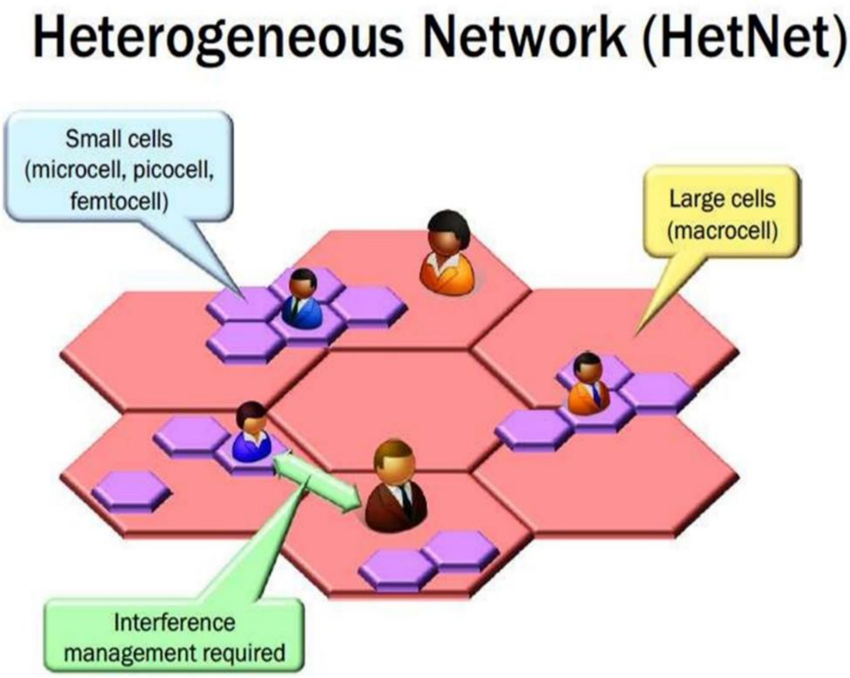


Figure 81: Network Architecture Evolution

Enhanced inter-cell interference coordination (eICIC)

eICIC introduced in 3GPP release 10 to deal with interference issues in Heterogeneous Networks (HetNet). eICIC mitigates interference on traffic and control channels. eICIC uses power, frequency and also time domain to mitigate intra-frequency interference in heterogeneous networks.

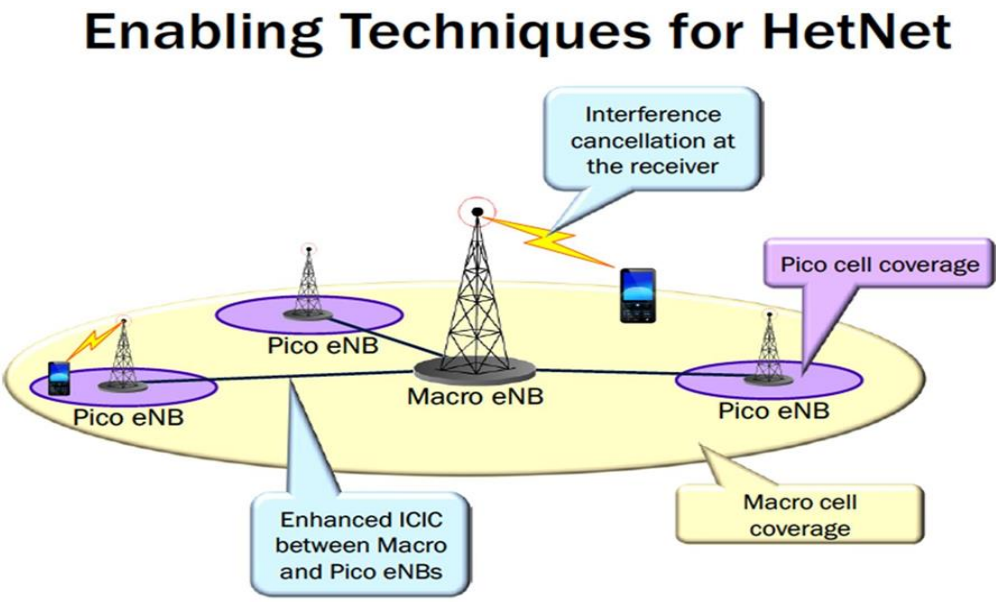


Figure 82: eICIC

Coordinated Multi-Point transmission (CoMP) : Coordinated Multi-Point (CoMP) transmission in the down link and reception in the uplink are LTE-Advanced solutions to help improve the cell edge throughput and spectrum efficiency performance.

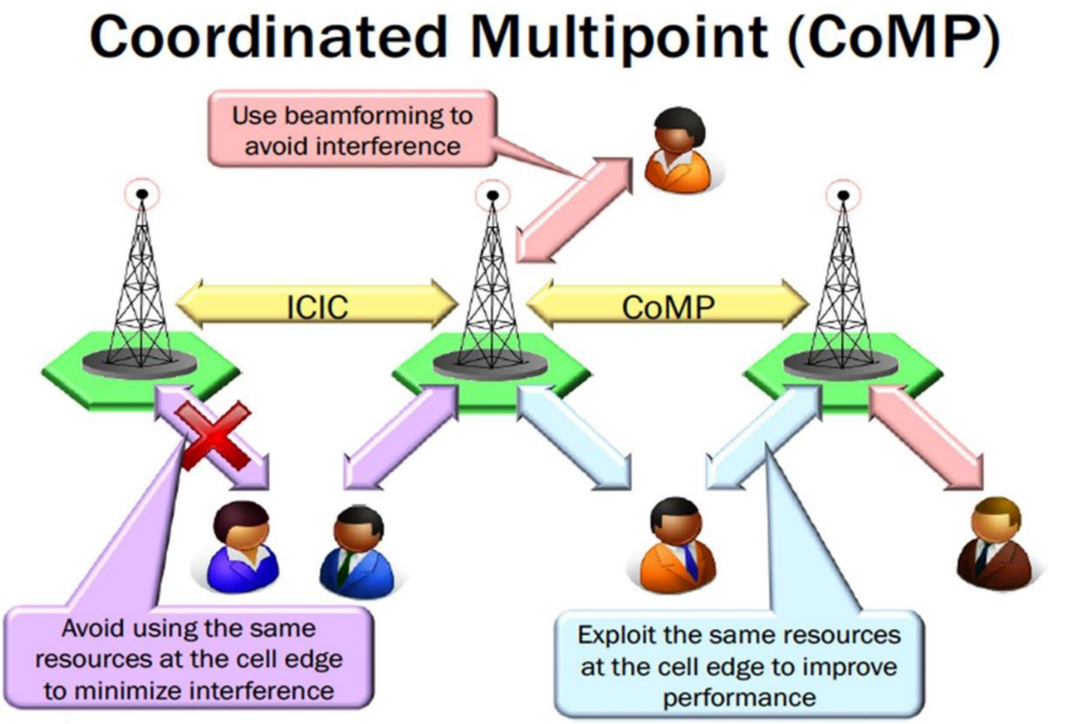


Figure 83: Coordinated Multi-Point transmission

SON Improvements: Release 10 provides enhancements to SON features introduced in release 9 which also considers self healing procedures.

6.6 ENHANCEMENT TO LTE ADVANCE (REL 11)

Release 11 includes enhancements to LTE Advanced features standardized in release 10. Some of the important enhancements are listed below .

Carrier Aggregation enhancements: Following are the major enhancements to carrier aggregation in release 11

- Multiple timing advances (TAs) for uplink carrier aggregation
- Non contiguous intra band carrier aggregation
- physical layer changes for carrier aggregation support in TDD LTE

Coordinated multipoint transmission and reception (CoMP): With CoMP the transmitter can share data load even if they are not collocated. Though they are connected by high speed fiber link

ePDCCH: New enhanced PDCCH introduced in 3GPP release 11 to increase control channel capacity. ePDCCH uses PDSCH resources for transmitting control information unlike release 8 PDCCH which can only use control region of subframes

Network based Positioning: In release 11, support for uplink positioning is added by utilizing Sounding reference signals for time difference measurements taken by many eNBs.

Minimization of drive test (MDT): Drive tests are always expensive. To decrease dependency on drive tests, new solutions introduced which are independent of SON though much related. MDT basically relies on information provided by UE.

RAN overload control for Machine type communication: For machine type devices new mechanism has been specified in release 11 where network in case of mass communication from devices can bar some devices to send connection request to network

In Device Co Existence: Now a days, all mobile devices would usually carry multi radio transceivers like for LTE, 3G, Bluetooth, WLAN etc. Now this co existence results in interference. To mitigate this interference, release 11 has specified solutions as mentioned below

- DRX based time domain solutions
- Frequency domain solutions
- UE autonomous denials

Smartphone Battery saving technique: Many applications on smart phones generate background traffic which consumes battery power. Release 11 specifies a method where UE can inform network whether it needs to be operated in battery saving mode or normal mode and based on UE request network can modify DRX parameters

6.7 FURTHER ENHANCEMENT TO LTE ADVANCED (REL 12)

Release 12 includes further enhancement to LTE Advanced features standardized in release 10 and 11. Some of the important enhancements are listed below

Small cells enhancements: Small cells were supported since beginning with features like ICIC and eICIC in release 10. Release 12 introduces optimization and enhancements for small cells including deployments in dense areas. Dual connectivity i.e. inter-site carrier aggregation between macro and small cells is also a focus area

Carrier aggregation enhancements: Release 12 now allows carrier aggregation between co-located TDD and FDD carriers. In addition to carrier aggregation between TDD and FDD, there are also now three carrier aggregations possible for total of 60 Mhz spectrum aggregated

Machine Type communication (MTC): Huge growth is expected in machine type communication in coming years which can result in tremendous network signalling, capacity issues. To cope with this, new UE category is defined for optimized MTC operations

Wifi integration with LTE: With integration between LTE and Wifi, operators will have more control on managing WiFi sessions. In release 12, the intent is to specify mechanism for steering traffic and network selection between LTE and WiFI

LTE in unlicensed spectrum: An LTE operation in unlicensed spectrum is one of the study items in release 12. Operations in Bandwidth rich unlicensed spectrum brings many benefits to operators like increase in network capacity, load and performance

6.8 RELEASE 13 AND BEYOND: LTE ADVANCED PRO

3GPP publishes its specifications in the form of releases. These releases are published regularly. A new release is published when a set of essential new features are developed and finalized. Often a set of such releases is given a marketing name. As shown in Figure, Rel. 8, 9 is called LTE; Rel. 10, 11, 12, LTE-Advanced; and Rel. 13 and beyond, LTE-A Pro.

LTE-A Pro is the marketing name for a set of releases that cellular standards body 3GPP (3rd Generation Partnership Project) publishes.3GPP has devised a set of advanced features to continue enhancing the capabilities of 4G LTE as part of Rel. 13 and onwards. This upgrade in capabilities has been called “LTE-Advanced Pro (LTE-A Pro),” which you may also see referred to as 4.5G or Pre-5G.

Figure 84: LTE Advanced PRO

Some of the important enhancements are listed below

Carrier aggregation enhancements: The goal in release 13 is to support carrier aggregation of upto 32 CC (component carriers) where as in release 10, the carrier aggregation was introduced with support of only upto 5 CC.

Enhancements for Machine-Type communication (MTC): Continuing from release 12, there are further enhancements in MTC, a new low complexity UE category is being defined to provide support for reduced bandwidth, power and support long battery life.

LTE in unlicensed enhancements: The focus in release 13 is the aggregation of primary cell from licensed spectrum with secondary cell from unlicensed spectrum to meet the growing traffic demand

Indoor Positioning: In release 13 there is work going on improving existing methods of indoor positioning and also exploring new positioning methods to improve indoor accuracy

Enhanced multi-user transmission techniques: Release 13 also covers potential enhancements for downink multiuser transmission using superposition coding

MIMO enhancements: Upto 8 antenna MIMO systems are currently supported, the new study in this release will look into high-order MIMO systems with up to 64 antenna ports.

6.9 BEYOND REL. 13

5G NR and LTE-A Pro are evolved in parallel. Rel. 15 introduces 5G NR, a new unified radio interface that significantly improves performance, efficiency and scalability of cellular networks.

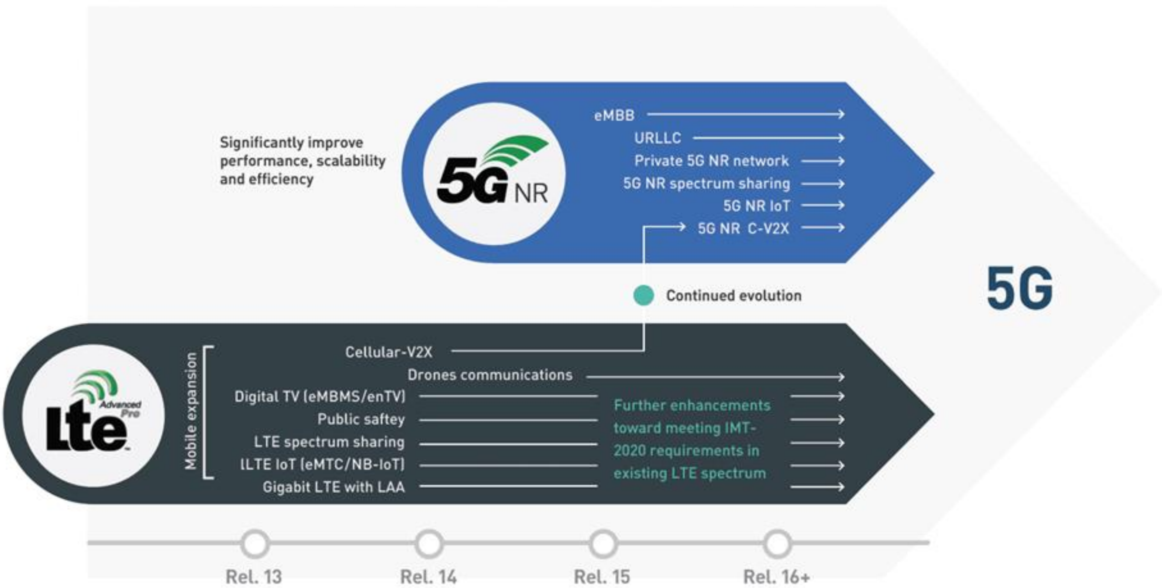


Figure 85: 5G NR and LTE-A Pro are evolving in parallel

6.10 INTRODUCTION TO 5G

5G is the 5th generation mobile network. It is a new global wireless standard after 1G, 2G, 3G, and 4G networks. 5G enables a new kind of network that is designed to connect virtually everyone and everything together including machines, objects, and devices.

5G wireless technology is meant to deliver higher multi-Gbps peak data speeds, ultra low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. Higher performance and improved efficiency empower new user experiences and connects new industries.

6.11 5G STANDARDIZATION

As of 3G, the generational designation corresponds to a standard defined by the 3rd Generation Partnership Project (3GPP). Even though its name has "3G" in it, the 3GPP continues to define the standards for 4G and 5G, each of which corresponds to a sequence of releases of the standard. Release 15 is considered the demarcation point between 4G and 5G. Complicating the terminology, 4G was on a multi-release evolutionary path referred to as Long Term Evolution (LTE). 5G is on a similar evolutionary path, with several expected releases over its lifetime.5G is defined by ITU-R as IMT-2020.

Figure 86: 5G Standardization

6.12 5G PERFORMANCE TARGET

As the preliminaries for the work for the new 5G mobile communications system, the outline requirements were set in place. These were defined by the ITU as part of IMT2020. ITU defined 5G requirements in terms of 8 parameters:

- A peak rate up to 20 Gbps per user,
- User experienced rate of 100 Mbps,
- Mobility support to 500 km/h,
- A latency of 1 ms,
- A density of a million connections per m2,
- Energy efficiency 100× of 4G
- Area Traffic Capacity 10 Mbits/sec/m2
- Spectral Efficiency 3 X of 4G

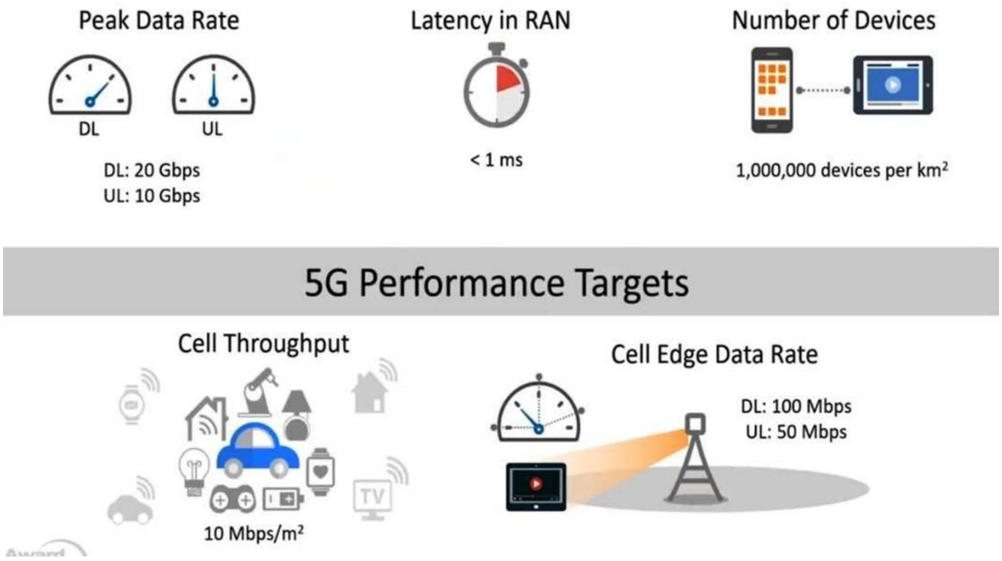


Figure 87: 5G Performance Target

6.13 5G KEY APPLICATION AREAS

The ITU-R has defined three main application areas for the enhanced capabilities of 5G. Enhanced Mobile Broadband (eMBB), Ultra Reliable Low Latency Communications (URLLC), and Massive Machine Type Communications (mMTC). Only eMBB is deployed in 2020; URLLC and mMTC are several years away in most locations.

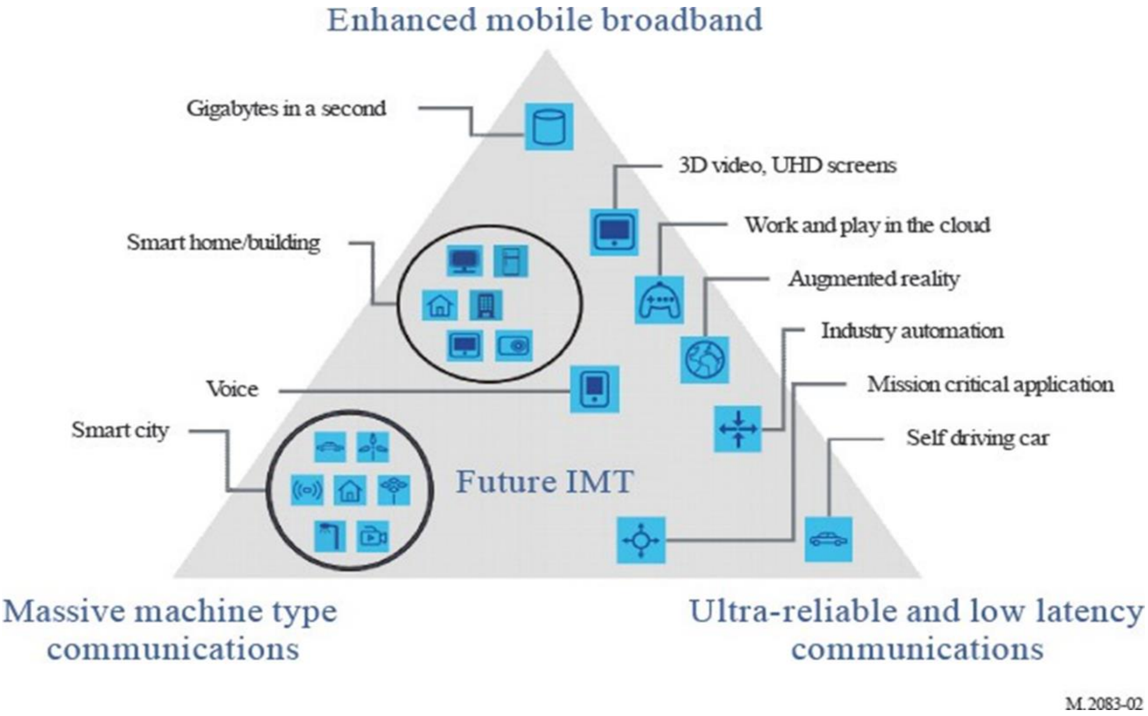


Figure 88: 5G Application Area

Enhanced Mobile Broadband (eMBB)

Uses 5G as a progression from 4G LTE mobile broadband services, with faster connections, higher throughput, and more capacity. This will benefit areas of higher traffic such as stadiums, cities, and concert venues.

Ultra-Reliable Low-Latency Communications (URLLC)

Human and Machine centric communication. URLLS refer to using the network for mission critical applications that require uninterrupted and robust data exchange. Vehicle-to-Vehicle communication, Industrial IoT, 3D Gaming are use case of URLLC.

Massive Machine-Type Communications (mMTC)

Machine-centric communication.MMTC would be used to connect to a large number of devices. 5G technology will connect some of the 50 billion connected IoT devices. Most will use the less expensive Wi-Fi. Drones, transmitting via 4G or 5G, will aid in disaster recovery efforts, providing real-time data for emergency responders. Most cars will have a 4G or 5G cellular connection for many services. Autonomous cars do not require 5G, as they have to be able to operate where they do not have a network connection.

6.14 5G NEW RADIO:

5G NR or 5G New Radio is the new radio air interface being developed for 5G mobile communications. With the demanding requirements being placed upon the new 5G mobile communications standard, a totally new radio interface and radio access network has been developed Called 5G New Radio or 5G NR.

The development of the 5G NR or 5G New Radio is key to enabling the 5G mobile communications system to work and it provides a number of significant advantages when compared to 4G.

5G NR has been developed from scratch taking the requirements and looking at the best technologies and techniques that will be available when 5G starts to be deployed.

5G NR utilises modulation, waveforms and access technologies that will enable the system to meet the needs of high data rate services, those needing low latency and those needing small data rates and long battery lifetimes amongst others. The first iteration of 5G NR appeared in 3GPP Release 15.

6.14.1 5G NR SPECTRUMS

The 5G new radio, 5G NR utilises a variety of different frequency bands. Like the other mobile communications systems, the frequency allocations are located in a variety of areas of the radio spectrum.

Frequency Range

Two different frequency ranges are available for the 5G technology and the different ranges have been designated FR1-frequency range 1 and FR -frequency range 2.

The bands in frequency range 1, FR1 are envisaged to carry much of the traditional cellular mobile communications traffic.

The higher frequency bands in range FR2 are aimed at providing short range very high data rate capability for the 5G radio. With 5G wireless technology anticipated to carry much higher speed data, the additional bandwidth of these higher frequency bands will be needed.

Originally the FR1 band was intended to define bands below 6 GHz, but with anticipated additional spectrum allocations, the FR1 range has now been extended to 7.125 GHz.

FREQUENCY RANGES, FR1 & FR2 FOR 5G NR	
FREQUENCY RANGE DESIGNATION	**FREQUENCY RANGE (MHZ)**
FR1	410 - 7125
FR2	24 250 - 52600

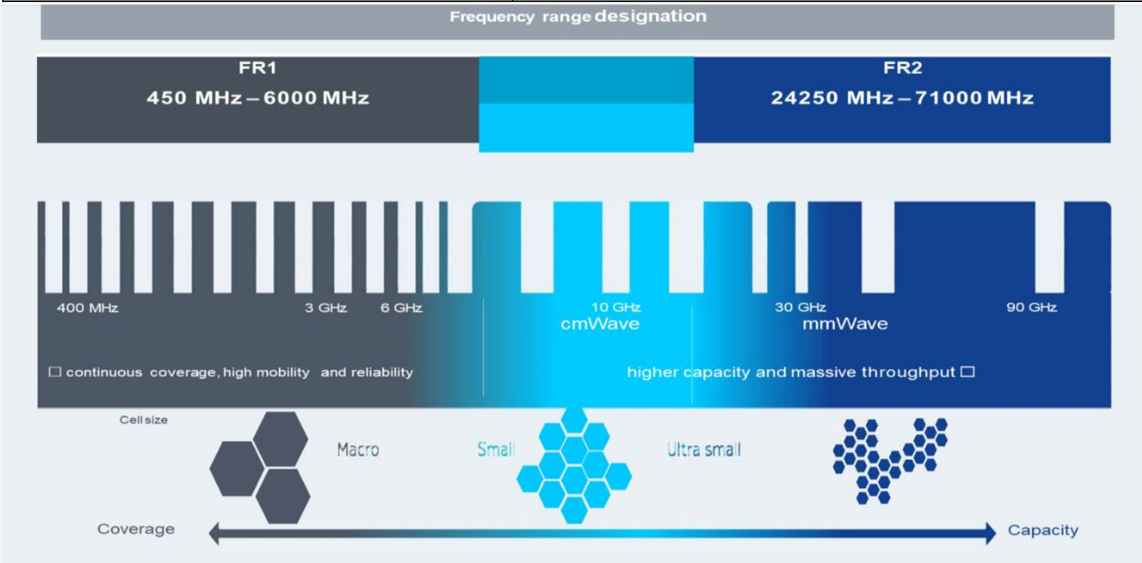


Figure 89: 5G Frequency Range

6.14.2 5G DUPLEXING MODE

Frequency Range 1 includes operating bands which support Frequency Division Duplexing (FDD), Time Division Duplexing (TDD),Supplemental Downlink (SDL) and Supplemental Uplink (SUL).

Whereas Frequency Range 2 supports only TDD. 3GPP has specified mechanisms to allow dynamic changes to the uplink and downlink transmission pattern used by TDD.

6.14.3 5G FREQUENCY BANDS

The frequency bands in FR1 utilise many of the same frequency bands as those used for 4G and other mobile communications cellular services. It is envisaged that over time, the channels and also the bands used for carrying 5G data will take over more of the bands already allocated to mobile or cellular telecommunications. In this way, 5G wireless technology will be able to carry the required traffic levels.

Bands have been set aside for frequency division duplex, FDD usage, or time division duplex, TDD usage. For FDD usage, frequency bands are required for the uplink and downlink, and therefore two bands are allocated. For TDD usage, only a single channel is used for the link: time slots are allocated for the uplink and downlink rather than different frequencies. As a result, for TDD only one band is needed.

In addition to the FDD and TDD bands, other bands have been allocated to provide supplementary uplink and downlink capacity. The bands marked SDL are for supplementary downlinks and SUL are for supplementary uplinks.

5G FR1 FREQUENCY BANDS			
5G NR FREQUENCY BAND	**UPLINK BAND (MHZ)**	**DOWNLINK BAND (MHZ)**	**DUPLEX MODE**
n1	1920 - 1980	2110 - 2170	FDD
n2	1850 - 1910	1930 - 1990	FDD
n3	1710 - 1785	1805 - 1880	FDD
n5	824 - 849	869 - 894	FDD
n7	2500 - 2570	2620 - 2690	FDD
n8	880 - 915	925 - 960	FDD
n12	699 - 716	729 - 746	FDD
n20	832 - 862	791 - 821	FDD
n25	1850 - 1915	1930 - 1995	FDD
n28	703 - 748	758 - 803	FDD
n34	2010 - 20225		TDD
n38	2570 - 2620		TDD
n39	1880 - 1920		TDD
n40	2300 - 2400		TDD
n41	2496 - 2690		TDD
n50	1432 - 1517		TDD
n51	1427 - 1432		TDD
n66	1710 - 1780		TDD
n70	1695 - 1710		TDD
n71	663 - 698		TDD
n74	1427 - 1470		TDD
n75	--	1432 - 1517	SDL
n76	--	1427 - 1432	SDL
n77	3300 - 4200		TDD
n78	3300 - 3800		TDD
n79	4400 - 5000		TDD
n80	1710 - 1785	--	SUL
n81	8800 - 915	--	SUL
n82	832 - 862	--	SUL
n83	703 - 748	--	SUL
n84	1920 - 1980	--	SUL
n86	1710 - 1780	--	SUL

Table 4. Frequency Range 1

5G NR FREQUENCY BAND	UPLINK BAND (MHZ)	DOWNLINK BAND (MHZ)	DUPLEX MODE
n257	26 500 - 29500	26500 - 29500	TDD
n258	24 250 - 27 500	24 250 - 27 500	TDD
n260	37 000 - 40 000	37 000 - 40 000	TDD
n261	27 500 - 28 350	27 500 - 28 350	TDD

Table 5. Frequency Range 2

The frequency range 2, FR2 5G bands are now starting to gain momentum with new development to make the microwave links viable for the large scale deployment that will be needed.

Allocations are being made in many areas of the spectrum above 20 GHz as it is relatively lightly used at the moment.

6.14.4 CARRIER AGGREGATION :

5G NR supports carrier aggregation to enable the system to provide the required bandwidth for the very high speed data transfers. The specification allows for up to 16 component carriers to be aggregated using various combinations of inter-band and intra-band carrier aggregation.

The feature can be used in a smart fashion to overcome some of the issues that may occur not only with increased bandwidth, but also to overcome the issues of increased path loss at higher frequencies. In terms of the allocations above it will be seen that supplementary uplinks, SUL and supplementary downlinks, SDL can be used.

6.14.5 CHANNEL BANDWIDTH:

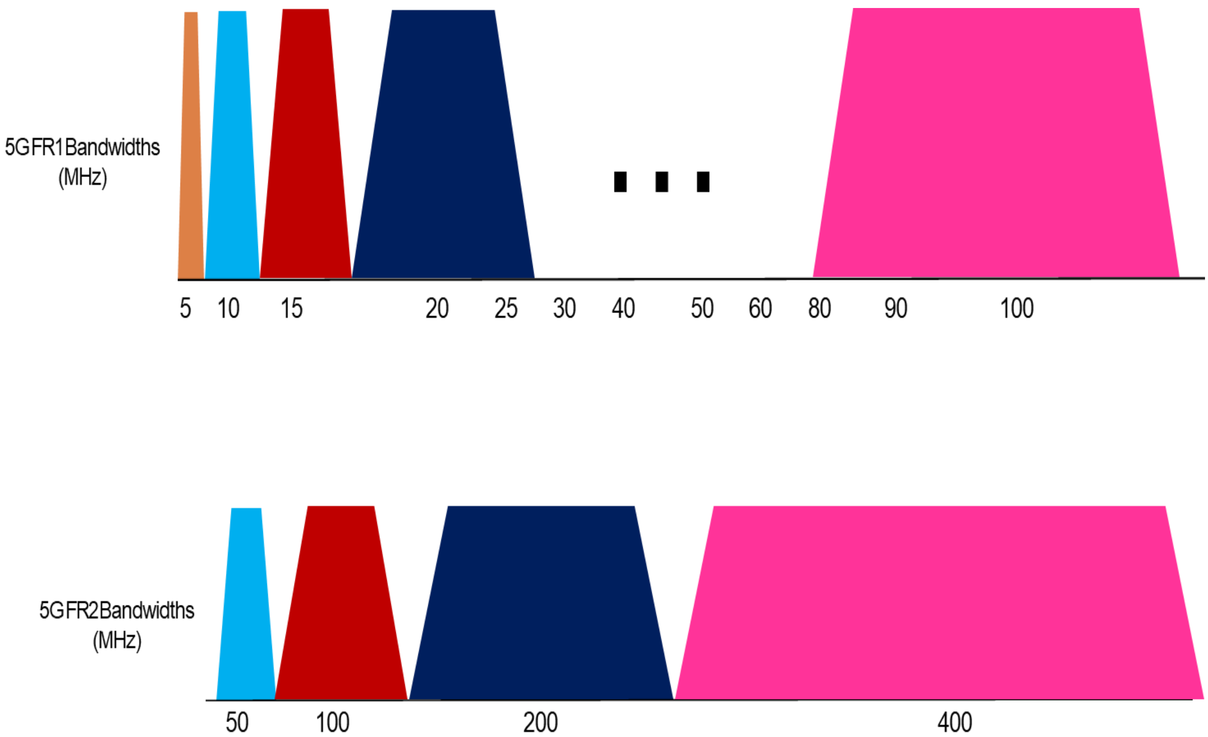


Figure 90: 5G Channel Bandwidth

6.14.6 5G NR PARAMETERS SUMMARY

5G NR PARAMETERS FOR DIFFERENT FREQUENCY BANDS		
5G NR PARAMETER	**FR1**	**FR2**
Bandwidth options per carrier	5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90, 100 MHz	50, 100, 200, 400 MHz
Subcarrier spacing	15, 30, 60 kHz	60, 120, 240 kHz
Maximum number of subcarriers	3300 (FFT 4096)	
Carrier Aggregation	Up to 16 carriers	
Modulation schemes	QPSK, 16QAM, 64QAM, 256QAM, uplink also allows π/2-BPSK (only for DFT-s-OFDM).	
Radio frame length	10ms	
Subframe duration	1ms	
Duplex mode	FDD, TDD	TDD
Multiple access scheme	Downlink: CP-OFDM Uplink: CP-OFDM; DFT-s-OFDM	
MIMO scheme	maximum of 2 code words mapped to maximum of 8 layers in downlink and to a maximum of 4 in uplink.	

Table 6. 5G NR PARAMETERS FOR DIFFERENT FREQUENCY BANDS

6.15 5G RADIO TECHNOLOGIES

5G also incorporates many technologies, many of which are new, to enable the it to provide the very high levels of performance required of it. By utilising these techniques the 5G New radio, 5G NR will be able to significantly improve the performance, flexibility, scalability and efficiency of current mobile networks.

6.15.1 MASSIVE MIMO WITH BEAM-STEERING

The antenna technologies for 5G have provided significant opportunities for enhancement of the performance over 4G. Although MIMO was used with 4G LTE, the technology has been taken further.

MIMO systems use multiple antennas at the transmitter and receiver ends of a wireless communication system. Multiple antennas use the spatial dimension in addition to the time and frequency ones, without changing the bandwidth requirements of the system.

The multiple data streams have their own weightings which include phase offsets to each stream to enable the waveforms to interfere constructively at the receiver. This maximises the signal strength to the user whilst also minimising the signal and hence interference to other users.

MU-MIMO on the downlink significantly improves the capacity of the gNB antennas. It scales with the minimum of the number of gNB antennas and the sum of the number of user devices multiplied by the number of antennas per UE device. This means that using 5G MU-MIMO the system can achieve capacity gains using gNB antenna arrays and much simpler UE devices.

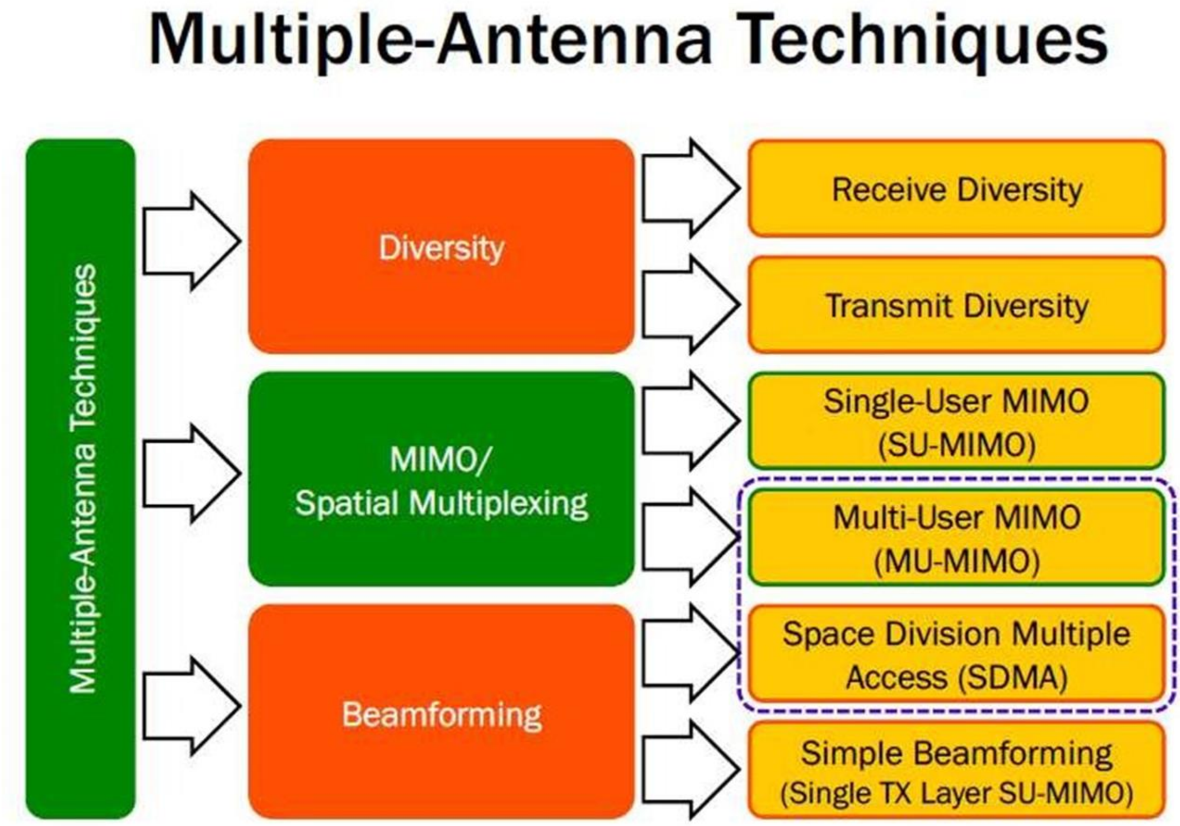


Figure 91: Use of MIMO

Massive MIMO (multiple input and multiple output) antennas increases sector throughput and capacity density using large numbers of antennas and Multi-user MIMO (MU-MIMO). Each antenna is individually-controlled and may embed radio transceiver components.

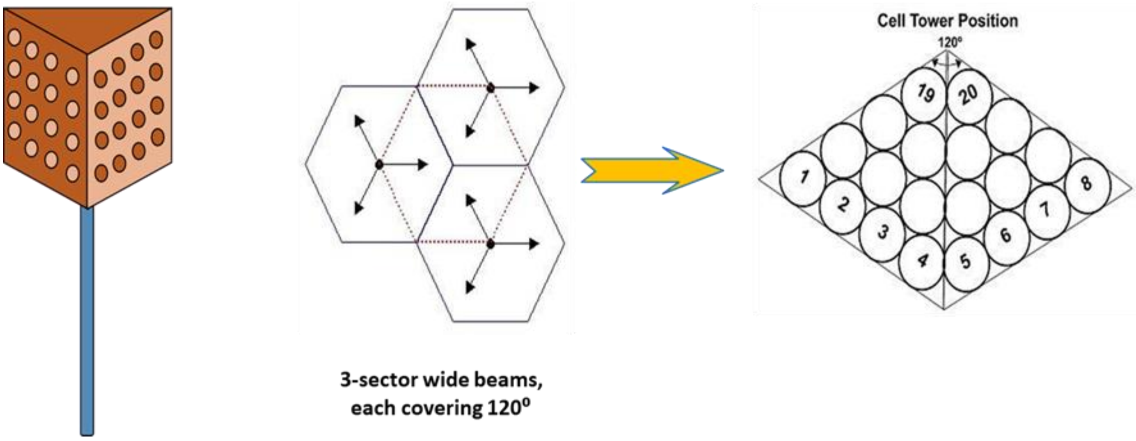


Figure 92: Massive MIMO

The release 15 version of the 3GPP specifications for New Radio (NR) supports MIMO in both the uplink and downlink directions.

The uplink supports 2x2 MIMO and 4x4 MIMO, whereas the downlink supports 2x2 MIMO. 4x4 MIMO and 8x8 MIMO.

The release 15 version of the specifications also supports Multi-User MIMO in both the uplink and downlink directions.

Beam-steering technology has also been adopted to enable the transmitter and receiver antenna beams to be focussed towards the mobiles with which they are communicating. Each mobile can have its own beam, using advanced antenna technology, and this focussed the transmitted power where it is required and reduces interference between mobiles. This gives a significant improvement in performance.

6.15.2 BEAMFORMING

Beamforming, as the name suggests, is used to direct radio waves to a target. This is achieved by shaping the radio waves to point in a specific direction. The technique combines the power from elements of the antenna array in such a way that signals at particular angles experience constructive interference, while other signals pointing to other angles experience destructive interference. This improves signal quality in the specific direction, as well as data transfer speeds. 5G uses beamforming to improve the signal quality it provides. Beamforming can be accomplished using phased array antennas.

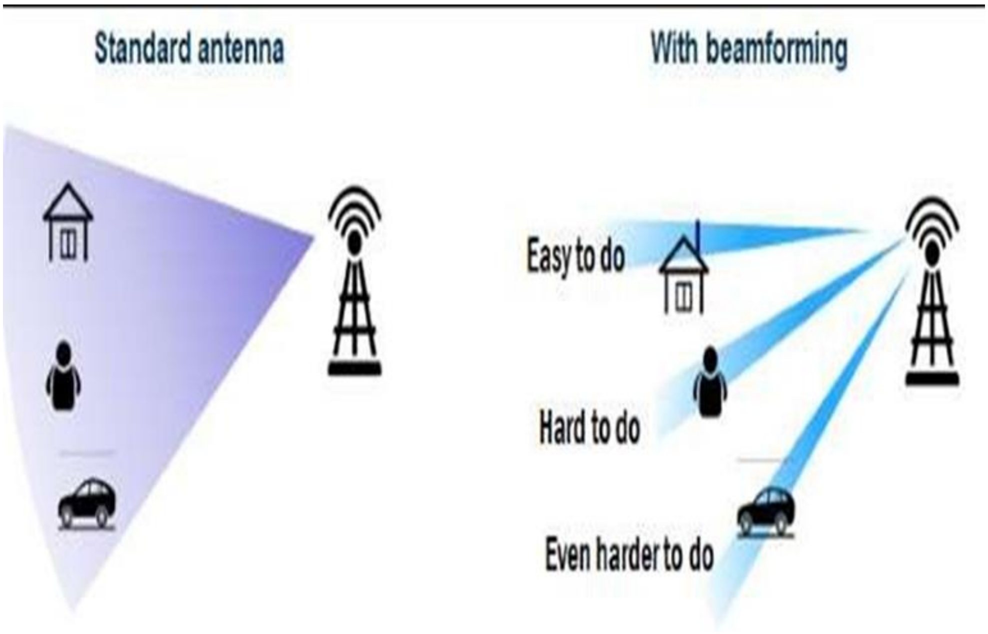


Figure 93: Beamforming Antenna

6.15.3 WAVEFORM AND MODULATION

An early decision was taken to use a form of OFDM as the waveform for phase one of the 5G New Radio. It has been very successfully used with 4G, the more recent Wi-Fi standards and many other systems and came out as the optimum type of waveform for the variety of different applications for 5G. With the additional processing power available for 5G, various forms of optimisation can be applied.

Basic concept of OFDM, Orthogonal Frequency Division Multiplexing. The specific version of OFDM used in 5G NR downlink is cyclic prefix OFDM, CP-OFDM and it is the same waveform LTE has adopted for the downlink signal.

5G adopted actual modulation formats dependent upon the link and these include QPSK, 16QAM, 64QAM, 256QAM and for the uplink when DFT-OFDM is used, π/2-BPSK can be used. For the future, other forms of waveform may be developed, but currently the waveform is based around OFDM.

6.15.4 MULTIPLE ACCESS

Again a variety of access schemes were discussed, but for the 5G New Radio, OFDMA was implemented. For the downlink CP-OFDM was used and in the uplink either CP-OFDM or DFT-OFDM could be used.

6.16 5G NEXTGEN NG CORE NETWORK

The requirements for the network for 5G will be particularly diverse. In one instance, very high bandwidth communications are needed, and in other applications there is a need for exceedingly low latency, and then there are also requirements for low data rate communications for machine to machine and IoT applications.

In amongst this there will be normal voice communications, Internet surfing and all the other applications that we have used and become accustomed to using.

As a result the 5G NextGen network will need to accommodate a huge diversity in types of traffic and it will need to be able to accommodate each one with great efficiency and effectiveness. Often it is thought that type suits all approach does not give the optimum performance in any application, but this is what is needed for the 5G network.

To achieve the requirements for the 5G network a number of techniques are being employed. These will make the 5G network considerably more scalable, flexible and efficient.

6.16.1 SERVICE BASED ARCHITECTURE :

The 5G System Service Based architecture specifies a set of Network Functions (NF) and a common bus which inter-connects those Network Functions. The Service Based architecture is applicable to the control plane section of the 5G Core Network. Each service is a function and several functions can be implemented in a physical node or a virtual machine

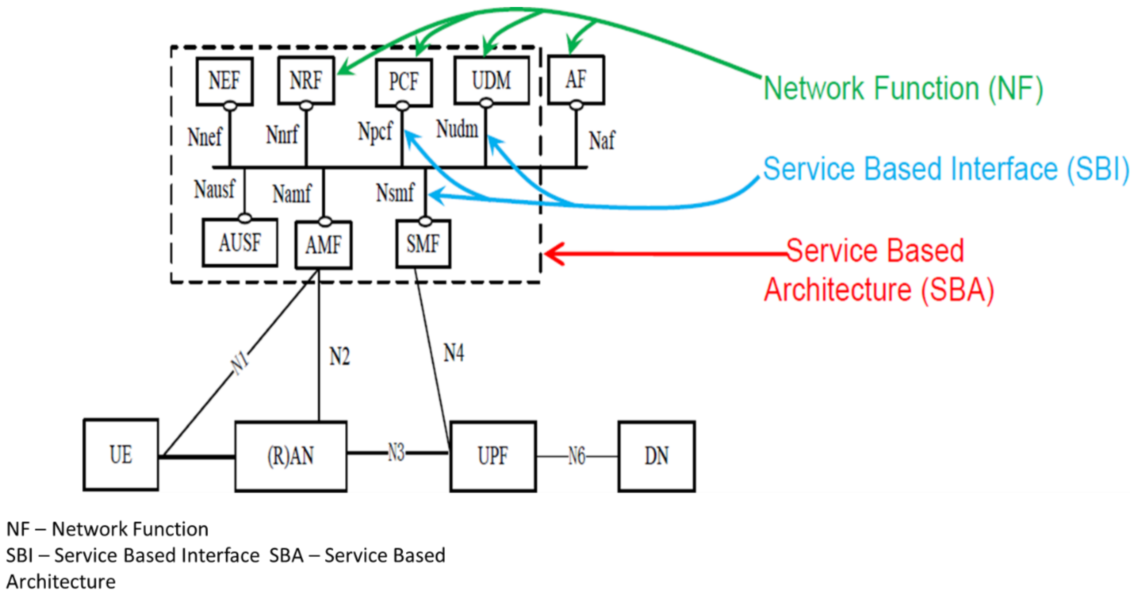


Figure 94: Service Based Architecture

Software defined networking, SDN:

Using software defined networks, it is possible to run the network using software rather than hardware. This provides significant improvements in terms of flexibility and efficiency. SDN separates the control and data planes and allows for network programmability

Network functions virtualisation, NFV :

When using software defined networks it is possible to run the different network function purely using software. This means that generic hardware can be reconfigured to provide the different functions and it can be deployed as required on the network.

Standard hardware is fast and cheap, No specialized hardware is required. All functions can be virtualised in cloud and capacity can be created on demand.

Network slicing:

As 5G will require very different types of network for the different applications, a scheme known as network slicing has been devices. Using SDN and NFV it will be possible to configure the type of network that an individual user will require for his application. In this way the same hardware using different software can provide a low latency level for one user, whilst providing voice communications for using different software and other users may want other types of network performance and each one can have a slice of the network with the performance needed.

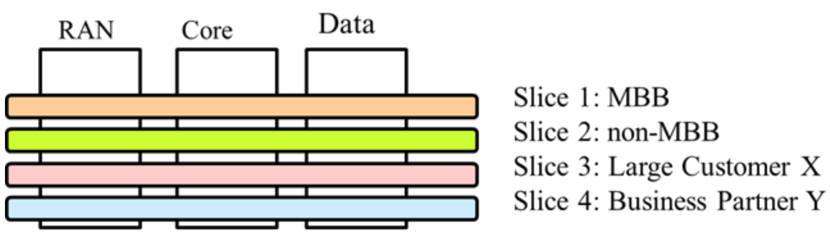


Figure 95: Network slicing

Slice = A logical network serving a particular application, business partner, or customer.

It is similar to Virtual Machines (VMs) on a computer. A network can be divided in too many slices. Each slice looks to the user as a separate network with reserved resources .

Edge computing

Edge computing is delivered by computing servers closer to the ultimate user. It reduces latency and data traffic congestion.

6.17 5G DEPLOYMENT OPTIONS

With an already deployed 4G RAN/EPC in the field and a new 5G RAN/NG-Core deployment underway, we can't ignore the issue of transitioning from 4G to 5G (an issue the IP-world has been grappling with for 20 years). 3GPP officially spells out multiple deployment options, which can be summarized as follows.

- Standalone 4G / Stand-Alone 5G
- Non-Standalone (4G+5G RAN) over 4G's EPC
- Non-Standalone (4G+5G RAN) over 5G's NG-Core

The second of the three options, which is generally referred to as "NSA", involves 5G base stations being deployed alongside the existing 4G base stations in a given geography to provide a data-rate and capacity boost. In NSA, control plane traffic between the user equipment and the 4G Mobile Core utilizes (i.e., is forwarded through) 4G base stations, and the 5G base stations are used only to carry user traffic. Eventually, it is expected that operators complete their migration to 5G by deploying NG Core and connecting their 5G base stations to it for Standalone (SA) operation. NSA and SA operations are illustrated in Figure

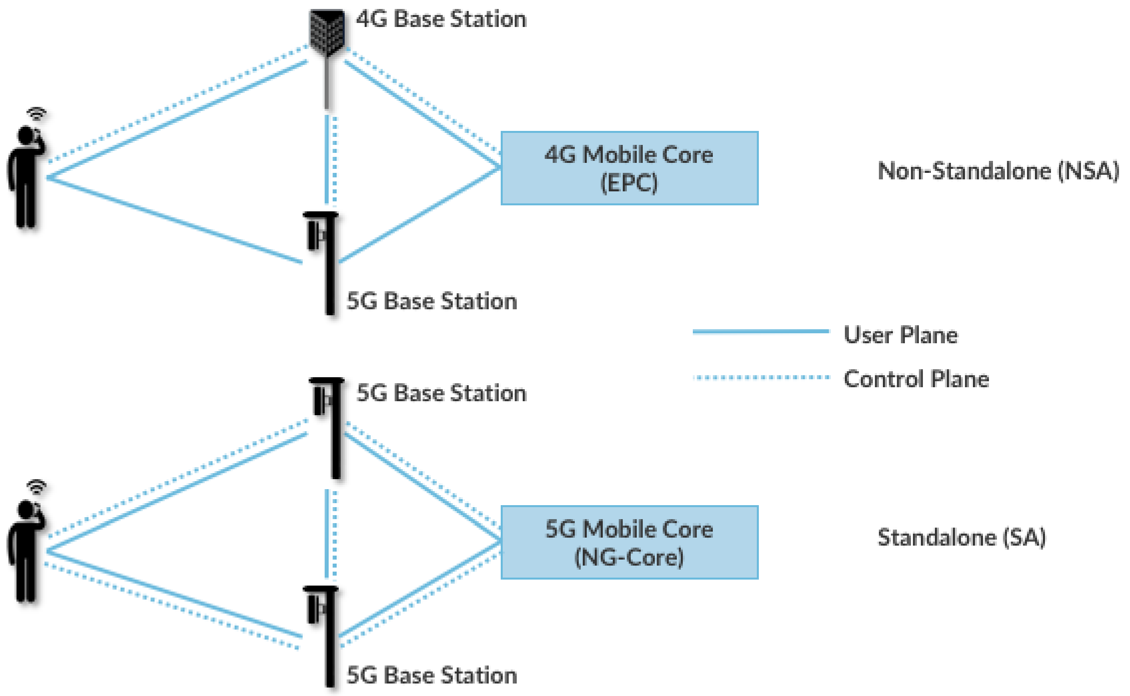


Figure 96: SA and Non SA Deployment

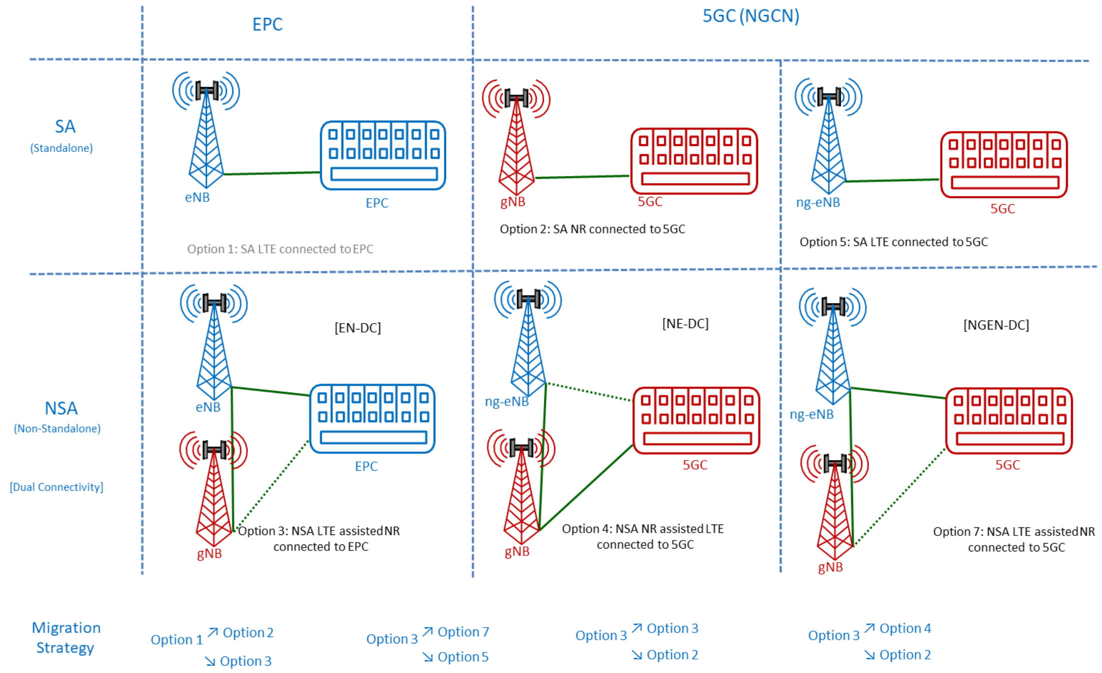


Figure 97: 5G Deployment Options

6.18 CONCLUSION

5G is going to be future technology as it has low latency and high efficiency. 5G is the future technology for supporting IoT and M2M communication. As of its unique feature of low latency it is a perfect technology for future generation.

7 LTE OVERVIEW AND OFDMA CONCEPT

7.1 LEARNING OBJECTIVE

After completion of this chapter participant will come to know:

- Overview of LTE
- Features of LTE
- LTE Advance
- OFDMA Concept
- OFDMA Working

7.2 OVERVIEW OF 4 G (LTE)

In 2004, 3GPP began a study into the long term evolution of UMTS. The aim was to keep 3GPP's mobile communication systems competitive over timescales of 10 years and beyond, by delivering the high data rates and low latencies those future users would require. Figure shows the resulting architecture and the way in which that architecture developed from that of UMTS.

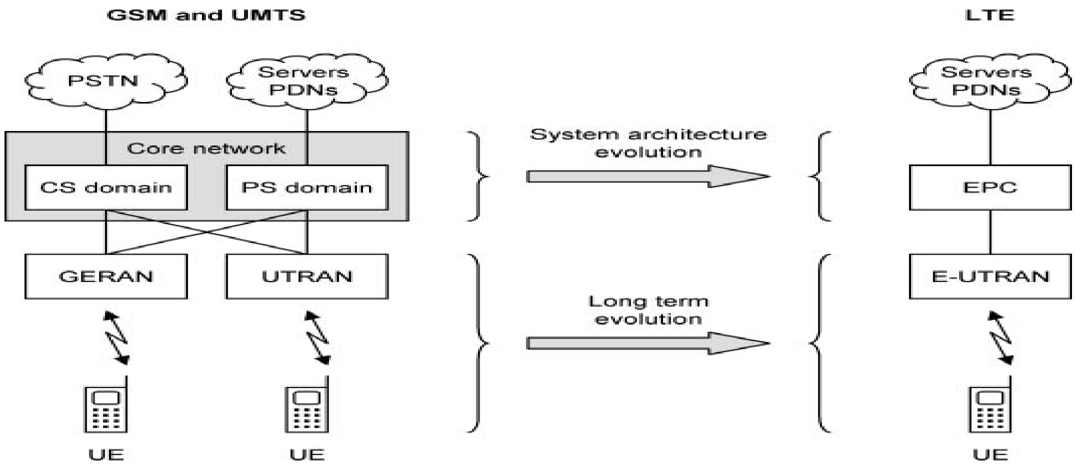


Figure 98: Evolution of the system architecture from GSM and UMTS to LTE

In the new architecture, the evolved packet core (EPC) is a direct replacement for the packet switched domain of UMTS and GSM. It distributes all types of information to the user, voice as well as data, using the packet switching technologies that have traditionally been used for data alone. There is no equivalent to the circuit switched domain, instead, voice calls are transported using voice over IP. The evolved UMTS terrestrial radio access network (E-UTRAN) handles the EPC's radio communications with the mobile, so is a direct replacement for the UTRAN. The mobile is still known as the user equipment, though its internal operation is very different from before.

The new architecture was designed as part of two 3GPP work items, namely system architecture evolution (SAE), which covered the core network, and long term evolution (LTE), which covered the radio access network, air interface and mobile. Officially, the whole system is known as the evolved packet system (EPS), while the acronym LTE refers only to the evolution of the air interface. Despite this official usage, LTE has become a colloquial name for the whole system, and is regularly used in this way by 3GPP.

7.3 FEATURES OF LONG TERM EVOLUTION

LTE was required to deliver a peak data rate of 100 Mbps in the downlink and 50 Mbps in the uplink. This requirement was exceeded in the eventual system, which delivers peak data rates of 300 Mbps and 75 Mbps respectively. However, these peak data rates can only be reached in idealized conditions. A better measure is the spectral efficiency, which expresses the typical capacity of one cell per unit bandwidth. LTE was required to support a spectral efficiency three to four times greater than that of Release 6 WCDMA in the downlink and two to three times greater in the uplink.

Latency is another important issue, particularly for time-critical applications such as voice and interactive games. There are two aspects to this. Firstly, the requirements state that the time taken for data to travel between the mobile phone and the fixed network should be less than five milliseconds, provided that the air interface is uncongested. Secondly, the mobile phones can operate in two states: an active state in which they are communicating with the network and a low-power standby state. The requirements state that a phone should switch from standby to the active state, after an intervention from the user, in less than 100 milliseconds.

There are also requirements on coverage and mobility. LTE is optimized for cell sizes up to 5 km, works with degraded performance up to 30 km and supports cell sizes of up to 100 km. It is also optimized for mobile speeds up to 15 km/Hr, works with high performance up to 120 km/Hr and supports speeds of up to 350 km/Hr. Finally, LTE is designed to work with a variety of different bandwidths, which range from 1.4 MHz up to a maximum of 20 MHz. The requirements specification ultimately led to a detailed design for the LTE air interface. Table-1 summarizes its key technical features, and compares them with those of WCDMA.

Feature	**WCDMA**	**LTE**
Multiple access scheme	WCDMA	OFDMA and SC-FDMA
Frequency re-use	100%	Flexible
Use of MIMO antennas	From Release 7	Yes
Bandwidth	5 MHz	1.4, 3, 5, 10, 15 or 20 MHz
Frame duration	10 ms	10 ms
Transmission time interval	2 or 10 ms	1 ms
Modes of operation	FDD and TDD	FDD and TDD
Uplink timing advance	Not required	Required
Transport channels	Dedicated and shared	Shared
Uplink power control	Fast	Slow

Table 7. Technical Features of LTE

7.3.1 SYSTEM ARCHITECTURE EVOLUTION

The evolved packet core routes packets using the Internet Protocol (IP) and supports devices that are using IP version 4, IP version 6, or dual stack IP version 4/version 6. In addition, the EPC provides users with always-on connectivity to the outside world, by setting up a basic IP connection for a device when it switches on and maintaining that connection until it switches off. This is different from the behavior of UMTS and GSM, in which the network only sets up an IP connection on request and tears that connection down when it is no longer required.

The EPC is designed as a data pipe that simply transports information to and from the user: it is not concerned with the information content or with the application. This is similar to the behavior of the internet, which transports packets that originate from any application software, but is different from that of a traditional telecommunication system, in which the voice application is an integral part of the system. Because of this, voice applications do not form part of LTE: instead, voice calls are controlled by some external entity such as the IP multimedia subsystem (IMS). The EPC simply transports the voice packets in the same way as any other data stream.

Unlike the internet, the EPC contains mechanisms to specify and control the data rate, error rate and delay that a data stream will receive. There is no explicit requirement on the maximum time required for data to travel across the EPC, but the relevant specification suggests a user plane latency of 10 milliseconds for a non roaming mobile, increasing to 50 milliseconds in a typical roaming scenario. The air interface, giving a typical delay in a non roaming scenario of around 20 milliseconds.

Feature	UMTS	LTE
IP version support	IPv4 and IPv6	IPv4 and IPv6
USIM version support	Release 99 USIM onwards	Release 99 USIM onwards
Transport mechanisms	Circuit & packet switching	Packet switching
CS domain components	MSC server, MGW	Not available.
PS domain components	SGSN, GGSN	MME, S-GW, P-GW
IP connectivity	After registration	During registration
Voice and SMS	Included	External

Table 8. Key features of the core networks of UMTS and LTE

7.4 LTE ARCHITECTURE

The high-level architecture of LTE is known as evolved packet system (EPS). There are three main components, namely the user equipment (UE), the evolved UMTS terrestrial radio access network (E-UTRAN) and the evolved packet core (EPC). In turn, the evolved packet core communicates with packet data networks in the outside world such as the internet, private corporate networks or the IP multimedia subsystem. The interfaces between the different parts of the system are denoted Uu, S1 and SG_i. The UE, E-UTRAN and EPC each have their own internal architectures and we will now discuss these one by one.

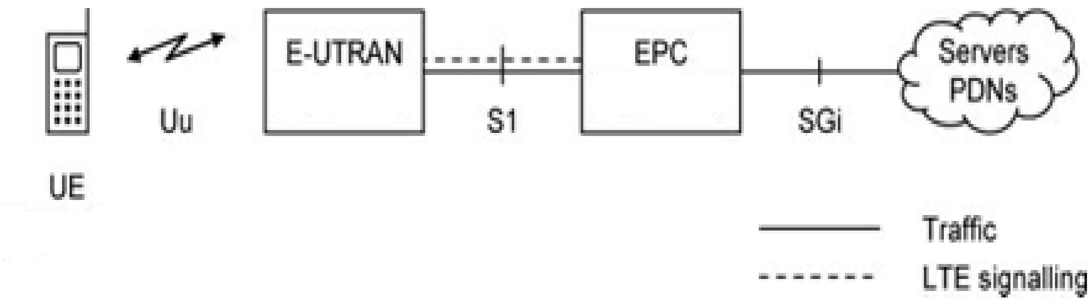


Figure 99: Overview of LTE Architecture

The actual communication device is known as the mobile equipment (ME). In the case of a voice mobile or a Smartphone, this is just a single device. However, the mobile equipment can also be divided into two components, namely the mobile termination (MT), which handles all the communication functions, and the terminal equipment (TE), which terminates the data streams. The mobile termination might be a plug-in LTE card for a laptop, for example, in which case the terminal equipment would be the laptop itself.

The universal integrated circuit card (UICC) is a smart card, colloquially known as the SIM card. It runs an application known as the universal subscriber identity module (USIM), which stores user-specific data such as the user's phone number and home network identity. The USIM also carries out various security-related calculations, using secure keys that the smart card stores. LTE supports mobiles that are using a USIM from Release 99 or later, but it does not support the subscriber identity module (SIM) that was used by earlier releases of GSM.

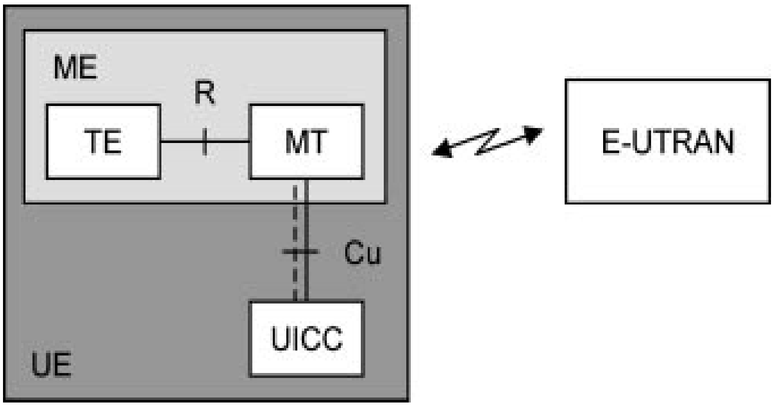


Figure 100: Internal Architecture of LTE UE

In addition, LTE supports mobiles that are using IP version 4 (IPv4), IP version 6 (IPv6), or dual stack IP version 4/version 6. A mobile receives one IP address for every packet data network that it is communicating with, for example one for the internet and one for any private corporate network. Alternatively, the mobile can receive an IPv4 address as well as an IPv6 address, if the mobile and network both support the two versions of the protocol. Mobiles can have a wide variety of radio capabilities, which cover issues such as the maximum data rate that they can handle, the different types of radio access technology that they support and the carrier frequencies on which they can transmit and receive. Mobiles pass these capabilities to the radio access network by means of signalling messages, so that the E-UTRAN knows how to control them correctly. The most important capabilities are grouped together into the UE category.

7.5 EVOLVED UMTS TERRESTRIAL RADIO ACCESS NETWORK

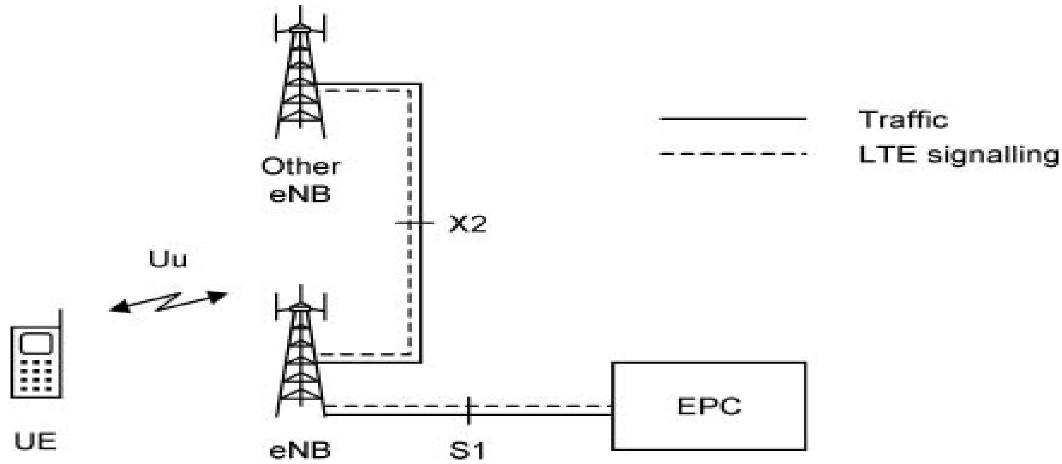


Figure 101: Architecture of Evolved UTRAN

The evolved UMTS terrestrial radio access network (E-UTRAN) is illustrated in Figure above The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved Node B (eNB).

Each eNB is a base station that controls the mobiles in one or more cells. A mobile communicates with just one base station and one cell at a time, so there is no equivalent of the soft handover state from UMTS. The base station that is communicating with a mobile is known as its serving eNB.

The eNB has two main functions. Firstly, the eNB sends radio transmissions to all its mobiles on the downlink and receives transmissions from them on the uplink, using the analogue and digital signal processing functions of the LTE air interface. Secondly, the eNB controls the low-level operation of all its mobiles, by sending them signalling messages such as handover commands that relate to those radio transmissions. In carrying out these functions, the eNB combines the earlier functions of the Node B and the radio network controller, to reduce the latency that arises when the mobile exchanges information with the network.

Each base station is connected to the EPC by means of the S1 interface. It can also be connected to nearby base stations by the X2 interface, which is mainly used for signalling and packet forwarding during handover. The X2 interface is optional, in that the S1 interface can also handle all the functions of X2, albeit indirectly and more slowly. Usually, the S1 and X2 interfaces are not direct physical connections: instead, the information is routed across an underlying IP based transport network. The same issue will apply to the EPC's interfaces below.

A home eNB (HeNB) is a base station that has been purchased by a user to provide femtocell coverage within the home. A home eNB belongs to a closed subscriber group (CSG) and can only be accessed by mobiles with a USIM that also belongs to the closed subscriber group. From an architectural point of view, a home eNB can be connected directly to the evolved packet core in the same way as any other base station, or can be connected by way of an intermediate device known as a home eNB gateway that collects the information from several home eNBs. Home eNBs only control one cell, and do not support the X2 interface until Release 10.

7.6 EVOLVED PACKET CORE

Figure below shows the main components of the evolved packet core. The home subscriber server (HSS), which is a central database that contains information about all the network operator's subscribers. This is one of the few components of LTE that has been carried forward from UMTS and GSM.

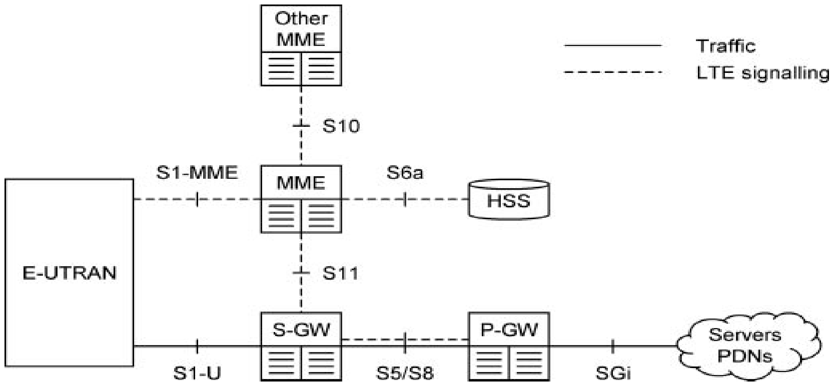


Figure 102: Architecture of Evolved Packet Core

The packet data network (PDN) gateway (P-GW) is the EPC's point of contact with the outside world. Through the SGi interface, each PDN gateway exchanges data with one or more external devices or packet data networks, such as the network operator's servers, the internet or the IP multimedia subsystem. Each packet data network is identified by an access point name (APN). A network operator typically uses a handful of different APNs, for example one for its own servers and one for the internet.

Each mobile is assigned to a default PDN gateway when it first switches on, to give it always-on connectivity to a default packet data network such as the internet. Later on, a mobile may be assigned to one or more additional PDN gateways, if it wishes to connect to additional packet data networks such as private corporate networks. Each PDN gateway stays the same throughout the lifetime of the data connection.

The serving gateway (S-GW) acts as a router, and forwards data between the base station and the PDN gateway. A typical network might contain a handful of serving gateways, each of which looks after the mobiles in a certain geographical region. Each mobile is assigned to a single serving gateway, but the serving gateway can be changed if the mobile moves sufficiently far.

The mobility management entity (MME) controls the high-level operation of the mobile, by sending it signalling messages about issues such as security and the management of data streams that are unrelated to radio communications. As with the serving gateway, a typical network might contain a handful of MMEs, each of which looks after a certain geographical region. Each mobile is assigned to a single MME, which is known as its serving MME, but that can be changed if the mobile moves sufficiently far. The MME also controls the other elements of the network, by means of signalling messages that are internal to the EPC.

Comparison with UMTS and GSM shows that the PDN gateway has the same role as the gateway GPRS support node (GGSN), while the serving gateway and MME handle the data routing and signalling functions of the serving GPRS support node (SGSN). Splitting the SGSN in two makes it easier for an operator to scale the network in response to an increased load: the operator can add more serving gateways as the traffic increases, while adding more MMEs to handle an increase in the number of mobiles. To support this split, the S1 interface has two components: the S1-U interface carries traffic for the serving gateway, while the S1-MME interface carries signalling messages for the MME.

The EPC has some other components that were not shown in Figure above. Firstly, the cell broadcast centre (CBC) was previously used by UMTS for the rarely implemented cell broadcast service (CBS). In LTE, the equipment is re-used for a service known as the earthquake and tsunami warning system (ETWS). Secondly, the equipment identity register (EIR) was also inherited from UMTS, and lists the details of lost or stolen mobiles.

7.7 OFDM CONCEPT:

Orthogonal Frequency Division Multiplexing (OFDM) is a digital multi-carrier modulation scheme that extends the concept of single subcarrier modulation by using multiple subcarriers within the same single channel. Rather than transmit a high-rate stream of data with a single subcarrier, OFDM makes use of a large number of closely spaced orthogonal subcarriers that are transmitted in parallel. Each subcarrier is modulated with a conventional digital modulation scheme (such as QPSK, 16QAM, etc.) at low symbol rate. However, the combination of many subcarriers enables data rates similar to conventional single-carrier modulation schemes within equivalent bandwidths.

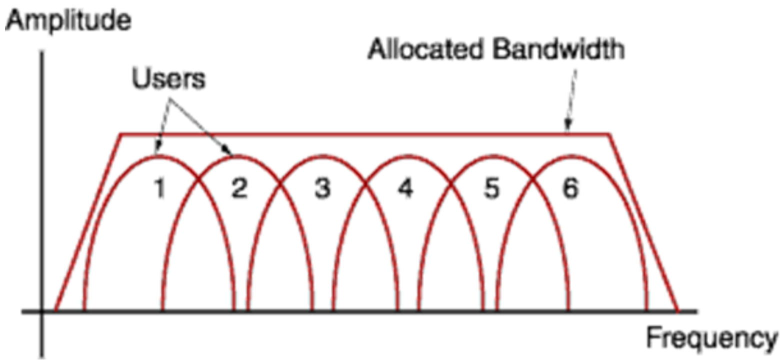


Figure 103: OFDM Concept

OFDM divides the available bandwidth into a number of equally spaced sub-carriers. The high serial bit stream data is transmitted over large number of sub-carriers (parallel), each of a different frequency and these carriers are orthogonal to each other.

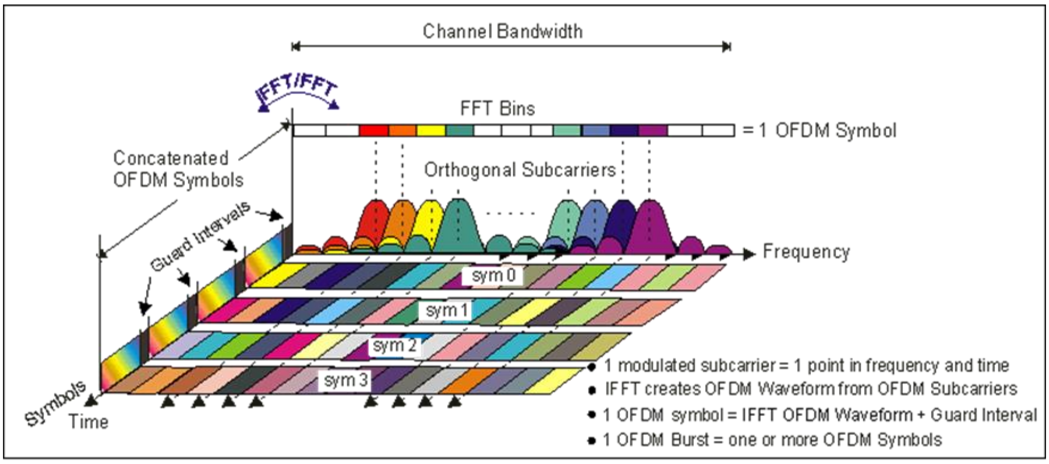
OFDM is based on the well-known technique of Frequency Division Multiplexing (FDM). In FDM different streams of information are mapped onto separate parallel frequency channels. Each FDM channel is separated from the others by a frequency guard band to reduce interference between adjacent channels.

The OFDM scheme differs from traditional FDM in the following interrelated ways:

1. Multiple carriers (called subcarriers) carry the information stream,
2. The subcarriers are orthogonal to each other, and

3. A guard interval is added to each symbol to minimize the channel delay spread and intersymbol interference.

The following figure illustrates the main concepts of an OFDM signal and the inter-relationship between the frequency and time domains. In the frequency domain, multiple adjacent tones or subcarriers are each independently modulated with complex data. An Inverse FFT transform is performed on the frequency-domain subcarriers to produce the OFDM symbol in the time-domain. Then in the time domain, guard intervals are inserted between each of the symbols to prevent inter-symbol interference at the receiver caused by multi-path delay spread in the radio channel. Multiple symbols can be concatenated to create the final OFDM burst signal. At the receiver an FFT is performed on the OFDM symbols to recover the original data bits.

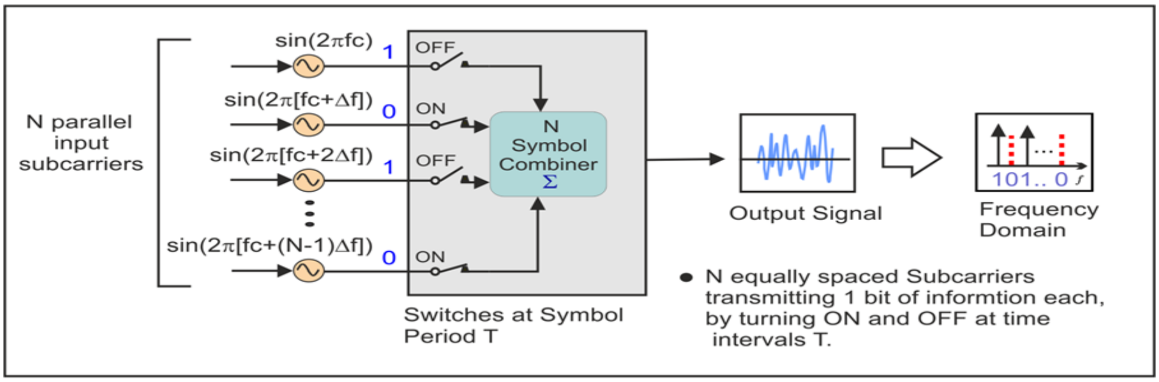


Frequency-Time Representative of an OFDM signal

Figure 104: Representation of OFDM

7.7.1 UNDERSTANDING OFDM

We will use a simple analog based implementation to show the basic principles of generating an OFDM signal. In this simple OFDM system there are N sinusoidal input signals. Each subcarrier transmits one bit of information (N bits total) as indicated by its presence or absence in the output spectrum. The frequency of each subcarrier is selected to form an orthogonal signal set. These frequencies are also known at the receiver for signal recovery. Note that the output is updated at a periodic interval T that forms the symbol period. To maintain orthogonality, T must be the reciprocal of the subcarrier spacing.

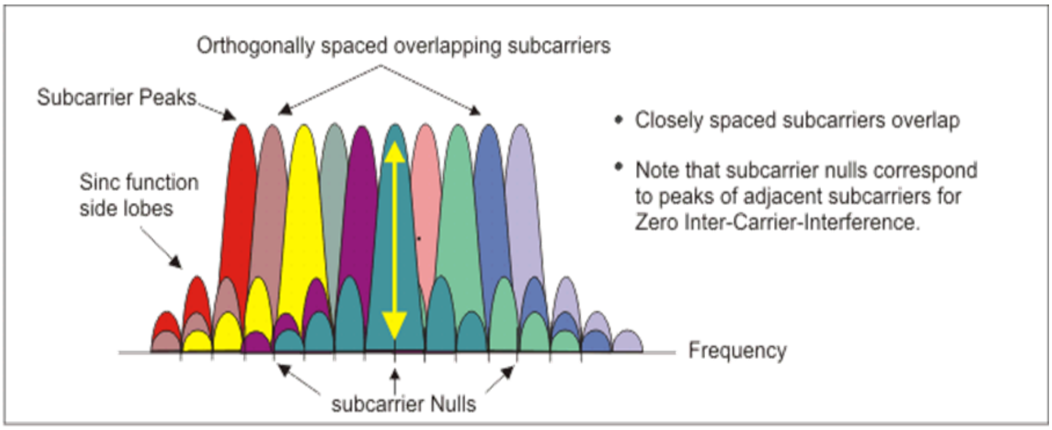


Simple OFDM Generation

Figure 105: OFDM Generation

7.7.2 UNDERSTANDING ORTHOGONALITY

The OFDM signal can be described as a set of closely spaced FDM subcarriers. In the frequency domain, each transmitted subcarrier results in a sinc function spectrum with side lobes that produce overlapping spectra between subcarriers, see "OFDM Signal Frequency Spectra" figure below. This results in subcarrier interference except at orthogonally spaced frequencies. At orthogonal frequencies, the individual peaks of subcarriers all line up with the nulls of the other subcarriers. This overlap of spectral energy does not interfere with the system's ability to recover the original signal. The receiver multiplies (i.e., correlates) the incoming signal by the known set of sinusoids to recover the original set of bits sent.



OFDM Signal Frequency Spectra

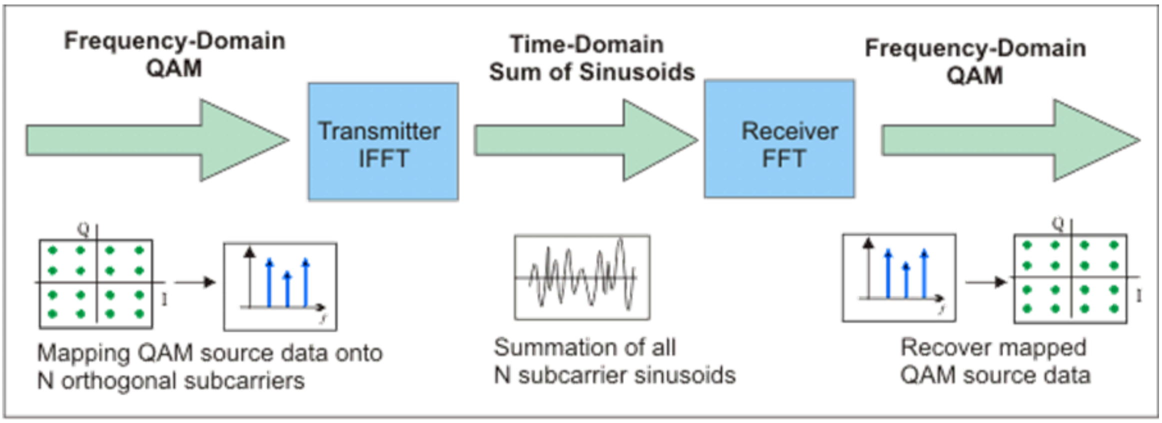
Figure 106: OFDM Frequency Spectra

The use of orthogonal subcarriers allows more subcarriers per bandwidth resulting in an increase in spectral efficiency. In a perfect OFDM signal, Orthogonality prevents interference between overlapping carriers. In FDM systems, any overlap in the spectrums of adjacent signals will result in interference. In OFDM systems, the subcarriers will interfere with each other only if there is a loss of orthogonality. For example, frequency error will cause the subcarrier frequencies to shift so that the spectral nulls will no longer be aligned resulting in inter-subcarrier-interference

7.7.3 SIMPLE DIGITAL OFDM SYSTEM IMPLEMENTATION USING FFT TRANSFORMS

The concepts used in the simple analog OFDM implementation can be extended to the digital domain by using a combination of Fast Fourier Transform (FFT) and Inverse Fast Fourier Transform (IFFT) digital signal processing. These transforms are important from the OFDM perspective because they can be viewed as mapping digitally modulated input data (data symbols) onto orthogonal subcarriers. In principle, the IFFT takes frequency-domain input data (complex numbers representing the modulated subcarriers) and converts it to the time-domain output data (analog OFDM symbol waveform).

In a digitally implemented OFDM system, the input bits are grouped and mapped to source data symbols that are a complex number representing the modulation constellation point (e.g., the BPSK or QAM symbols that would be present in a single subcarrier system). These complex source symbols are treated by the transmitter as though they are in the frequency-domain and are the inputs to an IFFT block that transforms the data into the time-domain. The IFFT takes in N source symbols at a time where N is the number of subcarriers in the system. Each of these N input symbols has a symbol period of T seconds. Recall that the output of the IFFT is N orthogonal sinusoids. These orthogonal sinusoids each have a different frequency and the lowest frequency is DC.



Simplified OFDM System Block Diagram

Figure 107: OFDM block Diagram

The input symbols are complex values representing the mapped constellation point and therefore specify both the amplitude and phase of the sinusoid for that subcarrier. The IFFT output is the summation of all N sinusoids. Thus, the IFFT block provides a simple way to modulate data onto N orthogonal subcarriers. The block of N output samples from the IFFT make up a single OFDM symbol.

After some additional processing, the time-domain signal that results from the IFFT is transmitted across the radio channel. At the receiver, an FFT block is used to process the received signal and bring it into the frequency domain which is used to recover the original data bits.

7.8 OFDM IN LTE

To overcome the effect of multi path fading problem available in UMTS, LTE uses Orthogonal Frequency Division Multiplexing (OFDM) for the downlink - that is, from the base station to the terminal to transmit the data over many narrow band careers of 180 KHz each instead of spreading one signal over the complete 5MHz career bandwidth ie. OFDM uses a large number of narrow sub-carriers for multi-carrier transmission to carry data.

OFDM meets the LTE requirement for spectrum flexibility and enables cost-efficient solutions for very wide carriers with high peak rates. The basic LTE downlink physical resource can be seen as a time-frequency grid, as illustrated in Figure below:

The OFDM symbols are grouped into resource blocks. The resource blocks have a total size of 180 kHz in the frequency domain and 0.5ms in the time domain. Each 1ms Transmission Time Interval (TTI) consists of two slots (Tslot).

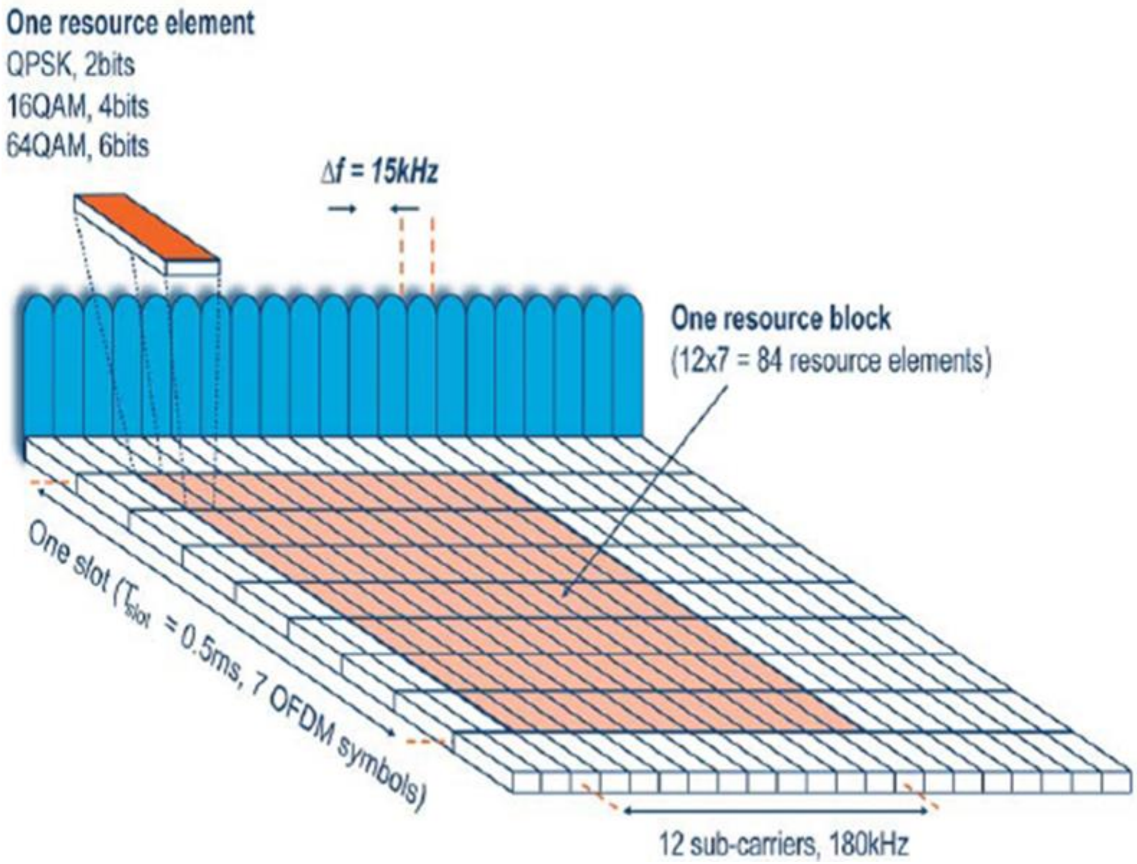


Figure 108: OFDM in LTE

Each user is allocated a number of so-called resource blocks in the time frequency grid. The more resource blocks a user gets, and the higher the modulation used in the resource elements, the higher the bit-rate. Which resource blocks and how many the user gets at a given point in time depend on advanced scheduling mechanisms in the frequency and time dimensions. The scheduling mechanisms in LTE are similar to those used in HSPA, and enable

Advantages of OFDM

The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization filters.

Channel equalization is simplified because OFDM may be viewed as using many slowly-modulated narrowband signals rather than one rapidly-modulated wideband signal.

The low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate inter symbol interference (ISI).

This mechanism also facilitates the design of single frequency networks (SFNs), where several adjacent transmitters send the same signal simultaneously at the same frequency, as the signals from multiple distant transmitters may be combined constructively, rather than interfering as would typically occur in a traditional single-carrier system.

7.9 DRAWBACKS OF OFDM

- High peak-to-average ratio
- Sensitive to frequency offset, hence to Doppler-shift as well
- Based on use of IFFT(Inverse First Fourier Transform) and FFT

7.10 CONCLUSION

OFDMA is used for LTE and gives very high spectral efficiency and modularity. With the use of OFDM the modularity of radio network has been achieved which resulted in very high spectral efficiency.

8 MOBILITY MANAGEMENT FOR 2G/3G/4G NETWORK

8.1 LERANING OBJECTIVE

After completion of this chapter participant will come to know:

- Need of Mobility Management
- Mobility Management Concept
- Network attach/detach Process in 2G/3G/4G
- Various identities used in Mobility Management.

8.2 MOBILITY MANAGEMENT CONCEPT:

Mobility management is used to keep track of a mobile station (MS), a term that refers to the combination of wireless hardware and associated subscriber information. Because a mobile station is always moving from one place to another, the network must be aware of the MS's position in order to maintain connectivity. Mobility management refers to the range of procedures that make this possible. These include identification and authentication of the mobile subscriber, security functionality, access to wireless services, transfer of subscriber data among network nodes, location updating, and registration.

Mobility management acts as a network layer. It works as a signalling and control entity for both the MS and the network node with which it communicates. A subscriber can access network services only if the MM functions are successfully completed and the network has granted permission, in which case the network may also ask for user authentication.

MM activities related to a subscriber are characterized by one or more different states. Each state describes a certain level of functionality and information allocation. This information is normally held on the SIM of the MS and on the network node that is handling MM functionality. This combination of stored information is referred to as the MM context.

In a mobile telecom network, the locations of the User Equipments (UEs) are tracked so that incoming calls can be delivered to the UEs. Typical mobility management procedures include location update and paging. When a UE moves from one location to another location, the UE reports its new location to the network through the location update procedure. When an incoming call to the UE arrives, the network identifies the location of the UE via the paging procedure.

8.3 FUNCTIONS FOR MOBILITY

There are several technologies that are needed to provide mobility for the different aspects and scenarios:

- **Registration:**
  Informs the networks which device a user currently uses and that it is ready to receive requests. Usually it is combined with authentication. This is needed for personal and device mobility. It may be needed for service and network mobility in static, nomadic and continuous mobility.
- **Paging:**

In power saving mode the cellular networks only know an area where the device is located. This area can contain many cells. Paging is needed to find the current cell where the device is located. Paging is only relevant for device mobility in continuous mobility.

- **Location Update:**
  Informs the network of new positions and is triggered by movement or by a timer. This is needed for personal and device mobility in continuous mobility.
- **Handover:**
  Keeps the link while moving from one access point to another. This is only needed for device mobility in continuous mobility while connections are active.
- **Rerouting:**
  Routes need to be redefined after handovers or new locations to optimize the traffic path. This is only needed for device mobility in continuous mobility and in nomadic mobility to reestablish sessions.

8.3.1 LOCATION MANAGEMENT

- Mechanisms to localize users in case of incoming calls, short messages, or data
- Requires to partition an operator's coverage area into location areas in order to efficiently perform location management.
- Two basic operations: Location update and Paging

Location Update (LU): Operation initialized by the terminal to inform the network about the user's location

Paging: Broadcast message initialized by the network to locate the current cell of a user

8.4 NETWORK ATTACHMENT

Network attachment is the process of selecting an appropriate cell (radio frequency) by the mobile station to provide the available services, and making its location known to the network.

The process starts when the mobile station is switched on, and ends when the mobile station enters the idle mode. In idle mode the mobile station does not have a traffic channel allocated to make or receive a call. But the Public Land Mobile Network (PLMN) is aware of the existence of the Mobile station within the chosen cell.

8.5 NETWORK ATTACHMENT PROCESS

The network attachment process consists of the following tasks:

Cell Identification

When a mobile station is switched on, it attempts to make contact with a GSM PLMN by performing the following actions:

- Measure the BCCH channels
- Search for a suitable cell
- The mobile station measures the signal strength of the BCCH (Broadcast Control Channel) channels received. It stores in list information about 30 of these BCCH

channels, such as the signal strength and the frequency corresponding to these BCCH channels.

PLMN selection

A suitable PLMN is chosen

Cell Selection

Cell selection is the process of selecting an appropriate cell (radio frequency) by the mobile station to provide the available services.

The following figure shows the network attachment process.

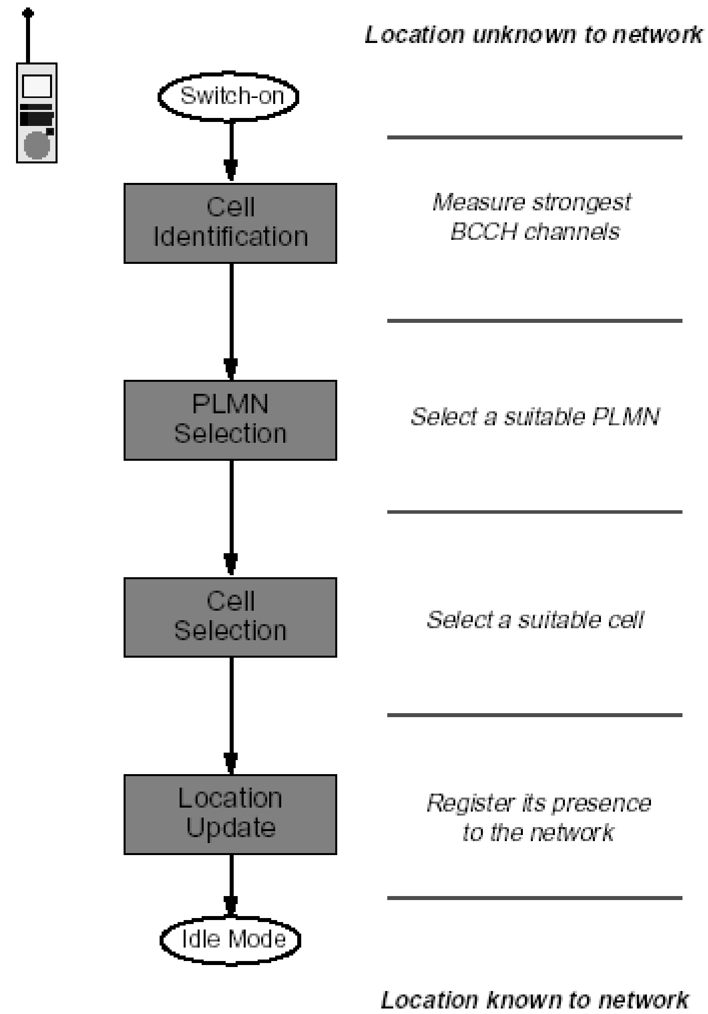


Figure 109: Network Attachment Process

Location update

In order to initiate a call or to receive a call, the mobile station tunes to the control channel (BCCH plus CCCH) of the chosen cell. Then, it registers its presence in this cell (registration process) by means of a location updating procedure.

No suitable cell found

If the mobile station is unable to find a suitable cell to access, it attempts to access a cell irrespective of the PLMN identity, and enters a "limited service" state in which it can only attempt to make emergency calls.

PLMN selection mechanism

The PLMN to be contacted can be selected either in one or the following modes:

- **Automatic mode**

In automatic mode, the mobile station will choose which PLMNs to try all by itself. The automatic mode is based on the existence of the preferred list, which is stored in a non-volatile memory in the SIM. This list includes a number of PLMN identities in order of preference and is under control of the user. The most preferred is usually the home PLMN. The list is filled in by the user through a mechanism to be specified by the mobile station manufacturer.

The automatic mode is normally used when the mobile station operates on its home PLMN that is the PLMN the mobile station is subscribed to).

- **Manual mode**

In manual mode, the user is presented a list containing all found PLMNs. The user chooses one of the PLMNs from the list.

Cell selection criteria

The mobile station attempts to find a suitable cell by passing through the list in descending order of received signal strength; the first BCCH channel which satisfies a set of requirements is selected.

The requirements that a cell must satisfy (before a mobile station can provide service from it) are:

- It should be a cell of the selected PLMN. The mobile station checks whether the cell is part of the selected PLMN. It should not be "barred".
- The PLMN operator may decide not to allow mobile stations to access certain cells. These cells may, for example, only be used for handover traffic. Barred cell information is broadcast on the BCCH to instruct mobile stations not to access these cells.
- The radio path loss between the mobile station and the selected BTS must be below a threshold set by the PLMN operator.

8.6 LOCATING A MOBILE

Call to an active mobile station

As an active Mobile Station (MS) moves around in the coverage area of a Public Land Mobile Network (PLMN), it reports its movements so that it can be located when required using the Location Update procedure.

When a Mobile-services Switching Center (MSC) in the network needs to establish a call to an MS operating in its area the following happens:

A page message is broadcast which contains the identifications code of the MS. Not every Base Station Controller (BSC) in the network is requested to transmit the page message. The broadcast is limited to a cluster of radio cells that together form a location area. The last reported position of the MS identifies the location area to be used for the broadcast.

The MS monitors the page messages transmitted by the radio cell in which it is located and, on detecting its own identification code, responds by transmitting a page response message to the Base Transceiver Station (BTS).

Communication is then established between the MSC and the MS via the BTS that received the page response message.

Location Update : As an active mobile station (MS) moves in the coverage area of a public land mobile network (PLMN), it reports its movements so that it can be located as needed, using the Location Update procedure . Location updates are taking place as per the requirements of the network, may be time or movement or distance based.

Network Configuration for Location Update:

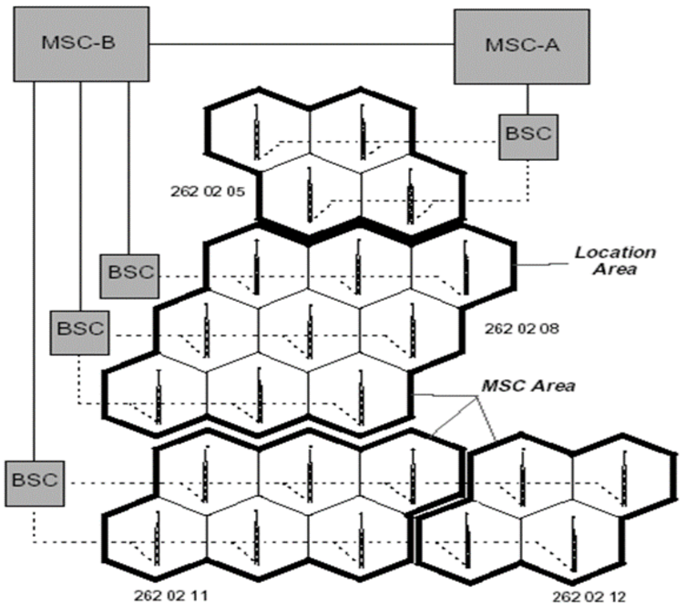


Figure 110: Network Configuration for Location Update

The configuration of a Public Land Mobile Network (PLMN) is designed so that active mobile station moving in the network area is still able to report its position. A network consists of different areas −

- PLMN area
- Location area
- MSC area
- PLMN Area

PLMN Area

A PLMN area is the geographical area in which land mobile communication services are provided to the public by a particular PLMN operator. From any position within a PLMN area, the mobile user can set up calls to another user of the same network, or to a user of another network. The other network may be a fixed network, another GSM PLMN, or another type of PLMN. Users of the same PLMN or users of other networks can also call a mobile user who is active in the PLMN area. When there are several PLMN operators, the geographical areas covered by their networks may overlap. The extent of a PLMN area is normally limited by national borders.

Location Area

To eliminate the need for network-wide paging broadcasts, the PLMN needs to know the approximate positions of the MSs that are active within its coverage area. To enable the approximate positions of any MS to be represented by a single parameter, the total area covered by the network is divided into location areas. A Location Area (LA) is a group of one or more radio cells. This group fulfils the following requirements −

- BTSs in one location area may be controlled by one or more BSCs.
- BSCs those serve the same location area are always connected to the same MSC.
- Radio cells with BTSs controlled by a common BSC can lie in different location areas.

Location Area Identity

Every radio transmitter in the PLMN broadcast, via a control channel BCCH, a Location Area Identity (LAI), code to identify the location area that it serves. When an MS is not engaged in a call, it automatically scans the BCCH transmitted by the base stations in the locality and selects the channel that is delivering the strongest signal. The LAI code broadcast by the selected channel identifies the location area in which the MS is currently situated. This LAI code is stored in the Subscriber Identity Module (SIM) of the mobile equipment.

As the MS moves through the network area, the signal received from the selected control channel gradually diminishes in strength until it is no longer the strongest. At this point the MS re-tunes to the channel that has become dominant and examines the LAI code that it is broadcasting. If the received LAI code differs from that stored on the SIM, then the MS has entered another location area and initiates a location update procedure to report the change to the MSC. At the end of the procedure, the LAI code in the SIM is also updated.

Location Area Identity Format

It is a Location Area Identity (LAI) code to identify the location area in a PLMN. The LAI code has three components −

- Mobile Country Code (MCC) :The MCC is a 3-digit code that uniquely identifies the country of domicile of the mobile subscriber (for example, India 404). It is assigned by the ITU-T.
- Mobile Network Code (MNC) :The MNC is a 2-digit code (3-digit code for GSM-1900) that identifies the home GSM PLMN of the mobile subscriber. If more than one GSM PLMN exists in a country, a unique MNC is assigned to each of them. It is assigned by the government of each country. (For example Cell one, Chennai 64).

- Location Area Code (LAC) :The LAC component identifies a location area within a PLMN; it has a fixed length of 2 octets and can be coded using hexadecimal representation. It is assigned by an operator.

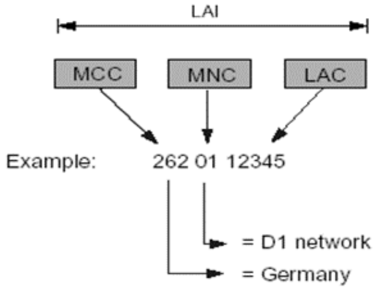


Figure 111: Location Area Code

MSC areas

An MSC area is a region of the network in which GSM operations are controlled by a single MSC. An MSC area consists of one more location areas. The boundary of an MSC area follows the external boundaries of the location areas on its periphery. Consequently, a location area never spans beyond the boundary of an MSC area.

VLR area

A VLR area is region of the network that is supervised by a single Visitor Location Register (VLR). In theory, a VLR area may consist of one more MSC areas. In practice, however the functions of the VLR are always integrated with those of the MSC so that the terms "VLR area" and "MSC area" have become synonymous.

Location Registration

Two databases are used by Location Management to store MS location related data.

- Visitor Location Register(VLR)
- Home Location Register(HLR)

Visitor Location Register

A VLR contains a data record for each of the MS that are currently operating in its area. Each record contains a set of subscriber identity codes, related subscription information, and a Location Area Identity (LAI) code. This information is used by the MSC when handling calls to or from an MS in the area. When an MS moves from one area to another, the responsibility for its supervision passes from one VLR to another. A new data record is created by the VLR that has adopted the MS, and the old record is deleted. Provided that an interworking agreement exists between the network operators concerned, data transaction can cross both network and national boundaries.

Home Location Register

The HLR contains information relevant to mobile subscribers who are fee-paying customers of the organization that operates the PLMN. The HLR stores two types of information −

Subscription Information
The subscription information includes the IMSI and directory number allocated to the subscriber, the type of services provided and any related restrictions.

Location Information

The location information includes the address of the VLR in the area where the subscribers MS is currently located and the address of the associated MSC.

The location information enables incoming calls to be routed to the MS. The absence of this information indicates that the MS is inactive and cannot be reached.

When an MS moves from one VLR area to another, the location information in the HLR is updated with the new entry for the MS, using subscription data copied from the HLR. Provided that an inter-working agreement exists between the network operators, concerned data transactions can move across both network and national boundaries.

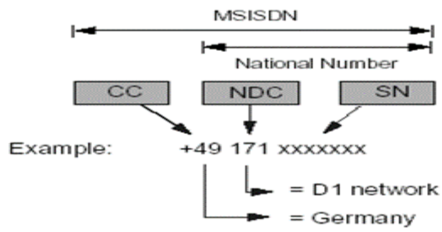
Types of Identification Numbers

During the performance of the location update procedure and the processing of a mobile call different types of numbers are used −

- Mobile Station ISDN Number(MSISDN)
- Mobile Subscriber Roaming Number(MSRN)
- International Mobile Subscriber Identity(IMSI)
- Temporary Mobile Subscriber Identity(TMSI)
- Local Mobile Station Identity(LMSI)

Each number is stored in the HLR and/or VLR.

Mobile Station ISDN Number : The MSISDN is the directory number allocated to the mobile subscriber. It is dialled to make a telephone call to the mobile subscriber. The number consists of Country Code (CC) of the country in which the mobile station is registered (e.g. India 91), followed by national mobile number which consists of Network Destination Code (NDC) and Subscriber Number (SN). An NDC is allocated to each GSM PLMN.



The composition of the MSISDN is such that it can be used as a global title address in the Signalling Connection Control Part (SCCP) for routing message to the HLR of the mobile subscriber.

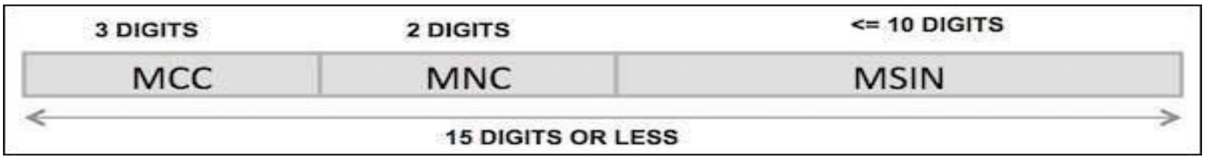
Mobile Station Roaming Number : The MSRN is the number required by the gateway MSC to route an incoming call to an MS that is not currently under the control of the gateway MSISDN. Using a mobile, terminated call is routed to the MSC gateway. Based on this, MSISDN gateway MSC requests for a MSRN to route the call to the current visited MSC

International Mobile Subscriber Identity (IMSI) : An MS is identified by its IMSI. The IMSI is embedded in the SIM of the mobile equipment. It is provided by the MS anytime it accesses the network.

Mobile Country Code (MCC) : The MCC component of the IMSI is a 3-digit code that uniquely identifies the country of the domicile of the subscriber. It is assigned by the ITU-T.

Mobile Network Code (MNC) : The MNC component is a 2-digit code that identifies the home GSM PLMN of the mobile subscriber. It is assigned by the government of each country. For GSM-1900 a 3-digit MNC is used.

Mobile Subscriber Identification Number (MSIN): The MSIN is a code that identifies the subscriber within a GSM PLMN. It is assigned by the operator.



Temporary Mobile Subscriber Identity (TMSI) : The TMSI is an identity alias which is used instead of the IMSI when possible. The use of a TMSI ensures that the true identity of the mobile subscriber remains confidential by eliminating the need to transfer a non ciphered IMSI code over a radio link.

A VLR allocates a unique TMSI code to each mobile subscriber that is operating in its area. This code which is only valid within the area supervised by the VLR is used to identify the subscriber, in messages to and from the MS. When a change of location area also involves a change of VLR area, a new TMSI code is allocated and communicated to the MS. The MS stores the TMSI on its SIM. The TMSI consists of four octets.

8.7 LOCATION UPDATE PROCESS

Phases of a location update

The following table lists the location update process:

Stage	*Description*
1.	*Request for service;* the MS detects that it has entered a new Location Area and requests to update its location. The new MSC/VLR identifies the MS.
2.	*Authentication;* the new MSC/VLR requests to the AUC for authentication parameters. Using these parameters the MS is authenticated.
3.	*Ciphering; using* the parameters that were made available earlier during the authentication the uplink and the downlink are ciphered.
4.	*Update HLR/VLR;* the new MSC/VLR requests to update the MS location in the HLR. The MS is de-registered in the old VLR.
5.	*TMSI re-allocation;* the MS is assigned a new TMSI.

Optional phases

The authentication and ciphering phases are optional: they might not take place in a Location Update, depending on the service supplier's decision.

Phases of a location update

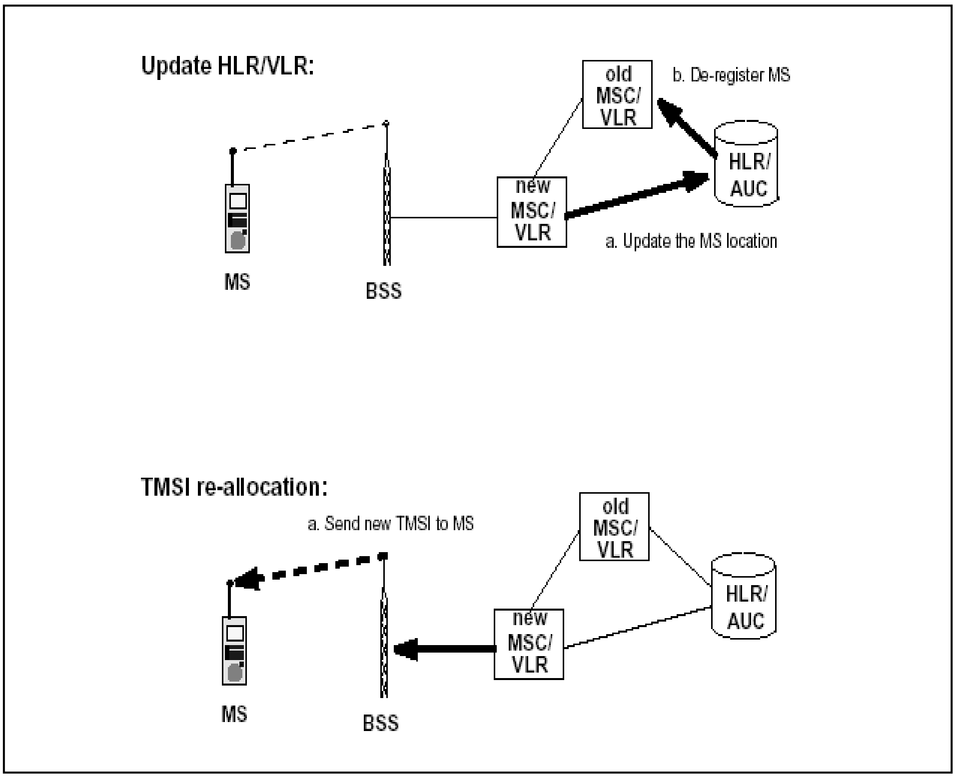


Figure 112: Phases of location Update

8.7.1 REQUEST FOR SERVICE PHASE

Steps in request for service phase

In the following location update scenario, it is assumed that a MS enters a new location area that is under the control of a different VLR (referred to as the "new VLR") than the one where the MS is currently registered (referred to as the "old VLR").

The MS enters a new cell area, listens to the Location Area Identity (LAI) being transmitted on the broadcast channel (BCCH), and compares this LAI with the last LAI (stored in the SIM) representing the last area where the mobile was registered.

- The MS detects that it has entered a new Location Area and transmits a Channel Request message over the Random Access Channel (RACH).

- Once the BSS receives the Channel Request message, it allocates a Stand-alone Dedicated Control Channel (SDCCH) and forwards this channel assignment information to the MS over the Access Grant Channel (AGCH). It is over the SDCCH that the MS will communicate with the BSS and MSC.

- The MS transmits a location update request message to the BSS over the SDCCH. Included in this message are the MS Temporary Mobile Subscriber Identity (TMSI) and the old Location Area Identification (old LAI). The MS can identify itself either with its IMSI or TMSI. In this example we'll assume that the mobile provided a TMSI. The BSS forwards the location update request message to the MSC.

- The VLR analyzes the LAI supplied in the message and determines that the TMSI received is associated with a different VLR (old VLR). In order to proceed with the registration, the IMSI of the MS must be determined. The new VLR derives the identity of the old VLR by using the received LAI, supplied in the location update request message. It also requests the old VLR to supply the IMSI for a particular TMSI.

The following figure shows the steps of the mobile location update scenario.

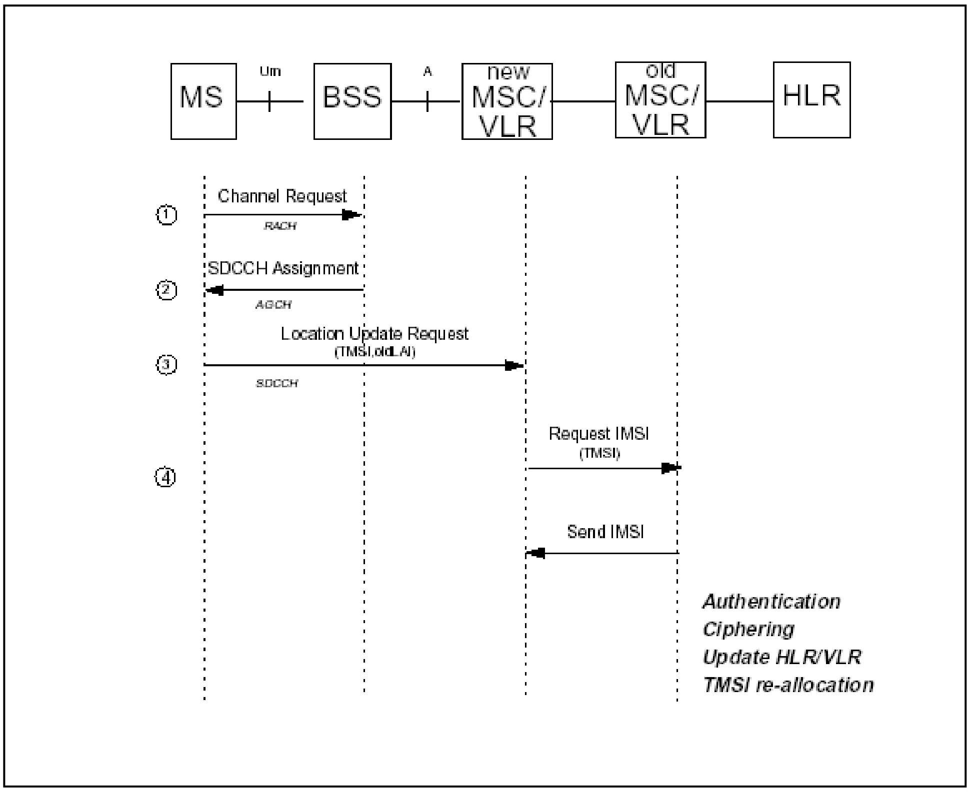


Figure 113: Service request process

Authentication and ciphering phases

Authentication

Since the air interface is vulnerable to fraudulent access, it is necessary to determine if the IMSI received from the MS is from the SIM that was assigned this IMSI. To prevent access of unregistered users, authentication of subscribers is used. Authentication is built around the notion and Authentication Key (Ki) that resides in only two places: in an Authentication Center (AUC) and in the user's SIM card. Since the authentication key, Ki, is (or should) never be transmitted, in is virtually impossible for un-authorized individuals to obtain this key to impersonate a give mobile subscriber.

Authentication Parameters

The MS is authenticated by the VLR with a process that uses three parameters.

RAND, which is completely random number.

SRES, which is an authentication signed response. It is generated by applying in an authentication algorithm (A3) to RAND and Ki.

Kc, which is a cipher key. The Kc parameter is generated by applying the cipher key generation algorithm (A8) to RAND and Ki.

These parameters (named an authentication triplet) are generated by the AUC at the request of the HLR to which the subscriber belongs. The algorithms A3 and A8 are defined by the PLMN operator and are executed by the SIM. The following figure shows the scheme of the algorithms.

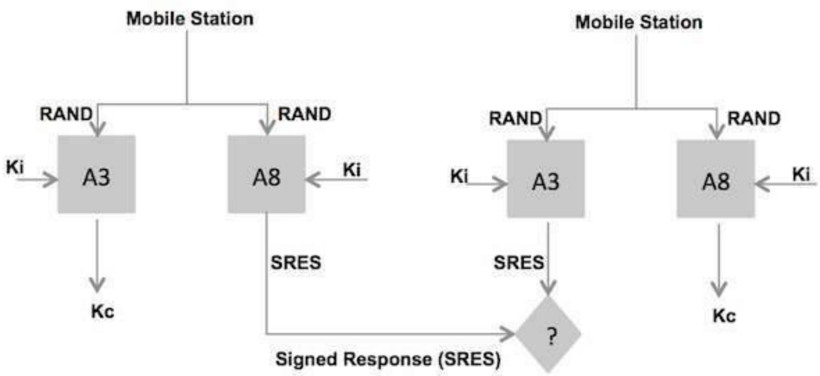


Figure 114: Authentication Process

Authentication process

To authenticate a subscriber, the VLR sends an authentication request message to the MS. (Refer figure above). The message contains the RAND parameter from an authentication triplet. The MS applies the A3 algorithm to the received RAND and the Ki key taken from the SIM. The resulting SRES is returned to the VLR for verification (step 3). The VLR authenticates the subscriber if the SRES value returned by the MS is equal to that in the triplet involved. As well as calculating the value of SRES, the MS applies the A8 algorithm to the received RAND and the Ki key from the SIM. The Result is the value of Kc to be used when the radio link has been switched to ciphered mode.

Steps in authentication phase

The step in the authentication phase is as follows:

- The new VLR sends a request to the HLR/AUC (Authentication and Kc) requesting the “authentication triplets” (RAND, SRES, and Kc) available for the specified IMSI.
- The AUC, using the IMSI, extracts the subscriber’s authentication key (Ki). The AUC then generates a random number (RAND), applies the Ki and RAND to both

the authentication algorithm (A3) and the cipher key generation algorithm (A8) to produce an authentication Signed Response (SRES) and a Cipher Key (Kc). The AUC then returns to the new VLR an authentication triplet: RAND, SRES, and Kc.

- The MSC/VLR keeps the two parameters Kc and SRES for later use and then sends a message to the MS. The MS reads its Authentication key (Ki) from the SIM, applies the received random number (RAND) and Ki to both its Authentication Algorithm (A3) and Cipher key generation Algorithm (A8) to produce an authentication Signed Response (SRES) and Cipher Key (Kc). The MS saves Kc for later, and will use Kc when it receives command to cipher the channel.
- The MS returns the generated SRES to the MSC/VLR. The VLR compares the SRES returned from the MS with the expected SRES received earlier from the AUC. If equal, the mobile passes authentication. If unequal, all signaling activities will be aborted. In this scenario, we'll assume that authentication passes. The figure the following figure shows the step in the authentication phase.

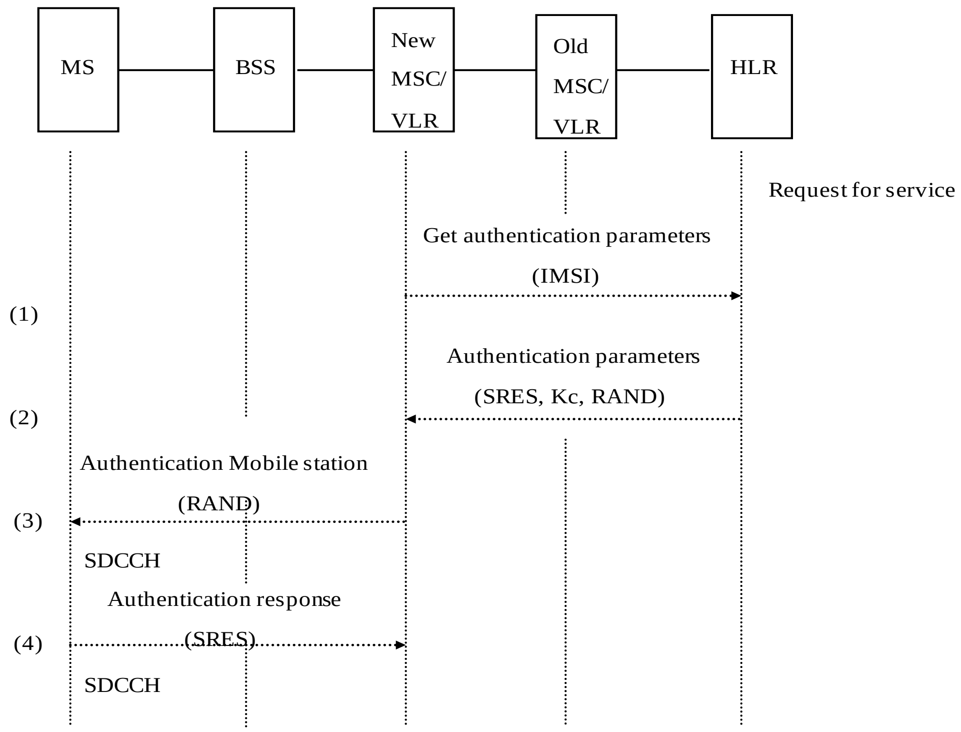


Figure 115: Authentication process

Steps in ciphering phase

The steps in the ciphering phase are as follows:

- The new MSC/VLR requests the BSS to cipher the radio channel. Included in this message is the Cipher Key (Kc), which was made available earlier during the authentication.
- The BSS retrieves the cipher key, Kc, from the message and then transmits a request to the MS requesting it to begin ciphering the uplink channel.

- The MS uses the cipher key generated previously when it was confirmed over the ciphered channel to the BSS
- The BSS upon ciphering the downlink channel sends a cipher complete message to the MSC.

The following figure shows the steps in the ciphering phase.

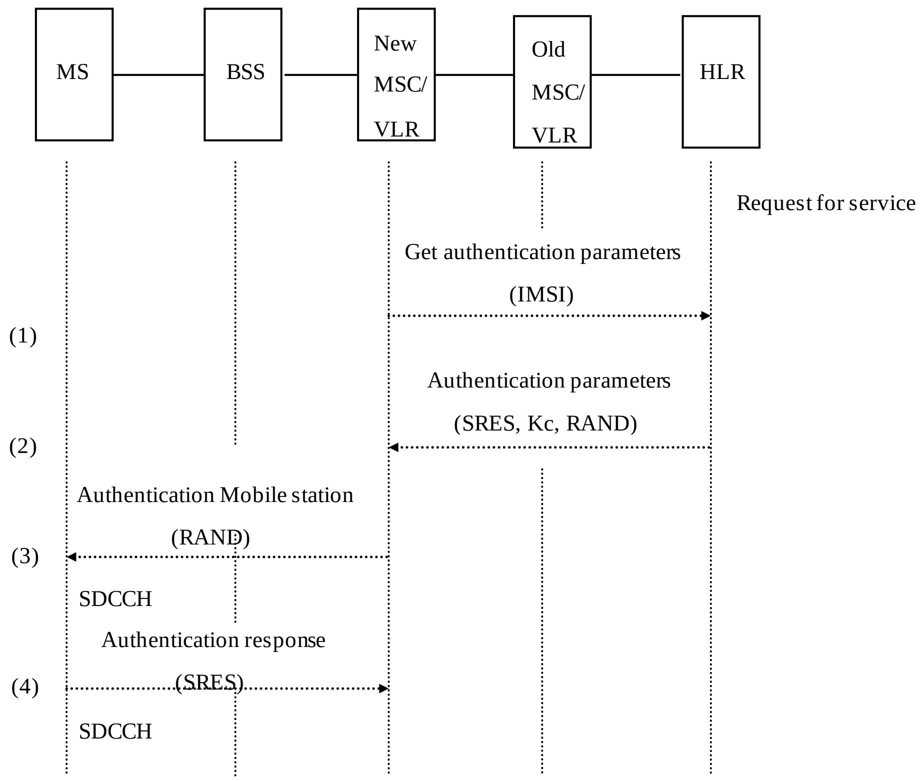


Figure 116: Ciphering phase

8.7.2 UPDATE HLR/VLR AND TMSI RE-ALLOCATION PHASES

Steps in update HLR/VLR phase

At this point, we are ready to inform the HLR that the MS is under control of a new VLR and that the MS can be de-registered from the old VLR.

The steps in the update HLR/VLR phase are:

- The new VLR sends a message to the HLR informing it that the given IMSI has changed locations and can be reached by routing all incoming calls to the VLR address included in the message

- The HLR requests the old VLR to remove the subscriber record associated with the given IMSI. The request is acknowledged.

- The HLR updates the new VLR with subscriber data (mobiles subscriber's customer profile).

The following figure shows the steps in the update location phase.

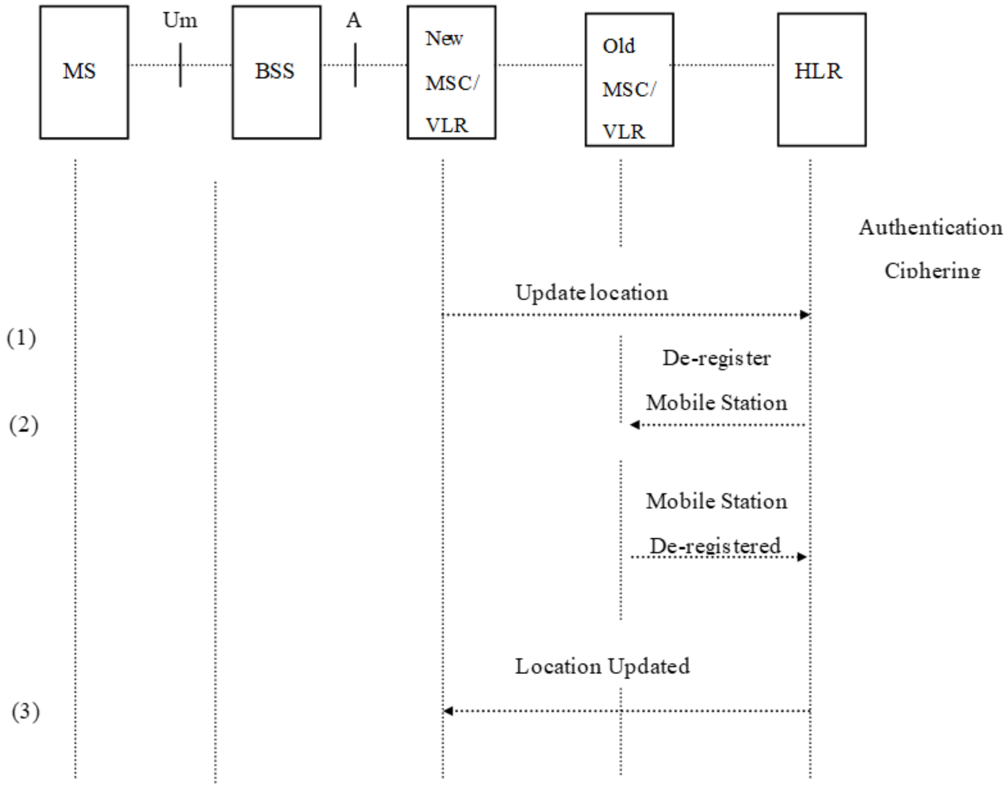


Figure 117: Location Update phase

Steps in TMSI re-allocation phase

At this point in time, the HLR and "old VLR" have been informed that the MS has registered with an MSC under the control of the "new VLR". The remaining task for the new VLR is to allocate and transmit a new TMSI to the MS. For security reasons, the radio channel is encrypted before sending the new TMSI to the MS.

The steps in the TMSI re-allocation phase are:

- The MSC forwards the location update accept message to the MS. This message includes the new TMSI.
- The MS retrieves the new TMSI value from the message and updates its SIM with this new value. The mobile sends then an update complete message back to the MSC.
- The MSC requests from the BSS that the signaling connection be released between the MSC and the MS.
- The MSC releases its portion of the signaling connection when it receives the clear complete message from the BSS.
- The BSS sends a "radio resource" channel release message to the MS and then frees up the Stand-alone Dedicated Control Channel (SDCCH) that was allocated previously. The BSS then informs the MSC that the signaling connections have been cleared.

o The following figure shows the steps of the TMSI Re-allocation phase.

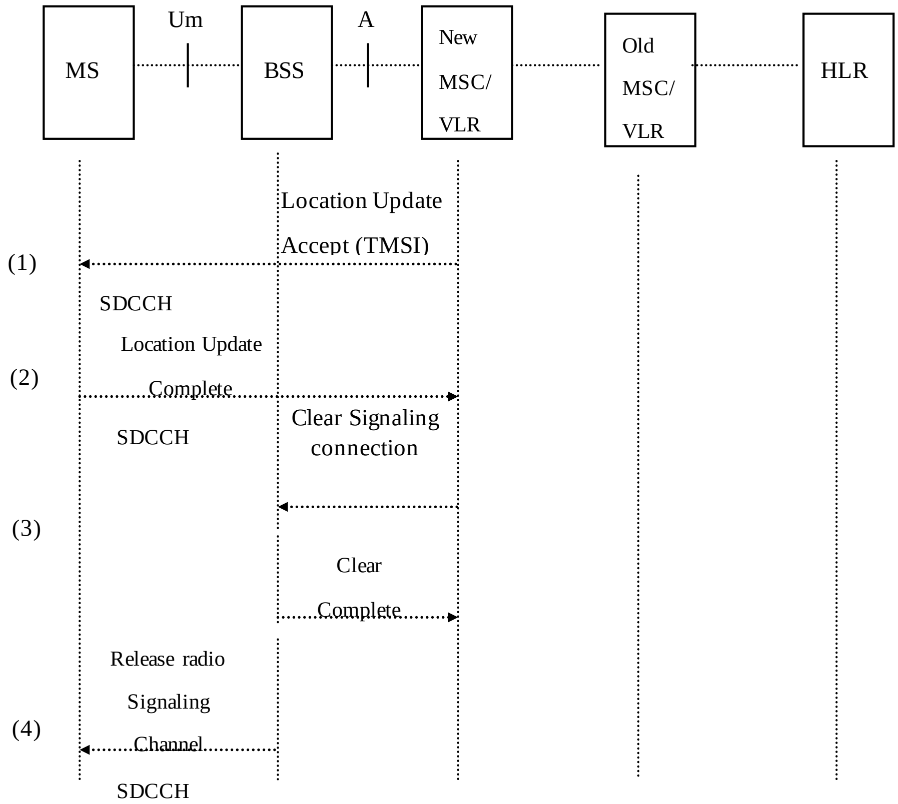


Figure 118: TMSI re-allocation phase

8.8 MOBILITY MANAGEMENT IN 3G UMTS

In UMTS UMM layer is responsible for mobility management in UMTS Network. The diagram shows the detail of UMTS Layers.

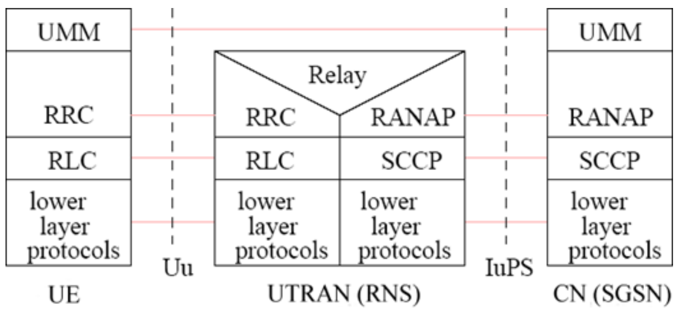


Figure 119: UMTS Layers

Location Update:

In order to track the MSs, the cells (i.e.,BTSs/NodeBs) in GPRS/UMTS service area are partitioned into several groups. To deliver services to an MS, the cells in the group covering the MS will page the MS to establish the radio link. The location change of an MS is detected as follows. The cells broadcast their cell identities. The MS periodically listens to the broadcast cell identity, and compares it with the cell identity stored in the MS's buffer. If the comparison indicates that the location has been changed, then the MS sends the location update message to the network. In the CS domain, cells are partitioned into location areas (LAs). The LA of an MS is tracked by the VLR. In the

PS domain, the cells are partitioned into routing areas (RAs). An RA is typically a subset of an LA. The RA of an MS is tracked by the SGSN. In GPRS, the SGSN also tracks the cell of an MS in PS connection (i.e., when packets are delivered between the MS and the SGSN). In UMTS, the cells in an RA are further partitioned into UTRAN RAs (URAs). The URA and the cell of an MS are tracked by the UTRAN.

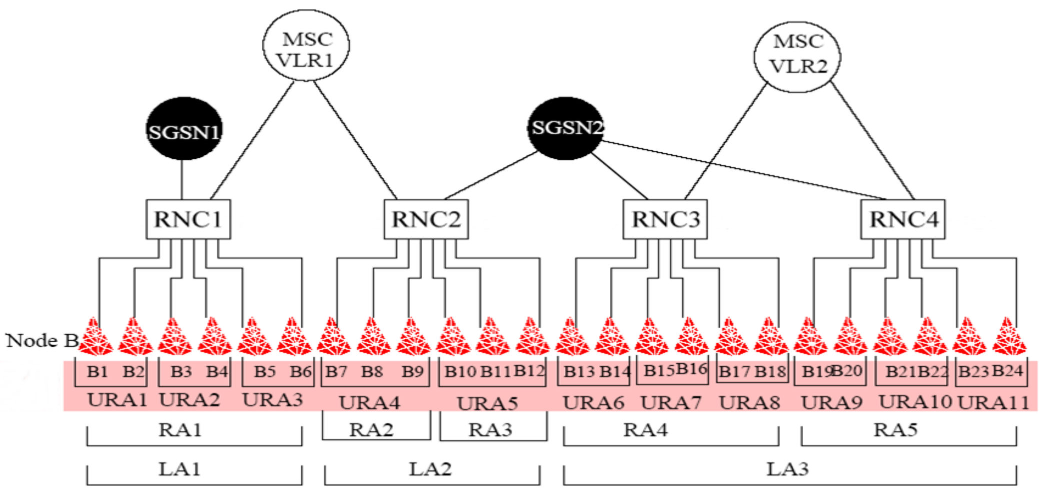


Figure 120: UMTS LA and RA

Location Area (LA):

A LA covers the area of one or even more RNS. A LA can only cover the area of more than one RNSs if the corresponding RNCs are managed by the same SGSN.

Routing Area (RA)

A RA is a subset of a LA. It only covers one RNS or even only a subset of a RNS.

UTRAN RA (URA)

An URA is a subset of an RA. It only covers some Node Bs of one RNS.

In UMTS, the UTRAN tracking is triggered by the establishment of the RRC connection. In the MS and the UTRAN, and RRC state machine is executed. In the RRC Idle mode, no RRC connection is established, and the MS is tracked by the SGSN at the RA level. When the RRC connection is established, the state moves from RRC Idle to RRC Cell Connected, and the MS is tracked by the UTRAN at the cell level. If, for example, no PDUs are transmitted before an *inactivity timer* expires, the state moves from RRC Cell Connected to RRC URA Connected, and the MS is tracked by UTRAN at the URA level.

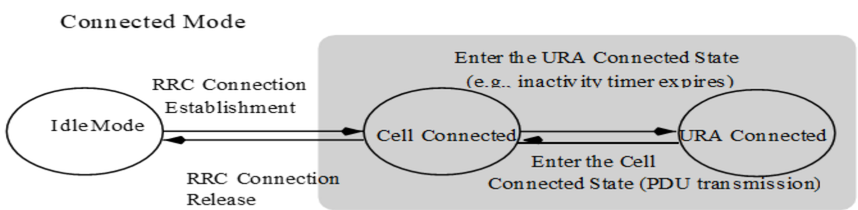


Figure 121: Mobile Mode

8.2.2 Mobility Management Functions

The mobility management functions emphasizing PS-based services are listed below.

- **PS attach procedure** allows an MS to be 'known' by the PS service domain of the network. For example, after the MS is powered on, the PS attach procedure must be executed before the MS can obtain access to the PS services. Note that the term 'PS attach' is used in UMTS and the term 'GPRS attach' is used in GPRS. Similarly, we have the term 'CS attach' for UMTS and 'IMSI attach' for GPRS.

- **PS detach procedure** allows the MS or the network to inform each other that the MS will not access the SGSN-based services.

- **Security procedures** include authentication, user identity confidentiality (e.g., P-TMSI reallocation and P-TMSI signature) and ciphering.

- **GPRS ciphering** is performed between the MS and the SGSN. On the other hand, UMTS ciphering is performed between the UTRAN and the MS.

- **Location management procedures** track the location of an MS.

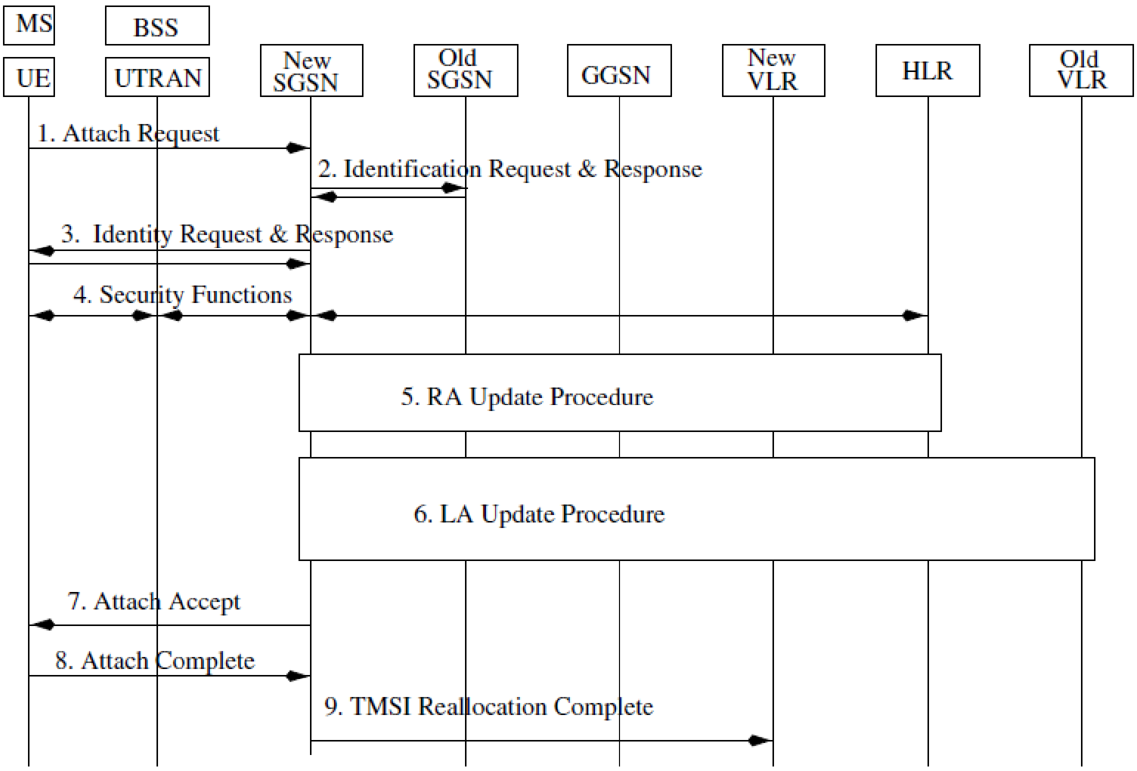


Figure 122: Combined PS/CS (GPRS/IMSI) attaches procedure.

- **Tunneling of non-GSM signaling message** procedures support communication between GPRS/ UMTS and non-GSM systems. The SGSN forwards the signaling messages to the non-GSM MSC/VLR using the BSSAP protocol in the Gs interface.

- **Subscriber management procedures** are used by the HLR to inform the SGSN about changes of the PS subscription data.

- **Service request procedure** (UMTS only) is used by the MS to establish a secure connection to the SGSN, so that the MS can send uplink signaling messages or user data. This procedure is used, for example, when the MS replies a page from the UMTS network or when the MS attempts to request resource reservation. In GPRS, LLC link is always established between the MS and SGSN after the attach procedure. Therefore, the service request procedure is not needed and is not defined in GPRS.

- **UMTS-GPRS intersystem change procedures** allow a dual mode MS to move between GPRS and UMTS systems.

8.8.1 MOBILITY MANAGEMENT STATES

In GPRS and UMTS, an MM finite state machine is exercised in both SGSN and MS to characterize the mobility management activities for the MS. In GPRS, the states in the machine are IDLE, STANDBY and READY. For UMTS PS service domain, these states are renamed as PMM-DETACHED, PMM-IDLE and PMM-CONNECTED, respectively. The MM states are stored in the MM contexts maintained by the MS and the SGSN.

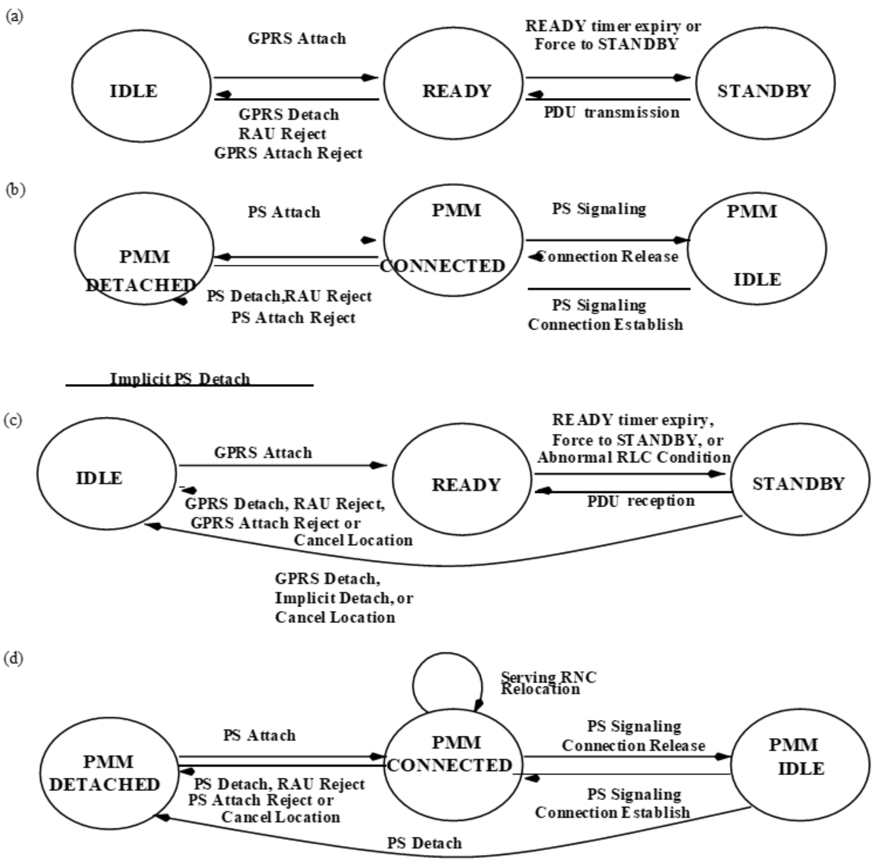


Figure 123: MM States

IDLE or PMM-DETACHED

The MS is not known (i.e., not attached) to GPRS (UMTS/PS). That is, the MS is not reachable by the network. In this state, the MS may perform attach procedure.

STANDBY or PMM-IDLE

The MS is attached to GPRS (UMTS/PS); that is, both the MS and SGSN have established MM contexts. In this state, the MS may perform the detach and location update procedures. The SGSN may perform paging procedure. The MS is tracked by the SGSN at the RA level.

READY or PMM-CONNECTED

PDUs can only be delivered in this state. In GPRS, the SGSN tracks the MS at the cell level. In UMTS, a PS signaling connection is established between the MS and the SGSN (that is, the MS is in RRC Connected mode). The SGSN tracks the MS with accuracy of the RA level, and the serving RNC is responsible for cell- level tracking. In UMTS, serving RNC relocation is executed in this state.

8.8.2 MM AND PDP CONTEXTS

***Mobility Management* (MM) context** provides mobility information of an MS, while *Packet Data Protocol* (PDP) context provides information to support packet delivery between an MS and the network. While an MS may be associated with several PDP contexts, it only has one MM context. The MM context is maintained in MS and SGSN. The PDP contexts are maintained in MS, SGSN, and GGSN.

8.8.3 ATTACH AND DETACH PROCESS:

With the attach procedure, the MS informs the network of its presence.

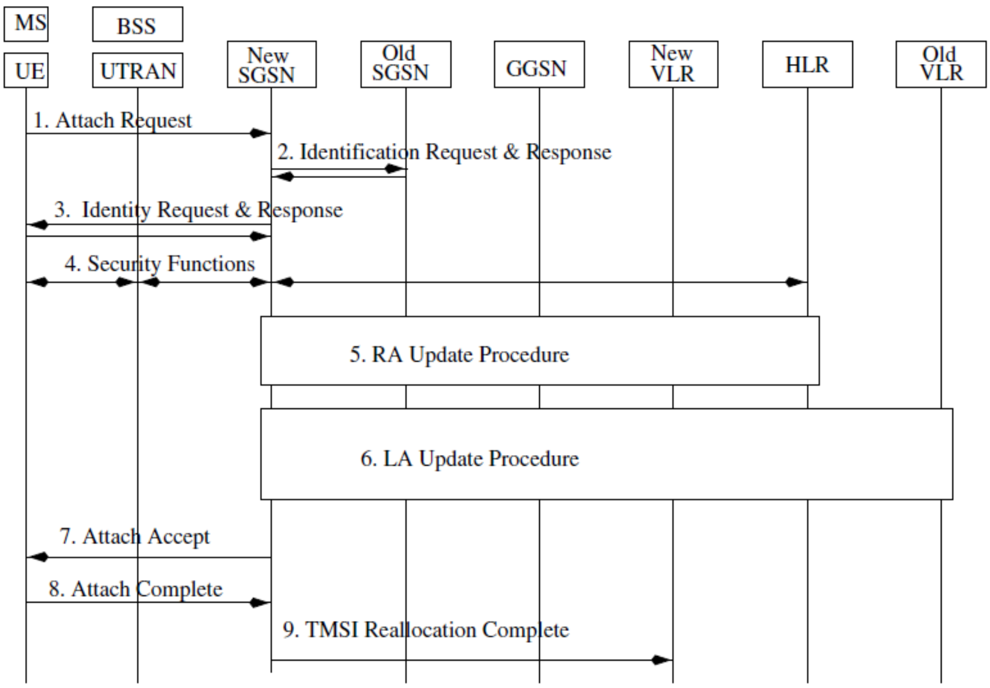


Figure 124: Attach and Detach Process

Step1.The MS initiates the attach procedure by sending the Attach Request message to the SGSN. In GPRS, besides the MS network access capability, the message includes parameters such as MS radio access capability. These radio related parameters are not included in UMTS Attach Request message. On the other hand, the UMTS message includes the 'follow on request' field to indicate if there is pending uplink traffic that needs Iu connection after the attach procedure is completed. This field is not needed in GPRS because the Iu interface does not exist. Furthermore, the security parameters for UMTS and for GPRS are different.

When the SGSN receives the attach request at the end of Step1, there are several possibilities:

- If the MS has changed SGSN since last detach, then Step 2 is executed so that the new SGSN can obtain the MS identity (i.e., IMSI) from the old SGSN.
- If the MS has not changed SGSN, then the received P-TMSI is used by the SGSN to identify the MM context of the MS. If the MM context has not been deleted since last detach (i.e., the MS is known by the new SGSN), then Steps 2 – 6 are skipped, and Step 7 is executed. Otherwise (the MS is not known by the old and the new SGSNs), Step 2 is skipped, and Step 3 is executed.

Step 2 (the MS is known by the old SGSN): The new SGSN sends the Identification Request message to the old SGSN. The P-TMSI is used to obtain the IMSI and authentication information from the old SGSN. If the old SGSN cannot find the MM con- text for the MS, then Step 3 is executed. Otherwise the IMSI is returned to the new SGSN, and Step 4 is executed.

Step 3 (the MS is unknown in both the old and the new SGSNs): The new SGSN asks the MS to supply IMSI through the Identity Request and Response messages exchange.

Step4 Authentication is mandatory if the MM context of the MS has been deleted since last detach. The equipment (IMEI) may be optionally checked.

Step 5 If the MS has moved from the old SGSN to the new SGSN since last detach or if the MS is performing the first attach, then the RA update procedure is executed so that the new SGSN can obtain the current MM context of the MS.

Step 6 If the Gs interface does not exist, then this step is skipped. Otherwise (Gs exists), the attach type in Step 1 is checked. If attach type indicates (1) combined PS/CS attach or (2) PS attach and the MS is already CS attach, then LA update is performed. The LA update is required so that the SGSN-VLR association is established and the VLR can maintain current LA information of the MS.

Step 7 For GPRS, if attach is successful, then the SGSN selects radio priority SMS and sends the Attach Accept message to the MS. P-TMSI is included in the message if the SGSN allocates a new P-TMSI. In UMTS, radio priority SMS is not maintained in mobility management. However, this parameter is still reserved in the UMTS Attach Accept message in order to support handoff between UMTS and GSM networks.

Step 8 If P-TMSI or TMSI have been changed, the MS sends the Attach Complete message to the SGSN to acknowledge receipt of the TMSIs.

Step 9 If TMSI has been changed, the SGSN sends the TMSI Reallocation Complete message to the VLR.

After PS attach, the MS is in the READY (for GPRS) or the PMM-CONNECTED (for UMTS) state and MM contexts are established in the MS and the SGSN.

When PS detach is executed, the MS will not receive the SGSN-based service. The network or the MS may request detach explicitly. On the other hand, implicit PS detach is executed by the network (without notifying the MS) if the mobile reachable timer expires or when radio path is disconnected due to errors. After implicit PS detach is performed, the MS's MM context is deleted after an implementation dependent timeout period. The PS detach procedure also inactivates the PDP contexts. The PS detach procedures are basically the same for both GPRS and UMTS.

8.8.4 LOCATION UPDATE

In location management, the MS informs the network of its location through RA and LA update procedures.

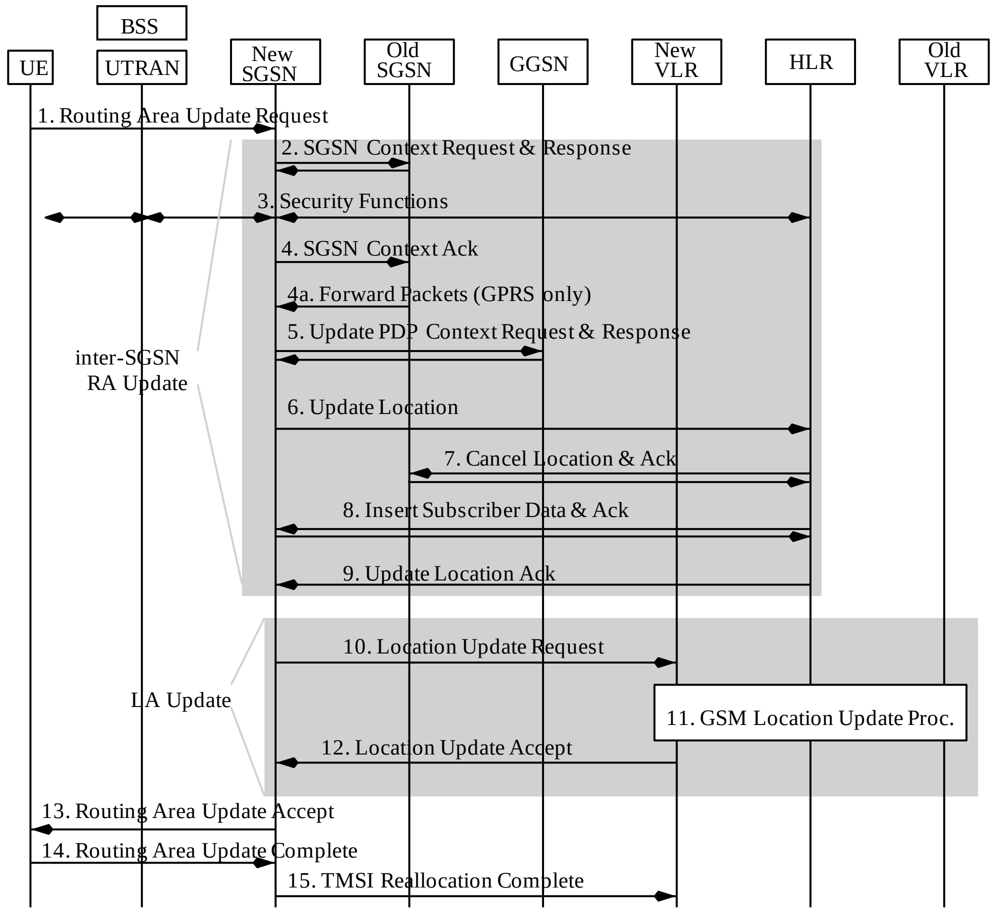


Figure 125: Location Update

The update procedures are executed in two situations.

- Normal location update is performed when the MS detects that the location has been changed.

- Periodic location update is exercised even if the MS does not move. That is, the MS periodically reports its 'presence' to the network. Periodic RA update allows the network to detect if an MS is still attached to the network. A *periodic RA update timer* is maintained in both the MS and the SGSN. Every time this timer expires, the MS performs periodic RA update. The periodic RA update timer value is set/changed by the SGSN, and is sent to the MS through the RA Update Accept or the Attach Accept messages when the MS visits an RA. This value cannot be changed before the MS leaves the RA.

RA update is periodically performed for a PS- attached MS that is not CS-attached. On the other hand, LA update is periodically performed for a CS attached MS that is not PS attached. For a PS/CS attached MS, two cases are considered:

8.8.5 RA/LA UPDATE PROCESS

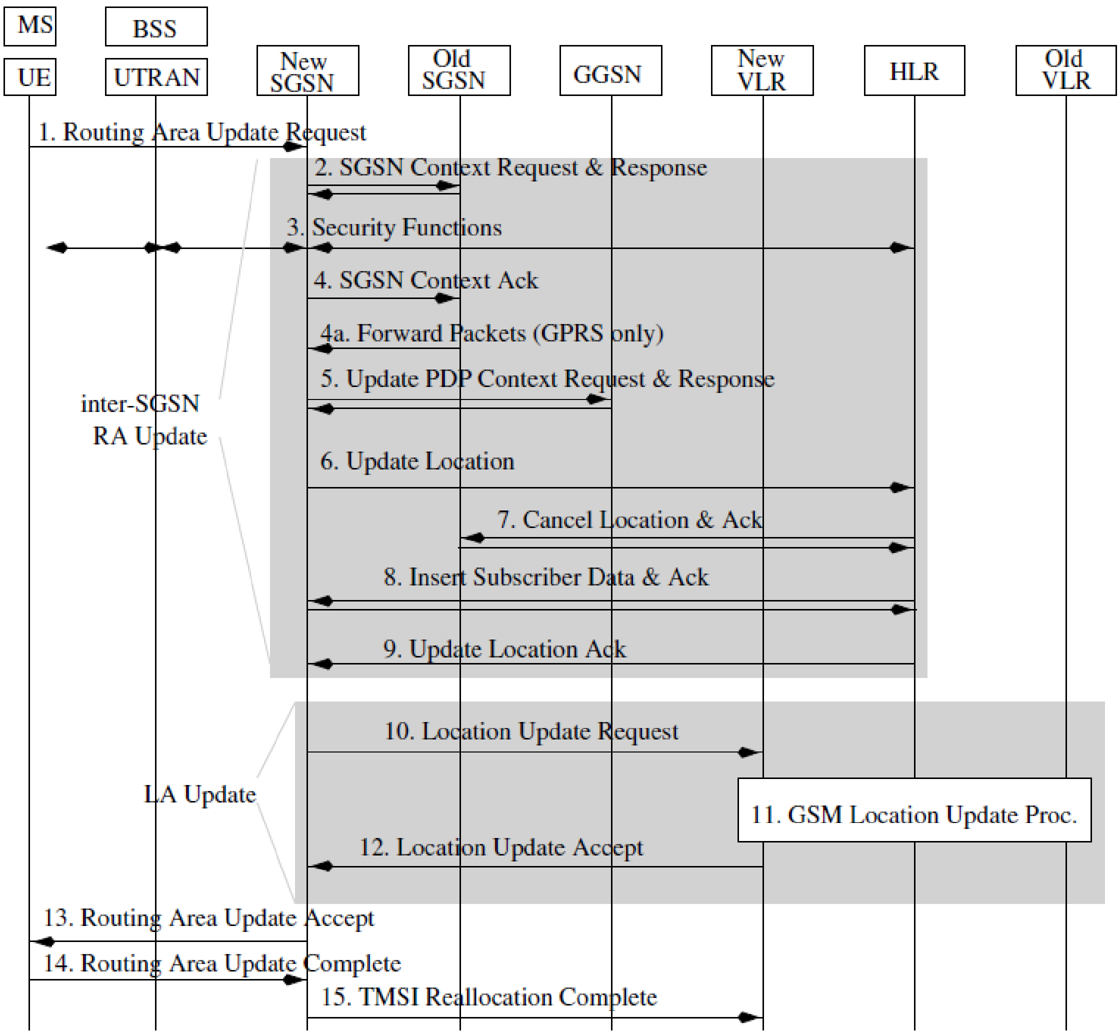


Figure 126: Combined RA/LA update

Step 1. The MS sends the Routing Area Update Request message to the new SGSN. This message is not ciphered so that the new SGSN can process the message. For both GPRS and UMTS, the update type can be RA update, periodic RA update, combined RA/LA update, or combined RA/LA update with IMSI attach. The ‘follow on request’ parameter is used in UMTS to indicate if the Iu connection should be kept for pending uplink traffic. This parameter does not exist in GPRS. In GPRS, before the BSS passes the message to the SGSN, it adds the cell global identity information (including cell, RA and LA identities). In UMTS, the area identity information (including RA and La identities).For inter-SGSN update, Steps 2 – 9 are executed. Otherwise (intra-SGSN update), these steps are skipped.

Step 2. To obtain the MM and PDP contexts of the MS, the new SGSN sends the SGSN Context Request message to the old SGSN. Basically, the old SGSN validates the old P-TMSI signature, and returns the MM and the PDP contexts of the MS using the SGSN Context Response message. The old SGSN starts a timer. The MM context in the old SGSN is deleted when both of the conditions are satisfied: the timer expires, and the old SGSN receives the Cancel Location message from the HLR. This timer mechanism ensures that if the MS initiates another inter-SGSN routing area update before the current update procedure is completed, the old SGSN still keeps the MM context. In GPRS, the old SGSN stops assigning SNDCP N- PDU numbers to downlink N-PDUs received. The old SGSN will forward buffered packets to the new SGSN at Step 4a. In UMTS, packet forwarding is not performed between the SGSNs. Also, the *temporary logical link identity* (TLLI) included in the GPRS SGSN Context Request message is not found in the UMTS message.

Step 3 If the old P-TMSI signature checking at Step 2 fails, security function involving MS, BSS/ UTRAN, new SGSN, and the HLR is performed. If this security procedure also fails, then the old SGSN continues as if the SGSN Context Request message is never received and this procedure exits. Otherwise (security check successes), Step 4 is executed.

Step 4 The new SGSN sends the SGSN Context Acknowledge message to the old SGSN, which invalids the SGSN-VLR association in the old MM context. In GPRS, this message includes the address of the new SGSN, which is used to inform the old SGSN that new SGSN is ready to receive the buffered packets to be forwarded from the old SGSN. The new SGSN address is not included in the UMTS SGSN Context Acknowledge message. Step 4a (GPRS only). The old SGSN then tunnels the buffered NPDUs to the new SGSN. Note that no packets are forwarded from the old SGSN to the new SGSN in UMTS.

Step 5 The new SGSN sends the Update PDP Context Request message to the corresponding GGSNs. With this message, the GGSN PDP contexts are modified. The GGSNs return the Update PDP Context Response messages.

Step 6 The SGSN issues the Update Location message to inform the HLR that the SGSN for the MS has been changed.

Step 7 The HLR and the old SGSN exchange the Cancel Location message pair. The MM and the PDP contexts in the old SGSN is not deleted until the timer described in Step 2 expires.

Steps 8 and 9 The HLR inserts the subscriber data to the new SGSN. For each PDP context, the new SGSN checks if the context is new, active, or inactive. If the PDP context is active, then extra tasks are performed by the SGSN. For example, the SGSN compares if the received 'QoS subscribed' value is the same as the value of the QoS negotiated parameter. If not, the SGSN should initiate the PDP context modification procedure to adjust the QoS parameters of the context.

Steps10–12areexecutedifthenewSGSNdetects that the LA has been changed or the update type in Step 1 indicates combined RA/LA update with IMSI (CS)attach.

Step 10 (LA Update). Through a table lookup technique, the SGSN translated *RA identity* (RAI) into the VLR number and sends the Location Update Request message to the VLR (after Step 8 is executed). The VLR creates or updates the SGSN- VLR association by storing the SGSN number.

Step 11 The standard GSM location update procedure is performed.

Step 12 The new VLR allocates a new TMSI and responds with Location Update Accept to the SGSN. Allocation of TMSI is optional if the VLR is not changed.

Step 13 The new SGSN sends the Routing Area Update Accept message to the MS. In GPRS, the new SGSN also confirms all mobile-originated N- PDUs successfully transferred before the start of the update procedure.

Step 14 The MS sends the Routing Area Update Complete message to the new SGSN to confirm the reallocation of the TMSI. In GPRS, the MS also confirms all received mobile-terminated N- PDUs before the RA update procedure started. This information is used by the new SGSN to check if the packets forwarded from the old SGSN have been received by the MS. If so, these redundant packets are discarded.

Step 15 If a new TMSI has been received by the MS, then the TMSI Reallocation Complete message is sent to the VLR.

In terms of RA update, the major differences between UMTS and GPRS are the following:

- In GPRS, packet forwarding is performed between old and new SGSN during RA update. In UMTS, packet forwarding is handled at the RNC level, and the SGSN is not involved.
- In the RA update, the UMTS MS may determine if the Iu connection should be maintained , which is not needed in GPRS.

8.8.6 UMTS-GPRS INTER SYSTEM CHANGE

When a GPRS/UMTS dual mode MS moves from a cell supporting GSM/GPRS radio technology to a cell supporting WCDMA radio technology (or vice versa), a UMTS-GPRS intersystem change may take place. To provide this feature, mechanisms should exist to derive the area identities (for LA, RA, and cell) and the routing-related information from one system to another.

For SGSN change from UMTS to GPRS, if the MS is in the PMM-IDLE state, then the normal GPRS RA update procedure is executed. If the MS makes the intersystem change decision when it is in the PMM- CONNECTED state, then it stops the transmission to the network, and the following steps are executed for intra SGSN change:

Step 1 An LLC link is established between the MS and the SGSN. The MS sends the Routing Area Update Request message to the SGSN through the new BSS. This step is exactly the same as Step 1 initiated by a GPRS MS.

Step 2 The SGSN exchanges the SRNS Context Request and Response messages with the old SRNS to obtain the following information: GTP- SND and GTP-SNU are used to resume transmission to the GGSN. PDCP-SNU is used to resume transmission to the MS for loss-less relocation. The SGSN converts the PDCP sequence number into the SNDCP sequence number and saved it in the GPRS PDP context. The SRNS stops sending packets to the MS, and starts buffering the packets received from the GGSN.

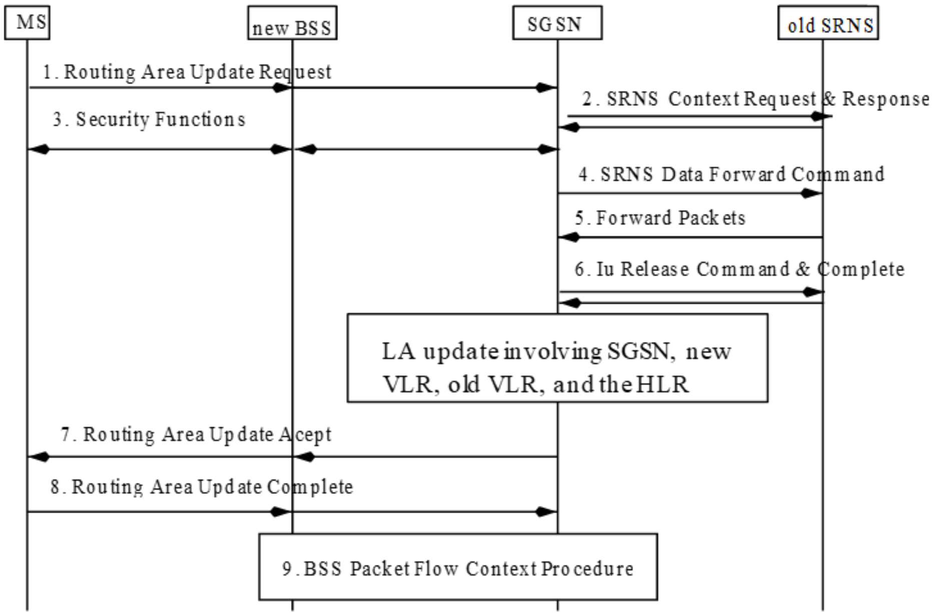


Figure 127: Intra SGSN change from GPRS to UMTS

Step 3 Security functions may be executed as in Step 3 of Figure above. If the MS is not allowed to attach in the RA, or if subscription checking fails, then the SGSN rejects this RA update.

Step 4 At this point, the SGSN is ready to receive packets. The SGSN sends the SRNS Data For- ward Command message to the old SRNS, which instructs the SRNS to forward the buffered packets to the SGSN. The SRNS starts a data-forwarding timer. Before this timer expires, the Iu connection between the SRNS and the SGSN will be maintained (see Step 6).

Steps 5 For the packets received by the old SRNS from the SGSN, but have not been sent to the MS, the packets are tunneled back from the SRNS to the SGSN.

Step 6 When the SGSN timer set at Step 4 expires, the Iu Release Command and Complete messages are exchanged to release the Iu connection. If the type parameter in the Routing Area Update Request message at Step 1 is combined RA/LA update (for Network Mode I), or if the LA has been changed, then the SGSN triggers LA update (see Steps 10 – 12 in Figure above) that involves the SGSN, new VLR, old VLR and the HLR.

Step 7 The SGSN updates the MM and PDP con- texts. New P-TMSI and new TMSI may be allocated. The SGSN sends the Routing Area Update Accept message to the MS.

Step 8 The MS returns the Routing Area Update Complete message to the SGSN if a new P-TMSI is allocated or if the MS needs to acknowledge the packets received from the network. If a new TMSI is allocated to the MS, then the SGSN sends a TMSI Reallocation Complete message to the new VLR.

Step 9 The SGSN and the BSS execute the BSS packet flow context procedure if no BSS packet flow context exists in the BSS. In this context, the SGSN provides the BSS with information related to ongoing user data transmission.

For SGSN change from GPRS to UMTS, if the MS is in the STANDBY state, then the normal UMTS RA update procedure is executed. If the MS makes the intersystem change decision when it is in the READY state, then it stops the transmission to the network by disconnecting the LL Clink. The following steps are executed for intra SGSN change:

Step 1 The MS establishes an RRC connection to the new SRNS, and sends the Routing Area Update Request to the SGSN through the SRNS.

Step 2 The SGSN stops the transmission to the old BSS. The security functions may be executed among SGSN, SRNS, and MS. If the type parameter in the Routing Area Update Request message at Step 1 is combined RA/LA update (for Net- work Mode I), or if the LA has been changed, then the SGSN triggers LA update (see Steps 10 – 12 in Figure above) that involves the SGSN, new VLR, old VLR and the HLR.

Step 3. The SGSN updates the MM and PDP con- texts for the MS. A new P-TMSI may be allocated. The SGSN sends the Routing Area Update Accept message to the MS. Reception of the new P-TMSI is acknowledged by the MS through the Routing Area Update Complete message. If a new TMSI is allocated to the MS, then the SGSN sends a TMSI Reallocation Complete message to the new VLR (this message is not shown in Figure).

Step 4 If the MS has pending uplink data or signaling, it sends the Service Request message to the SGSN.

Step 5 The SGSN requests the SRNS to set up the radio bearer between the SRNS and the MS. The N-PDU sequence numbers in GPRS PDP context of the SGSN is used to derive PDCP sequence numbers for the next packets to be delivered in the UTRAN radio bearer.

Step 6 Packet transmission is resumed between SGSN, SRNS, and MS.

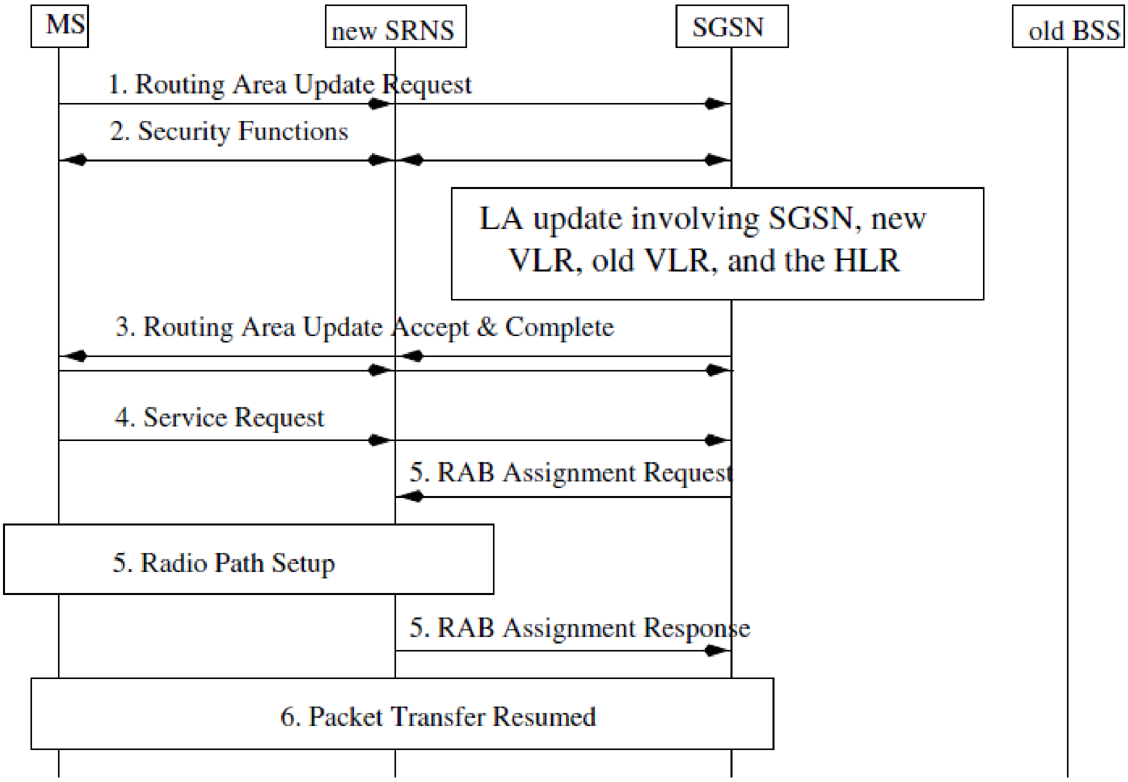


Figure 128: Intra SGSN change from GPRS to UMTS.

8.3 MOBILITY MANAGEMENT IN LTE

Mobility management in Long Term Evolution (LTE) is different from that in the third generation mobile telecom networks. In LTE, the Mobility Management Entity (MME) is responsible for the mobility management function. The MME is connected to a large number of evolved Node Bs (cells) that are grouped into the Tracking Areas (TAs). The TAs are further grouped into TA Lists (TALs). When a User Equipment (UE) moves out of the current TAL, it reports its new location to the MME. If the LTE network attempts to connect to the UE, the MME asks the cells in the TAL to page the UE. In LTE paging, the MME may sequentially page a cell, the TA of the cell, and/or the TAL of the cell. This paper investigates the performance of LTE paging, and provides the guidelines for the best paging sequence of cells.

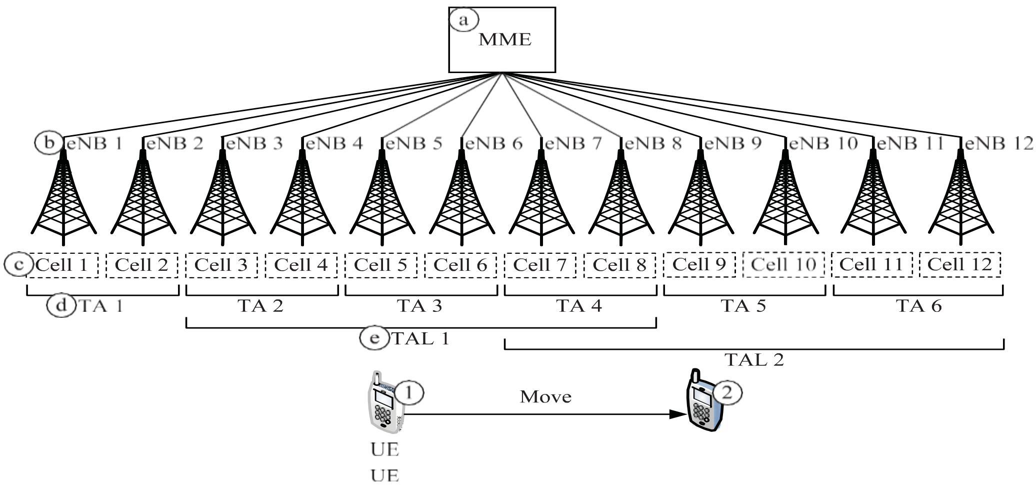


Figure 129: LTE Tracking Area

8.9 LTE TRACKING AREA

The tracking area is similar to Location Area and Routing area in UMTS, which is basically a geographical combination of several base stations (eNodeBs as in LTE).

Each Tracking Area has two main identities:

- Tracking Area Code (TAC)
- Tracking Area Identity (TAI)

The Tracking Area Code identifies the tracking area within a particular network and if we combine the TAC with PLMN-ID then we will get the globally unique Tracking Area Identity.

TAI = PLMN-ID + TAC

The Tracking Area Code has a range of 0 to 65536.

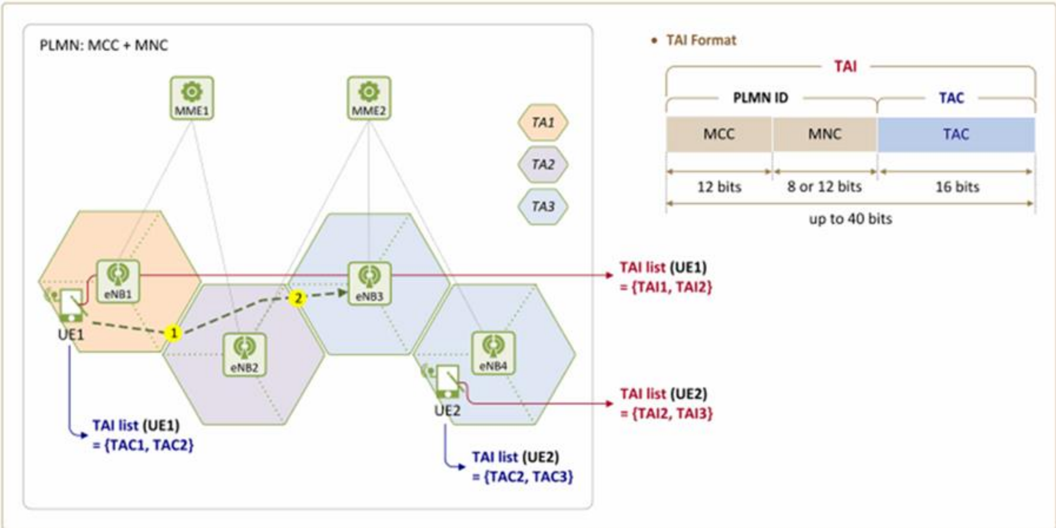


Figure 130: LTE Tracking Area Architecture

Tracking Area List (TAL): it is a group of Tracking Area Codes (TACs) which is used to page UE within the network TAL geographical area.

Tracking Area Codes (TACs) or TAs: it is group of eNodeBs in one small area with maximum number of 100 eNodeBs.

While an LTE device (UE) is in active state (i.e. while communicating, or while in EMM-Registered/ECM-Connected/RRC-Connected state in LTE terms), its location is known by the LTE network at cell level (i.e. on a cell granularity), e.g. in cell2 in eNB1. However, while the UE is in idle state (i.e. while not communicating, or while in EMM-Registered/ECM-Idle/RRC-Idle state in LTE terms), its location is known by the LTE network at TA level (i.e. on a TA granularity), instead of cell level. An operator defines a group of neighbore NBs as a TA (These grouping are performed at the initial deployment of the network. Each eNB is configured with its own TA.). A TA can be made up of cells or eNBs, but only those made up of eNBs will be used here in this post. For example, eNBs in A neighborhood are defined as TA1, those in B neighborhood as TA2, those in C neighborhood as TA3, and so on.

Why do we need TAs?

If there is data traffic heading to a UE in idle state (e.g. if someone sends a text message to a UE), the LTE network has to wake up the UE so that it can receive the data. Here, this "waking up (called paging)" is performed TA-wide. Let's say a UE is located in C neighborhood. Then, the network considers the UE is located in TA3. So, when the network has to wake up the UE as some data for the UE is being received, it sends a paging message to every eNB in TA3. Then each eNB broadcasts the paging message over the radio link to wake up the UE. A UE in idle state wakes up at certain periods to check for a paging message to see if there is any incoming data. If the UE finds it has been paged by an eNB, it turns back to active state to receive the data.

8.9.1 TRACKING AREA UPDATE (TAU)

The LTE network (the MME, to be accurate) has to have updated location information about UEs in idle state to find out in which TA a particular UE is located. For this, the UE notifies the LTE network (MME) of its current location by sending a TAU message (TAU Request message) every time it moves between TAs.

A UE obtains a TAI list when it attaches to an LTE network. This list shows the tracking areas where the LTE network believes a UE is located and within which a UE can travel without TAU. The UE does not have to send a TAU message to the MME as long as it stays in same TA, but it has to send one to the MME when it moves to a new TA. The MME is supposed to provide the UE with a new TAI list reflecting the specific details of the UE's move (e.g. new location, moving speed, etc.) for more efficient paging.

One more thing worth mentioning is Periodic TAU, through which a UE in idle state sends a TAU message (TAU Request message) to an MME periodically even when the UE stays within a TA in the TAI list. If a UE in idle state has stayed in one location (or moved within the TAs in the TAI list) and has not notified the MME of its current location, the network cannot tell whether the UE is still in idle state, or is not able to communicate. So, the UE, even when the TA is not changed sends TAU Request messages to the MME periodically to announce "it is able to receive data". Otherwise, the network believes the UE is not able to receive data and does not perform paging even when there is data traffic heading to the UE.

TAC and TAL planning are to determine the size of a TAC and TAL border. The TAC and TAL size is simply defined as the number of eNodeBs in the TAC or TACs in a TAL.

If only a few eNodeBs are in a TAL, Tracking Area Updates (TAUs) may occur frequently, and MME load and UE power consumption increase. If TAUs occur frequently, a UE cannot respond to a paging message during TAU, reducing the paging success rate.

If number of users increases in a TAL, paging load increases in this TAL and further split planning needed to solve paging overload.

Tracking Area Update Process

A UE starts the Tracking Area Update procedure in following events:

- When a UE moves to a new Tracking Area which is not included in its list of Tracking Areas with which the UE is registered.
- When the timer T3412 expires the UE triggers the Tracking Area Update procedure. The value of T3412 is initialised in the Attach Accept message during the Attach procedure.
- Registering with the CS domain for non-EPS service when the UE is already attached for EPS services. This involves completing an IMSI attach as part or Tracking Area Update procedure.
- Registering for EPS service after an inter-system change. For example reselecting to LTE from UMTS.
- Re-registering to LTE after CS-fallback completed.
- MME load balancing. The UE initiates TAU procedure if the eNodeB releases the RRC connection with a cause ‘Load Balancing TAU Required’.
- When UE-specific DRX cycle is updated.
- Indicating that the UE has selected a Closed Subscriber Group (CSG) cell whose CSG Identity is not included in the UE’s allowed CSG list.

Tracking Area Update Call Flow

The following example shows Tracking Area Update procedure when UE changes the MME but maintains the Serving Gateway. Also, we assume that the UE starts in RRC Idle mode. So the Tracking Area Update Request message is sent within the RRC Connection Setup Complete message.

If the UE is already in RRC Connected state when TAU procedure is triggered, the Tracing Area Update Request is sent within an Uplink Information Transfer message.

8.9.2 LTE PAGING MANAGEMENT:

The LTE paging procedure can be used for the following:

- To initiate mobile terminated PS call.
- To initiate mobile terminated CS fallback call
- To trigger LTE UE to re-acquire system information
- To provide an Earthquake and Tsunami Warning System (ETWS) indication

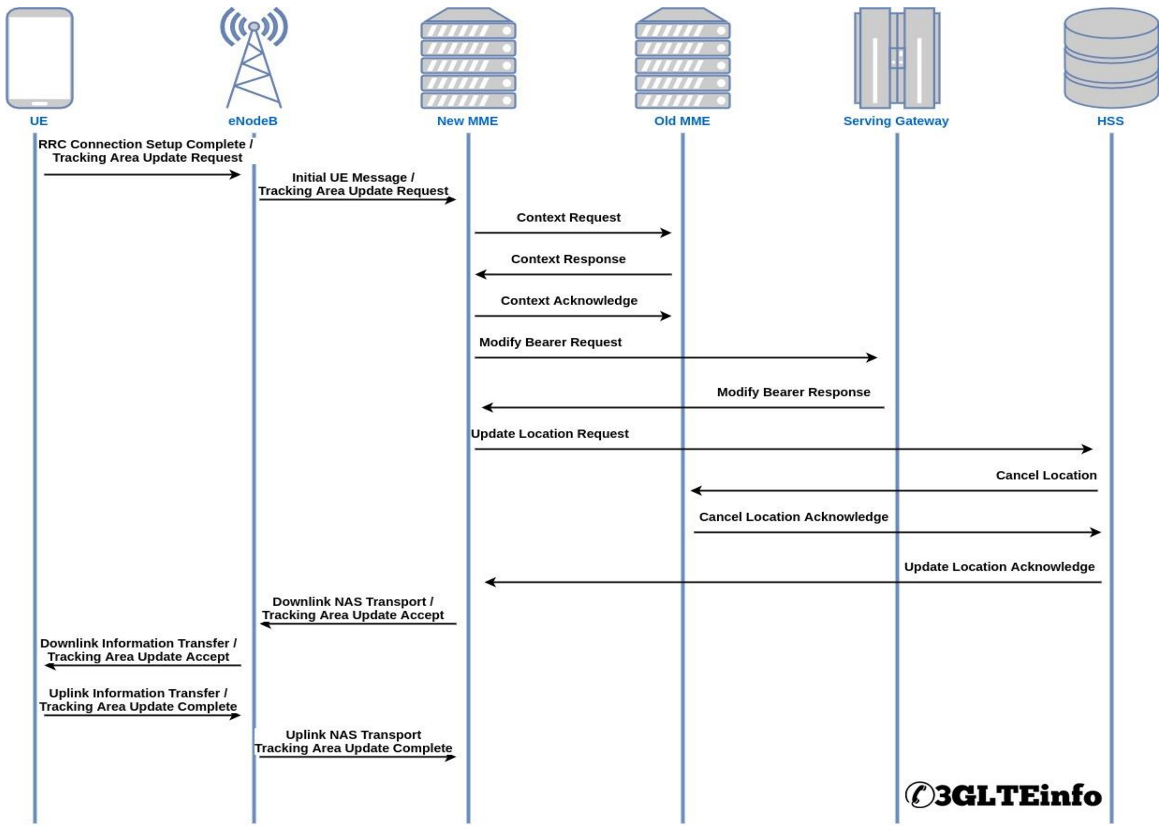


Figure 131: Tracking Area Update

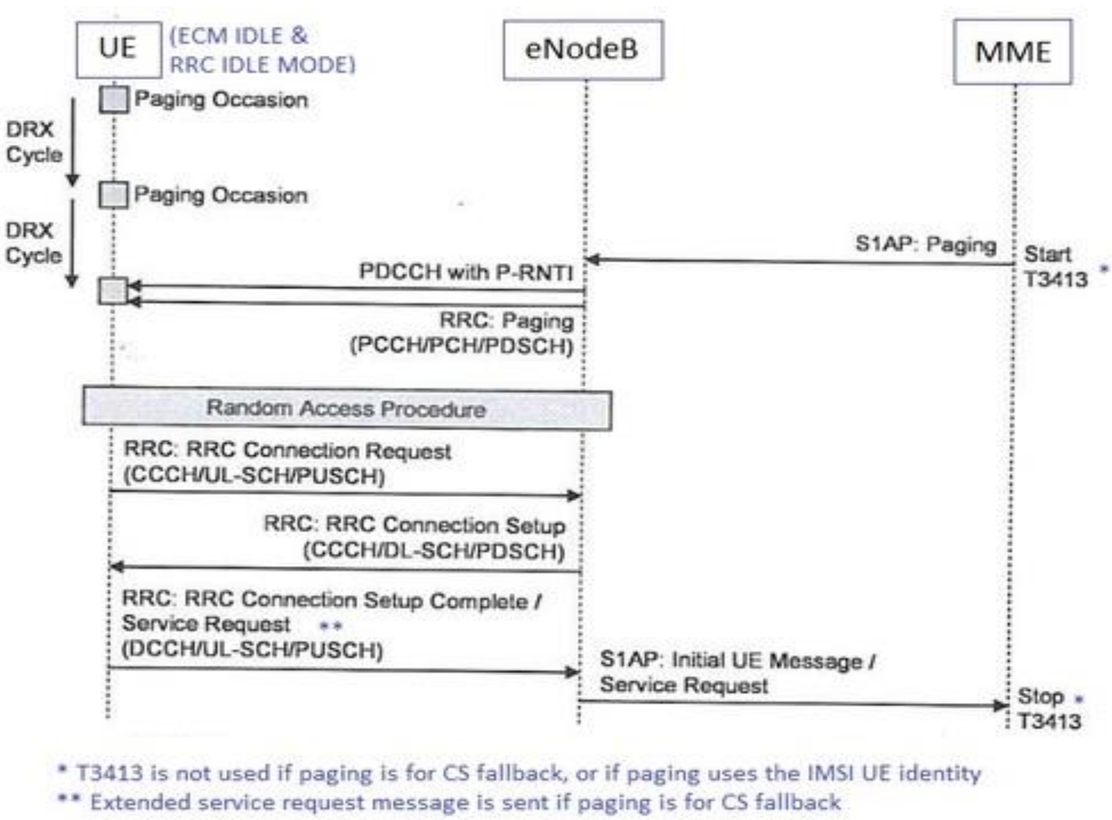


Figure 132: Paging

MME is responsible for the initiation of LTE paging procedure. MME does this by forwarding S1AP paging message to one or more eNodeB.

LTE Paging procedure

The LTE paging procedure is applicable to UE in ECM IDLE State. UE in this state are in RRC IDLE mode and do not have S1 connectivity with MME. The location of a UE in ECM IDLE state is known by MME on a per tracking area basis. The MME has to forward S1AP paging message to all eNodeB within the relevant tracking area.

- MME forward paging message to multiple eNodeBs as UE can be registered with more than a single tracking area.
- MME starts timer T3413 after sending S1AP paging message for PS data call and LTE UE is addressed by S-TMSI instead of IMSI.
- eNodeB receives S1AP paging message from MME and constructs RRC paging message. Single RRC can carry information from multiple S1AP. Paging message can include multiple paging records to page multiple UE.
- UE in RRC IDLE mode checks for paging once every DRX cycle. paging occasion within the paging frame defines specific subframe during which a LTE UE checks for paging message.
- UE searches for P-RNTI within PDCCH of subframe belong to paging occasion. P-RNTI has value of FFFE and indicates that UE may have a paging message on PDSCH.
- UE finds P-RNTU in PDCCH, it will decode resource allocation information. This information directs UE to PDSCH RB where in paging message has been sent. UE decodes RRC message from PDSCH RBs and checks UE identity in all the records. If UE do not find its identity in paging record then it will return to check PDCCH for P-RNTI at each of the paging occasions.
- If the UE find its identity, it will trigger random access procedure to establish RRC connection. UE sends RRC connection request message and eNodeB responds with RRC connection setup message.
- If the LTE paging procedure is for PS data call, UE includes service request NAS message within RRC connection setup complete message.
- If the paging procedure is for CS fallback call, UE includes extended service request NAS message within RRC connection setup complete message.
- The eNodeB forwards NAS message to MME which will stop T3413 if it is running and will proceed to establish connection with UE.

- A paging retransmission will be triggered if T3413 gets expire prior to MME receiving a NAS message from UE.

- UE checks for RRC paging message for SI modification flag and ETWS flag. If the former is present UE reacquires BCCH SI. If the later is present, UE reads ETWS notifications in SIB10 and/or SIB11.

8.10 CONCLUSION

Mobility management is very important as mobile is a moving device. Therefore mobility management plays and important role in mobile communication

9 LTE RADIO NETWORK AND PARAMETER

9.1 LEARNING OBJECTIVE

LTE evolved from an earlier 3GPP system known as the Universal Mobile Telecommunication System (UMTS), which in turn evolved from the Global System for Mobile Communications (GSM). Even related specifications were formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN). This chapter deals with LTE Radio Features, E-UTRAN and its interfaces, LTE operating bands, OFDMA and SC-FDMA,LTE frame structure and Resource block.

9.2 LTE RADIO FEATURES:

The main features of LTE are:

- High peak data rates : Up to 300 Mbps in downlink and 75 Mbps in uplink when using 4x4 MIMO and 20 MHz bandwidth
- High spectral efficiency
- Flexible bandwidths: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz
- Short round trip time: 5 ms latency for IP packets in ideal radio conditions
- Simplified Architecture
- OFDMA in downlink and SC-FDMA in uplink
- All IP network
- MIMO multiple antenna scheme
- Operation in paired (FDD) and unpaired spectrum (TDD)

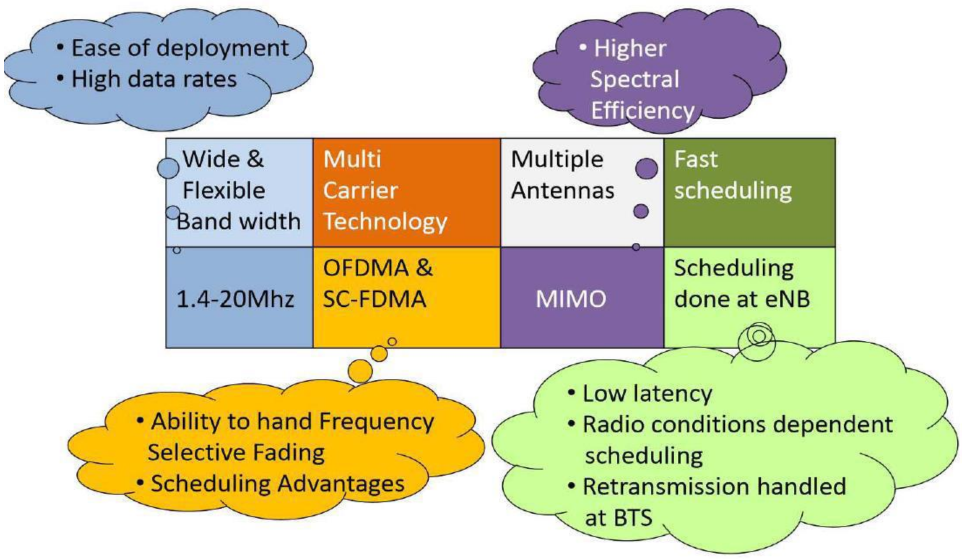


Figure 133: LTE Radio Features

9.3 LTE SYSTEM ARCHITECTURE:

A standard LTE system architecture consists of an Evolved UMTS Terrestrial Radio Access Network, more commonly known as E-UTRAN, and the System Architecture Evolution, also known as SAE. SAE's main component is the Evolved Packet Core, also known as an EPC.

LTE uses a flat architecture without a Radio Network Controller (RNC). LTE equivalent of a UMTS Node B is an 'evolved' Node B or eNode B. eNode B are connected to the Evolved Packet Core (EPC) using a Mobility Management Entity (MME) for control plane signalling and a Serving Gateway for user plane data.

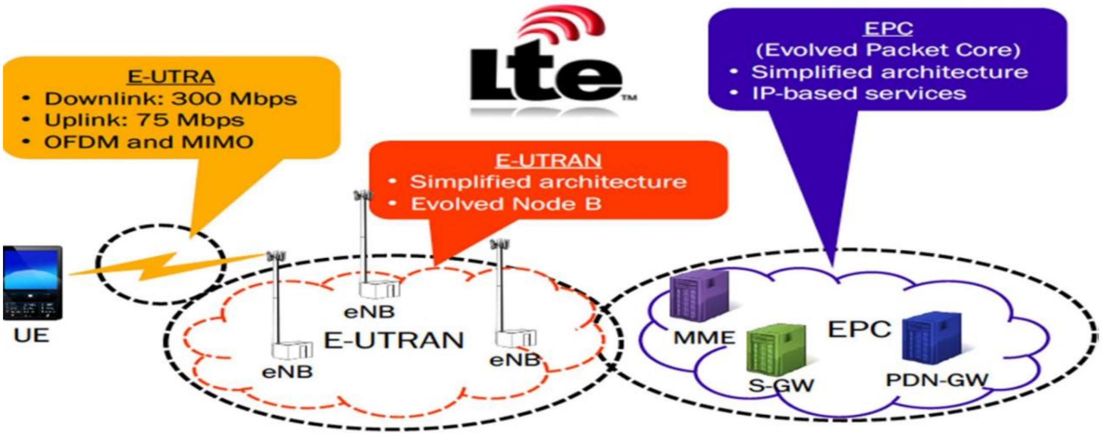


Figure 134: LTE System Architecture

9.4 LTE RADIO NETWORK: THE E-UTRAN

The E-UTRAN is comprised of

- User Equipment (UEs)
- Evolved Node B (eNodeB)
- The Evolved Universal Terrestrial Radio Access (E-UTRA)

The UE can be a device such as: mobile phone, laptop, tablet, computer, etc., used by a subscriber for communication. eNodeB is the base station and its radio interface is the E-UTRA, the Evolved Universal Terrestrial Radio Access.

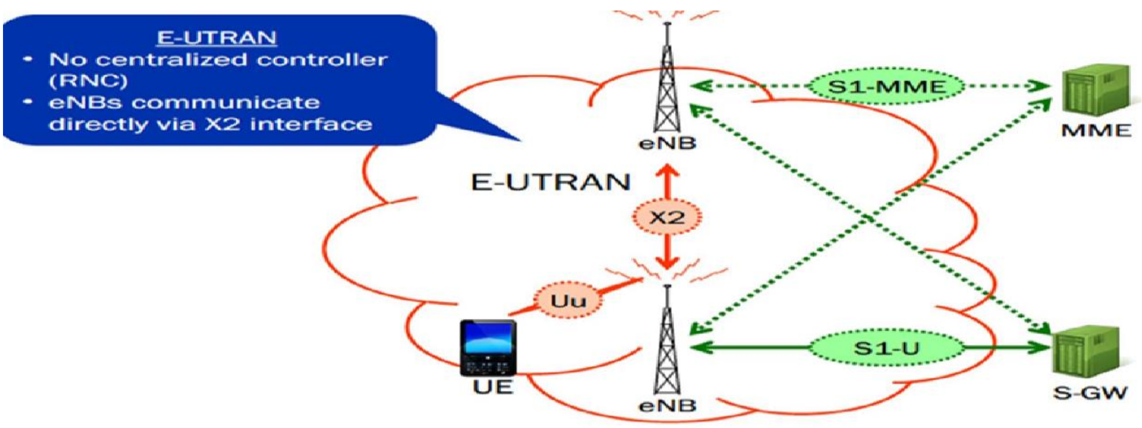


Figure 135: LTE Radio Network

9.4.1 E-UTRA

The E-UTRA is the air interface of an LTE network and is the equivalent of the UTRA air interface in UMTS networks. The E-UTRA enables a latency decrease, allows high bandwidth capabilities and is optimized for packet data.

The E-UTRA uses Orthogonal frequency-division multiple access (OFDMA) in the downlink and Single-Carrier Frequency-Division Multiple Access (SC-FDMA) in the uplink. OFDM splits data into small sub-carriers on neighboring frequencies, over a single channel. OFDM handles phenomena such as interference, noise or multipath significantly more efficiently than other modulation methods.

SC-FSMA is also a frequency division multiple access scheme and usually represents and alternative to OFDM. Its main advantage is a lower peak-to-average power ration, which is proven to be more efficient in networks where the transmit power is most important.

The E-UTRA also uses the MIMO technology and enables the simultaneous support of more users and a lower processing power required for each UE. In the case of a 2×2 MIMO antenna system, the two transmitters send different parts of the same data stream simultaneously, while the receivers have to piece them back together.

9.4.2 THE ROLE OF THE E-NODE B

The e-NodeB is a part of the E-UTRAN radio access network and is the component that allows UEs to connect to the LTE network. An e-NodeB typically communicates with the UE, with other e-NodeBs, and with the EPC through various interfaces: the Uu, X2 and S1.

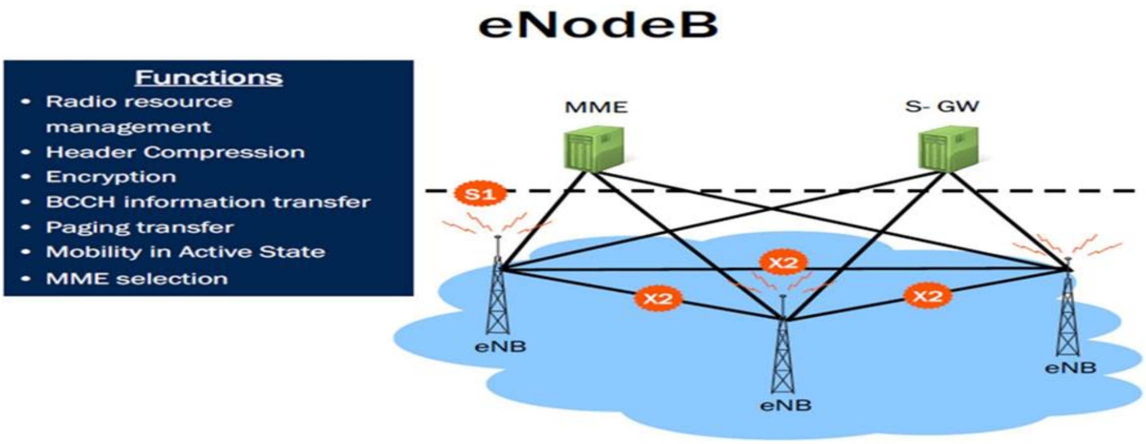


Figure 136: E-NodeB

The e-NodeB performs the following functions:

Radio resource management, which includes:

- Radio bearer control – is responsible for the setup, maintenance and the release of radio bearers and its resource configuration

- mobility management – handles the radio resource management for UEs in both idle and connected modes

- admission control – allows or denies radio bearer setup requests

- dynamic resource allocation, covering the release and allocation of radio resources in both the user plane and the control plane

Routing of user plane packets towards the S-GW
MME selection, which includes:

- Enabling the UE to be served by an MME while the UE is in the "attach" procedure
- Enabling the UE to be served by a different MME while being in a network
- The establishment of the route towards an MME, based on the information provided by the UE when the routing information is not available

Packet compression and ciphering, which includes:

- Encryption and decryption of packets through ciphering algorithms
- Header compression for downlink packets and header decompression for uplink packets

Message scheduling and transmission, which includes:

- The transmission of paging messages, OM messages or broadcast information via the Uu interface
- The reception of broadcast information and paging messages from an MME and the OM messages from the operation and maintenance center

9.4.3 INTERFACES OF THE E-NODE B

LTE-Uu Interface

The LTE-Uu is the radio interface that connects the UEs to the e-NodeBs, e-NodeB with the UE. It handles all the signalling messages between the e-NodeB and the MME as well as the data traffic between the UE and the S-GW.

S1 Interface

The S1 interface connects the E-UTRAN and the EPC for both the user and the control planes. It has two parts: the S1-AP, belonging to the control plane and the S1-U (GTP-U), belonging to the user plane. The S1-AP connects the eNodeB to the MME and is based on IP transmission. It transmits signalling messages of the radio network layer of the E-UTRAN through the Stream Control Transmission Protocol (SCTP)/IP stack.

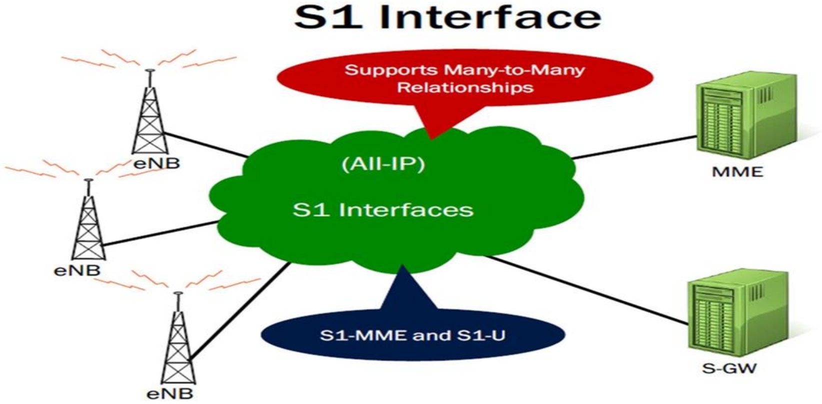


Figure 137: S1 Interface

Therefore, when the e-NodeB has to connect to an MME, it does so through the S1 interface seeking each MME node in the corresponding pool area. The next step is that of setting up the Transport Network Layer (TNL). One e-NodeB and one MME can set up a single Stream Control Transmission Protocol (SCTP) connection. Once the TNL has been established, the e-NodeB starts an S1 interface, which has the purpose of managing the configuration data for the operation exchange between the ENB and the MME.

The **S1-U** connects the e-NodeB to the S-GW through the GTP/UDP5/IP stack. In the user plane, the S1-U (GTP) is based on the GTP/UDP5/IP protocol stack from previous UMTS and GPRS networks. The GPRS Tunnelling Protocol User plane (GTP-U) is responsible for tunnelling the user plane bearers, acts as a reference point for inter-e-NodeB handover, and allows intra-3GPP mobility.

X2 Interface

The X2 interface provides connectivity between two or more e-NodeBs. There are two parts of the X2 interface, the X2-C, the interface between the control planes of e-NodeBs, and the X2-U, the interface between the user planes of e-NodeBs. The X2-C and the X2-U have the same structure as the S1 interface. As seen below. The only difference consists of the X2-AP replacing the S1-AP.Two or more e-NodeBs exchange information related to load interference or handover.

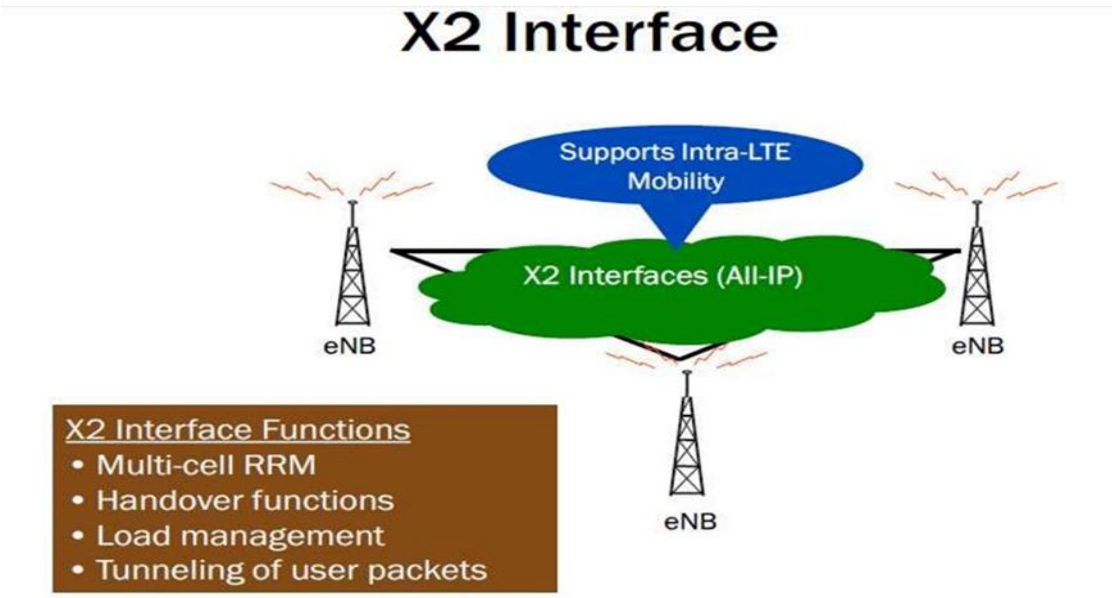


Figure 138: X2 Interface

Two or more e-NodeBs can exchange signalling information through the X2 interface. The main roles of the X2 interface are the following:

- Mobility management
- Load management
- Inter-cell interference management
- Inter-e-NodeB handover
- Tracing function

- X2 interface management and error handling

9.4.4 LTE DUPLEXING METHOD

LTE can utilise both FDD - frequency division duplex and TDD - time division duplex, often referred to as TD-LTE. Both forms of duplex, FDD and TDD have their advantages and the areas where their deployment is advantageous. For most normal LTE deployments the frequency division duplex, FDD is used, and paired spectrum with equal bandwidth in up and downlinks is utilised. LTE FDD using the paired spectrum was considered to be the migration path for the UMTS 3G services which typically utilised paired spectrum. However there was considerable development placed on the time division duplex form of LTE: TDD LTE or TD-LTE which was seen as the upgrade path for TD-SCDMA.

9.5 E-UTRA OPERATING BANDS

Following is the table for E-UTRA operating bands taken from LTE Specification 36.101(v860) Table 9

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
...							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD

Table 9. LTE Frequency Band

9.6 CHANNEL BANDWIDTH:

LTE supports flexible channel bandwidth upto 20 Mhz. Typical deployment channel bandwidths: 1.4, 3, 5, 10, 15, 20 MHz

9.7 MODULATION TECHNIQUE:

UL: QPSK, 16QAM, 64QAM (optional)

DL: QPSK, 16QAM, 64QAM

9.8 MULTIPLE ACCESS TECHNIQUE:

To achieve high radio spectral efficiency as well as enable efficient scheduling in both time and frequency domain, a multicarrier approach for multiple access was chosen by 3GPP. For the downlink, OFDMA (Orthogonal Frequency Division Multiple Access) was selected and for the uplink SC-FDMA (Single Carrier – Frequency Division Multiple Access) also known as DFT (Discrete Fourier Transform) spread OFDMA.

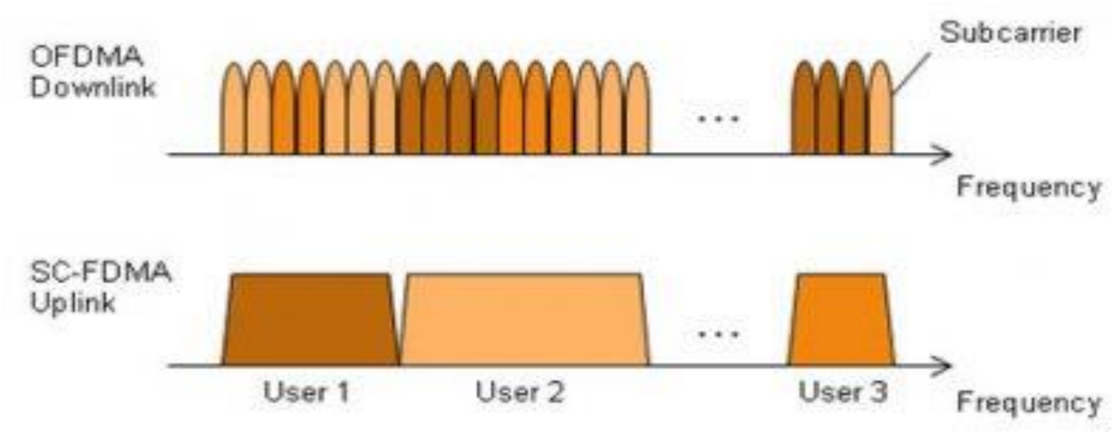


Figure 139: Multiple Access Technique

9.8.1 LTE DOWNLINK IN TIME DOMAIN :

- Time duration for one frame is 10 ms. This means that we have 100 radio frames per second.
- Sampling frequency for 20MHz bandwidth is 15 KHz * 2048 (IFFT_size) = 30.72 MHz = Fs
- Sampling time Ts = 1/Fs = 1/(15 KHz * 2048) = 1/30720000
- 30.72 MHz = 8 x 3.84 MHz (sampling frequency in UMTS)
- Duration of time slot is 7 OFDM symbols + 7 CPs (Cyclic Prefix)
- Number of subframe in one frame is 10.
- Number of slots in one subframe is 2. This means that we have 20 slots in one frame.
- Each slot consists of a number of OFDM symbols which can be either 7 (normal cyclic prefix) or 6 (extended cyclic prefix)

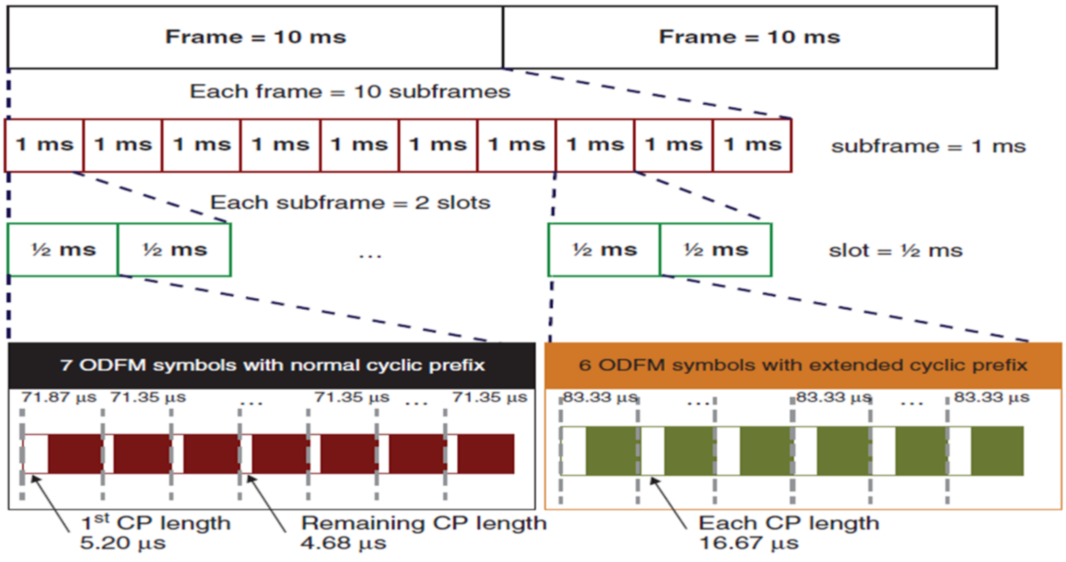


Figure 140: Downlink in Time domain

9.8.2 LTE DOWNLINK: FREQUENCY DOMAIN

- In the frequency domain, the number of sub-carriers N ranges from 128 to 2048, depending on channel bandwidth.
- N= 512 and 1024 correspond to 5 and 10 MHz, respectively, being most commonly used in practice.
- The sub-carrier spacing is Df = 1/Tu = 15 kHz.
- The sampling rate is fs = Df · N = 15000 N.
- This results in a sampling rate that is a multiple or sub-multiple of the WCDMA chip rate of 3.84 Mcps:
- LTE parameters have been chosen such that FFT lengths and sampling rates are easily obtained for all operation modes while at the same time ensuring the easy implementation of dual-mode devices with a common clock reference.

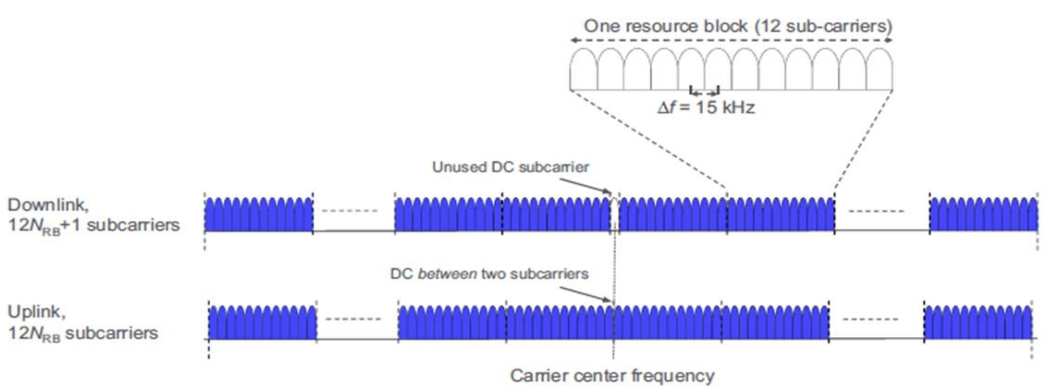


Figure 141: Downlink in frequency domain

9.8.3 LTE DOWNLINK: RESOURCE BLOCK

- The transmission can be scheduled by Resource Blocks (RB)
- 1 RB = 12 consecutive sub-carriers, or 180 kHz, for the duration of one slot (0.5 ms), that is for (7 OFDM symbols, or 6 for extended CP)
- A Resource Element (RE) is the smallest defined unit which consists of one OFDM sub-carrier during one OFDM symbol interval.
- Each Resource Block consists of 12 ・ 7 = 84 Resource Elements (RE) in case of normal cyclic prefix (72 for extended CP).
- Each RE can “carry” number of bits depending on the modulation employed.
- For example, using for QPSK: a RB carries 84*2 bits per 0.5 msec.

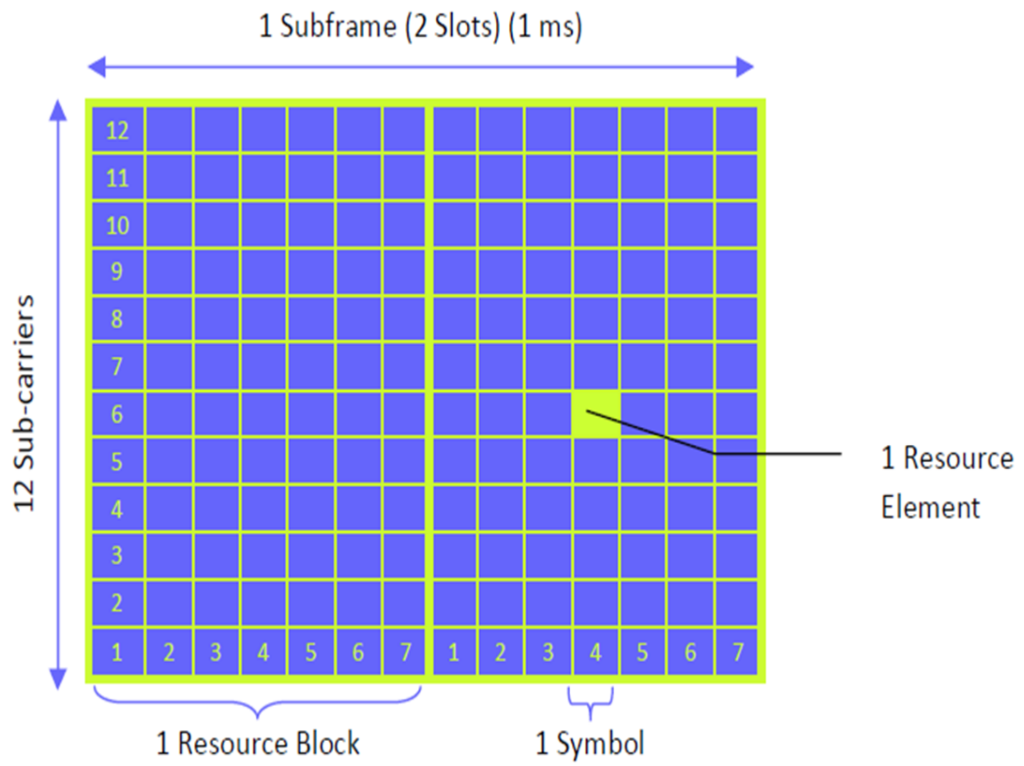


Figure 142: LTE Resource Block

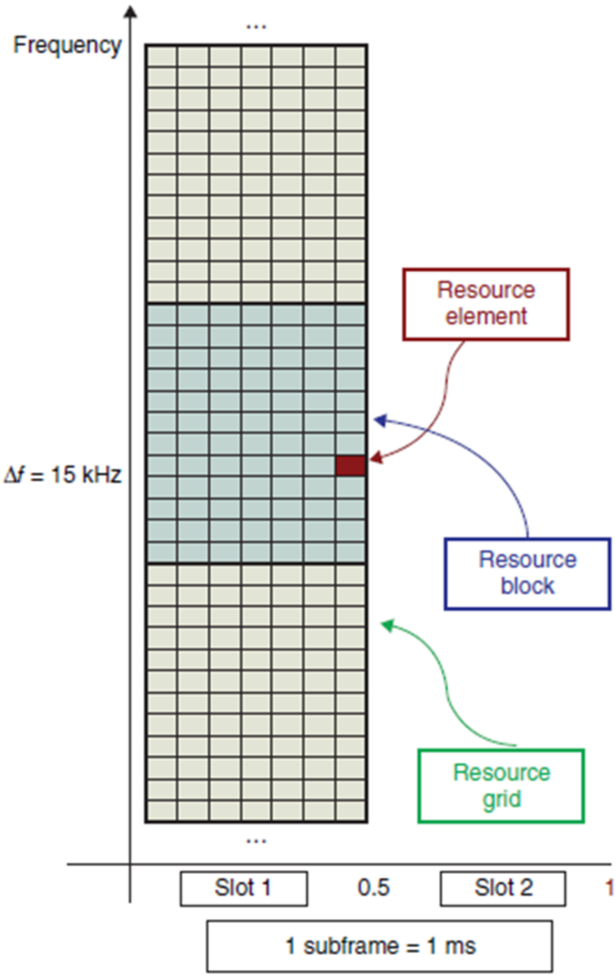


Figure 143: LTE Resource block in time and frequency domain

9.8.4 LTE UPLINK : SC-FDMA TECHNOLOGY

LTE uses a pre-coded version of OFDM called Single Carrier Frequency Division Multiple Access (SC-FDMA) in the uplink. This is to compensate for a drawback with normal OFDM, which has a very high Peak to Average Power Ratio (PAPR).High PAPR requires expensive and inefficient power amplifiers with high requirements on linearity, which increases the cost of the terminal and drains the battery faster.

SC-FDMA solves this problem by grouping together the resource blocks in such a way that reduces the need for linearity, and so power consumption, in the power amplifier. A low PAPR also improves coverage and the cell-edge performance.

- The uplink transmission structure is similar to the downlink. The smallest unit of resource is the Resource Element which consists of one SC-FDMA data block length on one sub-carrier (permissible to use this term because DFT is used for pre-coding with a 15 kHz sub-carrier spacing).
- A resource block (RB) consists of 12 REs for the duration of a slot (0.5 ms). The minimum allocated bandwidth to a UE is, therefore, 180 kHz.

- In the time domain, a 10 ms uplink frame consists of 10 one ms subframes and 20 slots. The supported uplink CP durations are the same as those of the downlink: normal CP of 4.69 μs and extended CP for 16.67 μs (duration of first CP in normal mode is 5.2 μs, also similar to the downlink).

- A slot consists of 7 or 6 SC-FDMA symbols in case of normal or extended mode CP, respectively.

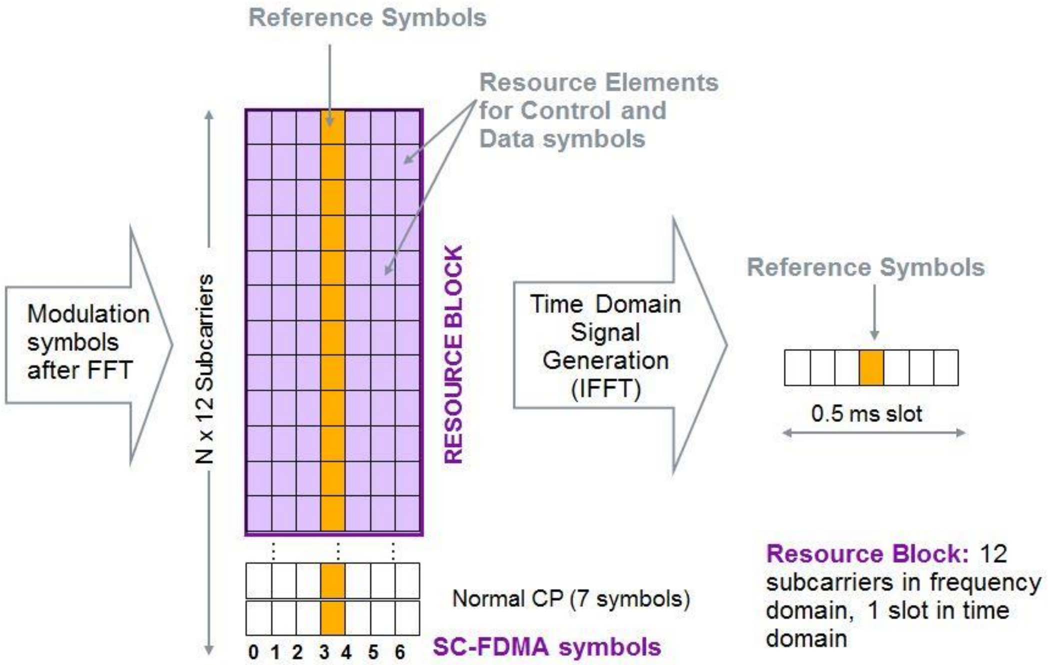


Figure 144: Uplink Resource block

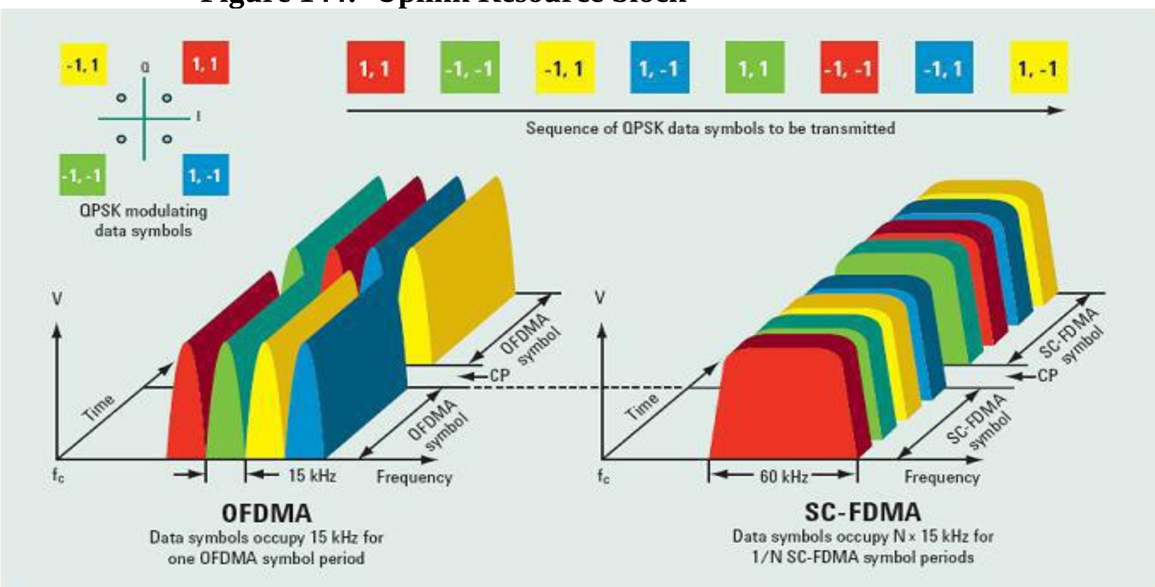


Figure 145: OFDMA vs SC-FDMA

9.8.5 LTE SCHEDULING :

Scheduling is a process through which e-NodeB decides which UEs should be given resources (RBs), how much resource (RBs) should be given to send or receive data

.In LTE, scheduling is done at per subframe basis i.e. every 1 mili second. The entity which is governed is known as scheduler.

Minimum allocate able resource in LTE is Resource Block pair. Resource block pair is 12 carriers wide in frequency domain and lasts for two time slots (1ms). Depending on the length of cyclic prefix RB pair may have 14 or 12 OFDM symbols. PHY channels consist of certain number of allocated RB pairs. Overhead channels are typically in a predetermined location in time frequency domain. Within a RB different AMC scheme may be used. Allocation of the radio block is done by scheduler at e-NodeB.

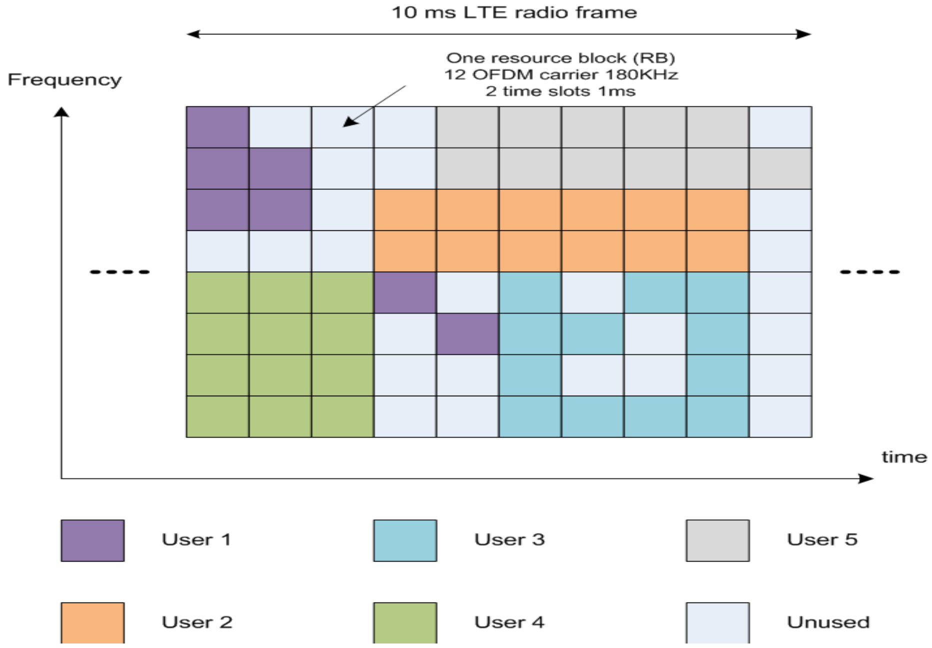


Figure 146: LTE Scheduling

Schedule :

A scheduler takes input from OAM as system configuration e.g. which scheduling algorithm is to be enable (round robin, Max C/I, Proportional Fair, Quos aware etc), consider Quos information (Which QCI, GBR/N-GBR etc.) and channel quality information (CQI, Rank, SINR etc) to make the decisions.

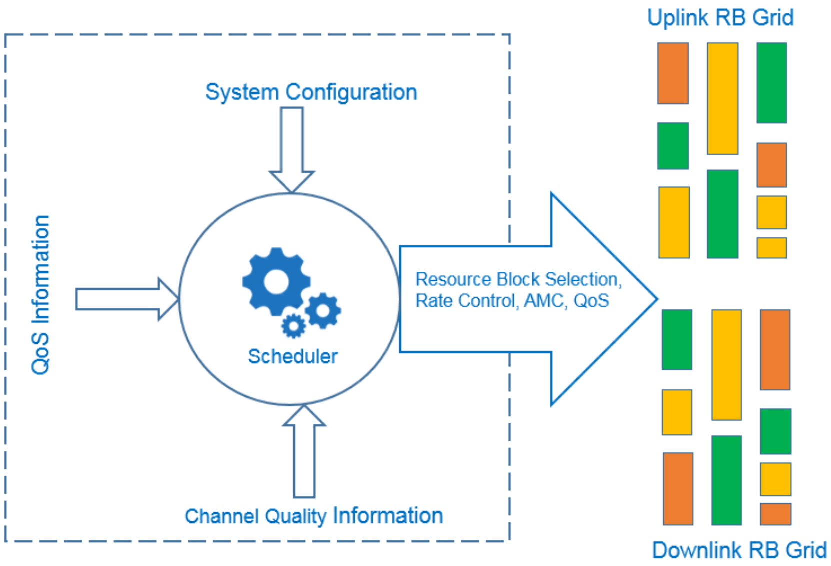


Figure 147: LTE Scheduling Process

A LTE scheduler performs following function for efficient scheduling:

- **Link Adaptation**: It selects the optimal combination of parameters such as modulation, channel Coding & transmit schemes i.e. Transmission Mode (TM1/TM2/TM3/TM4) as a function of the RF conditions.

- **Rate Control:** It is in charge of resource allocation among radio bearers of the same UE which are available at the end for DL and at the UE for UL.

- **Packet Scheduler:** It arbitrates access to air interface resources on 1ms-TTI basis amongst all active
  Users (Users in RRC Connected State).

- **Resource Assignment:** It allocates air interface resources to selected active users on per TTI basis.

- **Power Control:** Provides the desired SINR level for achieving the desired data rate, but also controls
  the interference to the neighbouring cells.

- **HARQ (ARQ + FEC):** It allows recovering from residual errors by link adaptation.

9.9 FRAME-STRUCTURE IN LTE :

In LTE, DL and UL transmissions are organized into radio frames of 10 ms each. Each frame is divided into ten equally sized subframes. The duration of each subframe is 1 ms. Moreover, each subframe is further divided into two equally sized time slots, that is, each slot is 0.5 ms.

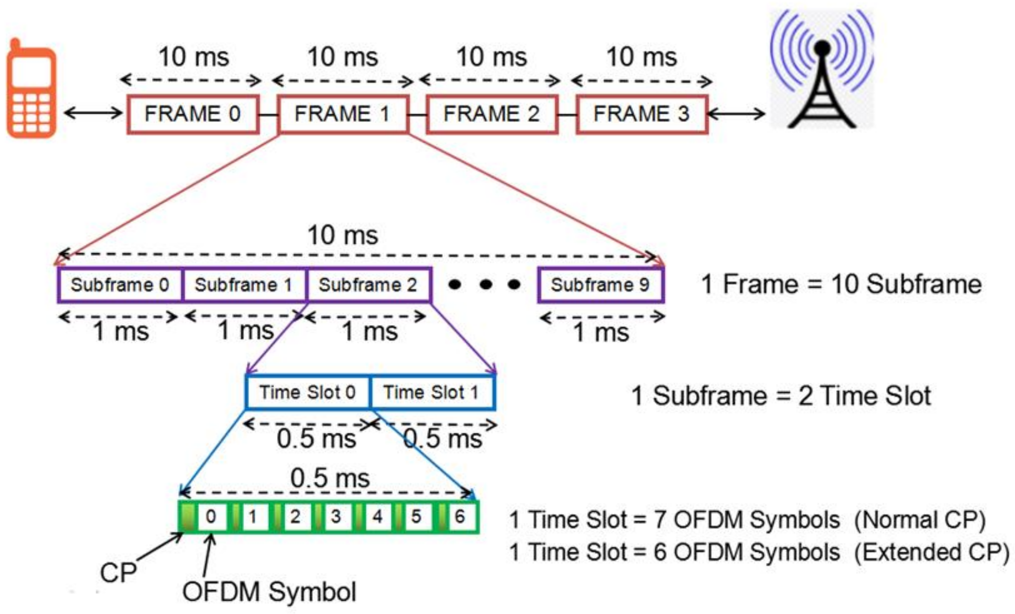


Figure 148: LTE Frame Structure

3GPP defines two types of frames based on the duplexing scheme used. These are Type 1 when FDD is used and Type 2 when TDD is used.

1. Type 1: used for the LTE FDD mode systems.
2. Type 2: used for the LTE TDD systems.

9.9.1 TYPE 1: FDD FRAME STRUCTURE

As LTE FDD is full duplex system, means both the downlink and uplink transmission happens at the same time at different frequencies.

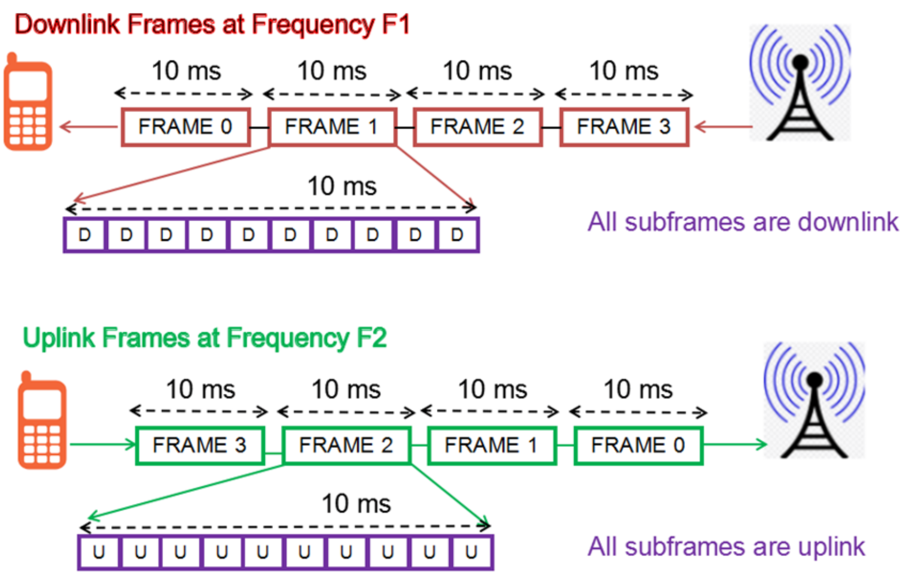


Figure 149: LTE FDD Frame Structure

9.9.2 TYPE 2: TDD FRAME STRUCTURE

In TDD, the transmission is divided into time domain, means at one moment of time either downlink subframe is transmitted or uplink. The two transmissions share the same frequency bands but are separated in time. Hence, they share the frames. In fact, every frame is divided into two halves, one for the DL transmission while the other is for the UL transmission. Nevertheless, a Type 2 frame is similar in structure to a Type 1 frame. The only difference is the existence of one or two special subframes that help switching between UL and DL transmissions.

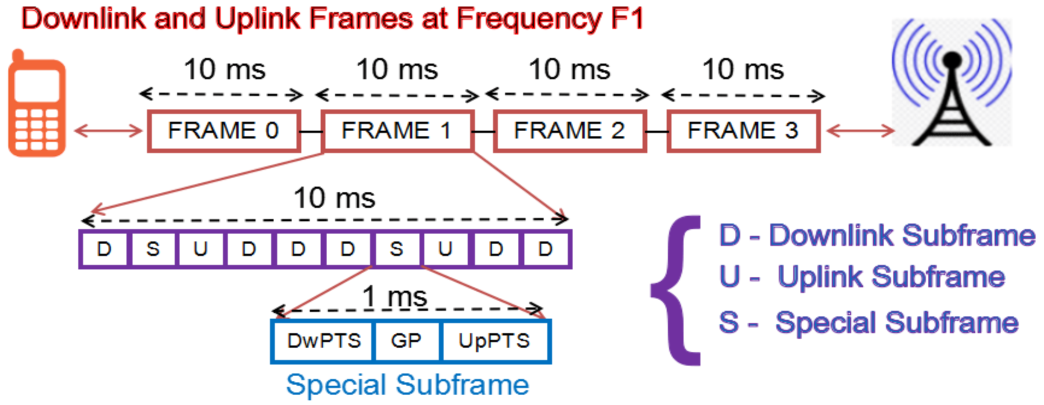


Figure 150: LTE TDD Frame Structure

As one can see in above image, one frame is divided into 10 subframes (1ms each), and that subframe can be either downlink, uplink or special subframe.

Now the question comes, who decides the sequence of these subframes. That has been defined by 3GPP with the name TDD Frame Configurations. There are fixed patterns of these configurations and network operator has to choose out of these defined patters. There are total 7 TDD configurations as shown below:

Configuration	3GPP release	Downlink to uplink switch point periodicity (ms)	Subframe number										Number of subframes / frame		
			0	1	2	3	4	5	6	7	8	9	D [DL]	U [UL]	S [SSF]
0	8	5	D	S	U	U	U	D	S	U	U	U	2	6	2
1	8	5	D	S	U	U	D	D	S	U	U	D	4	4	2
2	8	5	D	S	U	D	D	D	S	U	D	D	6	2	2
3	8	10	D	S	U	U	U	D	D	D	D	D	6	3	1
4	8	10	D	S	U	U	D	D	D	D	D	D	7	2	1
5	8	10	D	S	U	D	D	D	D	D	D	D	8	1	1
6	8	5	D	S	U	U	U	D	S	U	U	D	3	5	2

And there comes a Special subframe which comes when there is transition from downlink subframe to uplink subframe. It has three parts – DwPTS (Downlink Pilot Time Slot),GP (Guard Period) and UpPTS (Uplink Pilot Time Slot) and all of these have configurable lengths, which depends upon Special subframe configuration.

Special subframe configuration as shown below:

Configuration	3GPP release	Number of OFDM symbols / subframe		
		Dw	GP	Up
0	8	3	10	1
1	8	9	4	1
2	8	10	3	1
3	8	11	2	1
4	8	12	1	1
5	8	3	9	2
6	8	9	3	2
7	8	10	2	2
8	8	11	1	2
9	11	6	6	2

- DwPTS is considered as a "normal" DL subframe and carries reference signals and control information as well as data for those cases when sufficient duration is configured. It also carries PSS.

- GP is used to control the switching between the UL and DL transmission. Switching between transmission directions has a small hardware delay for both UE and e-NodeB and needs to be compensated by GP. GP has to be large enough to cover the propagation delay of DL interferes. Its length determines the maximum supportable cell size.

- UpPTS is primarily intended for sounding reference signals (SRS) transmission from UE. Mainly used for RACH transmission

9.10 MIMO (MULTIPLE-INPUT MULTIPLE-OUTPUT)

MIMO, Multiple Input Multiple Output is a technology that was introduced into many wireless communications systems including 4G LTE to improve the signal performance.

MIMO is being used increasingly in many high data rate technologies including Wi-Fi and other wireless and cellular technologies to provide improved levels of efficiency. Essentially MIMO employs multiple antennas on the receiver and transmitter to utilise the multi-path effects that always exist to transmit additional data, rather than causing interference.

LTE MIMO adds complexity to the system, but it is able to provide some significant improvements in performance and spectral efficiency and these more than justify its inclusion in the LTE standard.

The use of MIMO technology has been introduced successively over the different releases of the LTE standards.

MIMO has been a cornerstone of the LTE standard, but initially, in releases 8 and 9 multiple transmit antennas on the UE was not supported because in the interested of power reduction, only a single RF power amplifier was assumed to be available.

It was in Rel. 10 that a number of new schemes were introduced. Closed loop spatial multiplexing for SU-MIMO as well as multiple antennas on the UE.

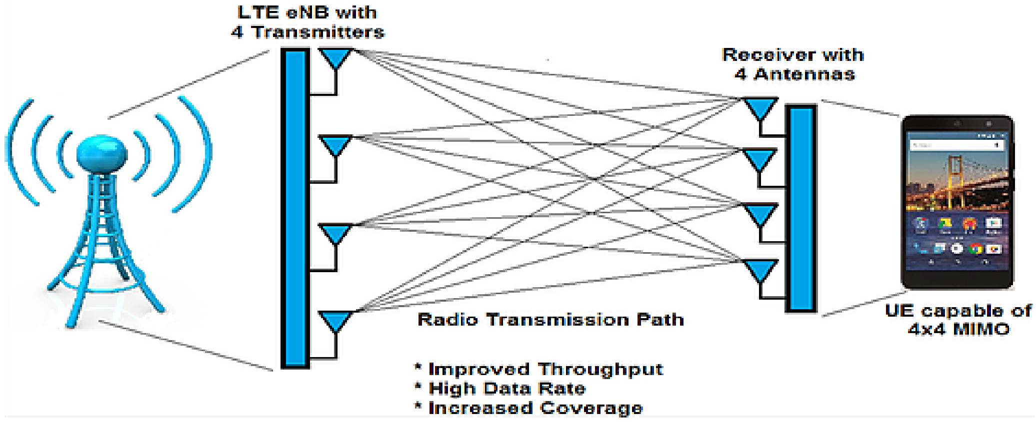


Figure 151: MIMO Concept

9.11 SUMMARY OF LTE BASIC PARAMETER

Parameters	Description
Duplexing	FDD, TDD, half-duplex FDD
Channel coding	Turbo code
Mobility	350 km/h
Channel Bandwidth (MHz)	1.4, 3, 5,10,15,20
Transmission Bandwidth Configuration NRB : (1 resource block = 180kHz in 1ms TTI)	6,15,25,50,75,100
Modulation Schemes	UL: QPSK, 16QAM, 64QAM(optional) DL: QPSK, 16QAM, 64QAM
Multiple Access Schemes	UL: SC-FDMA (Single Carrier Frequency Division Multiple Access) supports 50Mbps+ (20MHz spectrum) DL: OFDM (Orthogonal Frequency Division Multiple Access) supports 100Mbps+ (20MHz spectrum)
Multi-Antenna Technology	UL: Multi-user collaborative MIMO DL: TxAA, spatial multiplexing, CDD ,max 4x4 array
Peak data rate in LTE	UL: 75Mbps(20MHz bandwidth) DL: 150Mbps(UE Category 4, 2x2 MIMO, 20MHz bandwidth) DL: 300Mbps(UE category 5, 4x4 MIMO, 20MHz bandwidth)
MIMO	UL: 1 x 2, 1 x 4

(Multiple Input Multiple Output)	DL: 2 x 2, 4 x 2, 4 x 4
Coverage	5 - 100km with slight degradation after 30km
QoS	E2E QOS allowing prioritization of different class of service
Latency	End-user latency < 10mS

Table 10. LTE Basic Parameters

9.12 CONCLUSION

LTE Plays a important role in delivering high speed data and therefore managing its radio parameters are of prime importance. LTE radio network parameters plays an important role in network delivery.

10 KPI REPORTS FOR 2G/3G/4G

10.1 LEARNING OBJECTIVE

Telecom Service Providers use Key Performance Indicators (KPIs) to judge their network performance and evaluate the Quality of Service (QoS). Regulatory authority also uses KPIs to monitor Quality of Service of different operator. The KPIs are actually the statistical measure of network quality and encompass all the QoS parameters related to Network Accessibility, Service Accessibility, and Network Retainability.

This chapter deals with Key Performance Indicators used in GSM, UMTS, HSPA, and LTE networks to gauge or compare performance in terms of meeting mobile network's strategic and operational goals. KPIs vary between management, marketing, operations and network engineering people depending on their priorities, perspectives or performance criteria sometimes referred to as "key success indicators (KSI)".

10.2 KPI OF GSM

In GSM all the events being occurred over air interface are triggering different counters in the Base Station Controller (BSC). The KPIs are derived with the help of these counters using different formulations. RF Optimizer makes frequent use of statistical data for routine optimization activities. This raw data, which is actually based on counters, makes optimization tasks quite cumbersome as counters are in thousands. So, to make the tasks simpler, counters are appended into formulae, whereas, each formula reflects a specific performance indicator. All major performance indicators are categorized as Key Performance Indicators (KPIs). The KPIs are available in report form through OMC.

Following 2G network KPI optimizations are covered in this chapter:

- SDCCH congestion Rate
- SDCCH drop Rate
- TCH congestion/Blocking Rate
- Call Setup Success Rate
- TCH (call) drop Rate
- Handover Success Rate
- Paging Success Rate
- RACH Success Rate
- Data KPI improvement

10.2.1 SDCCH CONGESTION RATE

During Location Update and set up of MO and MT calls, MS usually seizes SDCCH to exchange signalling. SMS is also sent/delivered through SDCCH channel in idle mode. When BSC receives SDCCH request from MS, it checks SDCCH resource. If all SDCCHs are occupied at that moment, SDCCH congestion takes place. Its day average value should be ≤ 1%.

Causes and solutions:

(a) Large traffic volume exceeding network capacity

Solution: Increase cell capacity by adding more TRXs.

(b) Too many location update at LAC boundaries

Solution: (i) Adjust LAC selection and/or modify LAC boundaries

(ii) Adjust CRH (Cell Reselection Hysteresis)

(iii) Adjust parameter setting of periodic location update timer (T3212)

(c) Too much SMS traffic

Solution: (i) Implement dynamic SDCCH allocation mode

(ii) Increase SDCCH channels

(d) Hardware fault in TRX or transmission system (Abis link etc.)

Solution: (i) Replace the faulty hardware

(ii) Check and repair the transmission system

(e) Unreasonable setting of system parameters and RACH parameters

Solution:

(i) Increase RACH access threshold appropriately to cope with interference

(ii) Reduce Max Retrans appropriately

10.2.2 SDCCH DROP RATE:

When MS is already on SDCCH and in-between communication with Base station SDCCH channel got disconnected abruptly then SDCCH Drop has occurred.

Process for Optimization:

Identify the Bad performing Cells for SDCCH Drop Rate. Then follow the below mentioned Process after Analyzing detailed report

a) The Main Reasons for High SDCCH Drop Rate are improper Parameters Configuration and Bad RF & Environmental factors.
b) First Audit for any parameters related discrepancies and define as per standard parameters set.
c) Check for Neighbour Relations and correct if it is not proper.
d) Low Coverage: Through Drive Test Find out the low coverage patched and try to improve the coverage.
e) Interference: Check for interference from repeaters, Intra-Network interference due to aggressive reuse or improper Freq., Inter-Network can also be the case. Find out the actual cause and rectify it.
f) Antenna System: High VSWR due to feeders, improper antenna configuration (Ex. Sector cable Swap)
g) Check for Hardware Issue and rectify if you found any.
h) After the activity check the subsequent days report and repeat the procedure for pin pointing the actual cause.

10.3 TCH CONGESTION/BLOCKING RATE

If during call attempt MS is not getting a TCH as all the available TCH in the cell are already occupied, TCH congestion/blocking occurs. Its day average value should be ≤ 2%.

Process for Optimization:

- Check TRX/Hardware Fault in the affected cell
- Check carried Traffic (Erlang) from BH Report and increase no. of TRX in the cell (If possible). No. of TCH required according to traffic can be analyzed from Erlang-B table (please see the table)

- Implement Half Rate/AMR-Half Rate if already maximum no. of TRX is equipped.

Explore possibilities of sharing the traffic of affected cell with neighbouring cell by:

- Antenna azimuth/tilt/height adjustment of affected/ neighbouring cells.
- HO margin adjustment for making logical slope to neighbouring cells.
- Directed Retry/Traffic handover may be enabled.
- In very exceptional cases power of affected cell may be reduced.
- Additional sector may be installed in the affected BTS.
- Dual band may be implemented in the affected BTS to increase no. of TRX.
- Last option: Introduction of new BTS in the affected area

Erlang B Traffic Table

Maximum Offered Load Versus B and N
B is in %

N/B	0.01	0.05	0.1	0.5	1.0	2	5	10	15	20	30	40
1	.0001	.0005	.0010	.0050	.0101	.0204	.0526	.1111	.1765	.2500	.4286	.6667
2	.0142	.0321	.0458	.1054	.1526	.2235	.3813	.5954	.7962	1.000	1.449	2.000
3	.0868	.1517	.1938	.3490	.4555	.6022	.8994	1.271	1.603	1.930	2.633	3.480
4	.2347	.3624	.4393	.7012	.8694	1.092	1.525	2.045	2.501	2.945	3.891	5.021
5	.4520	.6486	.7621	1.132	1.361	1.657	2.219	2.881	3.454	4.010	5.189	6.596
6	.7282	.9957	1.146	1.622	1.909	2.276	2.960	3.758	4.445	5.109	6.514	8.191
7	1.054	1.392	1.579	2.158	2.501	2.935	3.738	4.666	5.461	6.230	7.856	9.800
8	1.422	1.830	2.051	2.730	3.128	3.627	4.543	5.597	6.498	7.369	9.213	11.42
9	1.826	2.302	2.558	3.333	3.783	4.345	5.370	6.546	7.551	8.522	10.58	13.05
10	2.260	2.803	3.092	3.961	4.461	5.084	6.216	7.511	8.616	9.685	11.95	14.68
11	2.722	3.329	3.651	4.610	5.160	5.842	7.076	8.487	9.691	10.86	13.33	16.31
12	3.207	3.878	4.231	5.279	5.876	6.615	7.950	9.474	10.78	12.04	14.72	17.95
13	3.713	4.447	4.831	5.964	6.607	7.402	8.835	10.47	11.87	13.22	16.11	19.60
14	4.239	5.032	5.446	6.663	7.352	8.200	9.730	11.47	12.97	14.41	17.50	21.24
15	4.781	5.634	6.077	7.376	8.108	9.010	10.63	12.48	14.07	15.61	18.90	22.89
16	5.339	6.250	6.722	8.100	8.875	9.828	11.54	13.50	15.18	16.81	20.30	24.54
17	5.911	6.878	7.378	8.834	9.652	10.66	12.46	14.52	16.29	18.01	21.70	26.19
18	6.496	7.519	8.046	9.578	10.44	11.49	13.39	15.55	17.41	19.22	23.10	27.84
19	7.093	8.170	8.724	10.33	11.23	12.33	14.32	16.58	18.53	20.42	24.51	29.50
20	7.701	8.831	9.412	11.09	12.03	13.18	15.25	17.61	19.65	21.64	25.92	31.15
21	8.319	9.501	10.11	11.86	12.84	14.04	16.19	18.65	20.77	22.85	27.33	32.81
22	8.946	10.18	10.81	12.64	13.65	14.90	17.13	19.69	21.90	24.06	28.74	34.46
23	9.583	10.87	11.52	13.42	14.47	15.76	18.08	20.74	23.03	25.28	30.15	36.12
24	10.23	11.56	12.24	14.20	15.30	16.63	19.03	21.78	24.16	26.50	31.56	37.78
25	10.88	12.26	12.97	15.00	16.13	17.51	19.99	22.83	25.30	27.72	32.97	39.44
26	11.54	12.97	13.70	15.80	16.96	18.38	20.94	23.89	26.43	28.94	34.39	41.10
27	12.21	13.69	14.44	16.60	17.80	19.27	21.90	24.94	27.57	30.16	35.80	42.76
28	12.88	14.41	15.18	17.41	18.64	20.15	22.87	26.00	28.71	31.39	37.21	44.41
29	13.56	15.13	15.93	18.22	19.49	21.04	23.83	27.05	29.85	32.61	38.63	46.07
30	14.25	15.86	16.68	19.03	20.34	21.93	24.80	28.11	31.00	33.84	40.05	47.74
31	14.94	16.60	17.44	19.85	21.19	22.83	25.77	29.17	32.14	35.07	41.46	49.40
32	15.63	17.34	18.21	20.68	22.05	23.73	26.75	30.24	33.28	36.30	42.88	51.06
33	16.34	18.09	18.97	21.51	22.91	24.63	27.72	31.30	34.43	37.52	44.30	52.72
34	17.04	18.84	19.74	22.34	23.77	25.53	28.70	32.37	35.58	38.75	45.72	54.38
35	17.75	19.59	20.52	23.17	24.64	26.44	29.68	33.43	36.72	39.99	47.14	56.04
36	18.47	20.35	21.30	24.01	25.51	27.34	30.66	34.50	37.87	41.22	48.56	57.70
37	19.19	21.11	22.08	24.85	26.38	28.25	31.64	35.57	39.02	42.45	49.98	59.37

Table 11. Erlang B Table

10.3.1 CALL SETUP SUCCESS RATE (CSSR)

CSSR indicates the probability of successful calls initiated by MS. It is an important KPI for evaluating the network performance. If CSSR is too low, the subscribers are not likely to make calls successfully. Its value should be ≥95%

CSSR value depends on

I. SDCCH Assignment success Rate
II. SDCCH Drop Rate

III. TCH Assignment Success Rate

Process of optimisation

Find out the causes of a low CSSR.(Check whether a low CSSR is caused by SDCCH/Immediate Assignment Success Rate problems, SDCCH Drop Rate problems, or TCH Assignment Success Rate problems.) and accordingly following actions may be taken

a) Minimise SDCCH Congestion (Refer SDCCH Congestion in the same chapter)
b) Minimise SCDDH Drop (Refer SDCCH Drop in the same chapter)
c) Minimise TCH Congestion (Refer TCH Congestion in the same chapter)
d) Check Hardware/Transmission Faults and Feeder Cable Swap (if any)
e) Check value of parameters like RXLEV_ACCESS_MIN/RACH Min Access Level/Tx-integer etc.

10.3.2 CALL DROP RATE

Call drops are identified through SACCH messages. A Radio Link Failure counter (RLT) value is broadcast on the BCH. The counter value may vary from network to network. At the establishment of a dedicated channel, the counter is set to the broadcast value (which will be the maximum allowable for the connection). The mobile decrements the counter by 1 for every FER (unrecoverable block of data) detected on the SACCH and increases the counter by 2 for every data block that is correctly received (up to the initial maximum value). If this counter reaches zero, a radio link failure is declared by the mobile and it returns back to the idle mode. If the counter reaches zero when the mobile is on a SDCCH then it is an SDCCH Drop. If it happens on a TCH, it is a TCH drop. Sometimes an attempted handover, which may in itself have been an attempt to prevent a drop, can result in a dropped call.

When the quality drops, a mobile is usually commanded to perform a handover. Sometimes however, when it attempts to handover, it finds that the target cell is not suitable. When this happens it jumps back to the old cell and sends a Handover Failure message to the old cell. At this stage, if the handover was attempted at the survival threshold, the call may get dropped anyway. If on the other hand the thresholds were somewhat higher, the network can attempt another handover. Call Drop Rate should be ≤ 2%.

Causes of call drop

a) Blind spot, low coverage level.
b) Unavoidable interference can be the inter network interference, interference from repeaters, or intra network interference resulting from aggressive frequency reuse.
c) Poor transmission quality and unstable transmission links over the Abis interface end other interfaces.
d) Faulty hardware/high VSWR/ Feeder Cable swap
e) Unreasonable settings of handover parameters/during inter BSC/MSC handover.
f) If pre-emption is used in MSC then lower priority MS will face call drop.
g) Unreasonable setting of radio parameters.

Process of optimisation

a) Check radio parameters. Adjust unreasonable settings of radio parameters.
b) Proper frequency plan viz. achieve minimum interference level by proper BCCH planning, HSN, MAIO planning.

c) Minimizing coverage holes by physical optimization (Orientation, Height, E.Tilt, M.Tilt).
d) Setting Radio link timeout parameter as per inter site distance viz. for rural sites RLT can be of higher value.
e) Similar for Rural site where uplink quality is poor, Rxlev Access min, Rach Access min parameter can be set appropriately. Proper balance should be maintained for this parameter else path imbalance will result and TCH drop will increase.
f) Minimize Abis and other interface fluctuation – Link stability plays very vital role.
g) Check and remove BTS/BSC hardware fault and Cable swap/high VSWR (if any).
h) During HO to neighbour cells should be having free TCH resources else call drop may increase. For this proper half rate thresholds should be defined as per traffic pattern, decongestion of these cells by capacity argument.
i) Proper Neighbour definition should be maintained – some handovers cannot be performed and thus call drops.

10.3.3 HANDOVER SUCCESS RATE (HOSR)

Handovers are meant for maintaining call continuity when subscriber crosses over from one cell to another cell. KPI to be monitored for handover performance in GSM is "Handover Success Rate".

Handover Process: The overall handover process is implemented in the MS, BSS & MSC.

- Measurement of radio subsystem downlink performance and signal strengths received from surrounding cells, is made in the MS.
- These measurements are sent to the BSS for assessment.
- The BSS measures the uplink performance for the MS being served and also assesses the signal strength of interference on its idle traffic channels.
- Initial assessment of the measurements in conjunction with defined thresholds and handover strategy may be performed in the BSS. Assessment requiring measurement results from other BSS or other information resident in the MSC, may be perform. In the MSC.
- The MS assists the handover decision process by performing certain measurements.
- When the MS is engaged in a speech conversation, a portion of the TDMA frame is idle while the rest of the frame is used for uplink (BTS receive) and downlink (BTS transmit) timeslots.
- During the idle time period of the frame, the MS changes radio channel frequency and monitors and measures the signal level of the six best neighbour cells.
- Measurements which feed the handover decision algorithm are made at both ends of the radio link.

Process of optimisation

a) Identify the Bad performing Cells for HOSR
b) Take the detailed report showing cause & target cell

c) Check whether HO parameters are defined correctly.

d) BCCH & BSIC confusion i.e. check whether same BCCH and BSIC combination is repeated in nearby cells.

e) Minimise TCH Congestion as TCH congestion in target cell results HO fail.

f) Unnecessary Handovers – more number of handovers, higher risk of facing quality problem and even in call drop

g) Missing neighbour – Best server is not in there in neighbour list

h) Feeder cable swap

i) One way neighbour handover

j) If neighbour is defined through external cells (between cells in different OMC servers e.g. 2G-3G HO/HO b/w cells of different vendors) - need to define correct CGI, BCCH, BSIC etc. in external cells.

10.3.4 PAGING SUCCESS RATE

Paging Success rate is the percentage of valid page responses received by the system.
Paging Channel Congestion should be ≤ 1%.

Process of optimisation

a) Removal of non existing Cell site database created in BSCs

b) Correct LAC dimensioning; split LA if paging discard is due to big LA.

c) Define correct channel configuration for CCCH. Avoid combining SDCCH in the BCH+CCCH timeslot.

d) Remove SDCCH congestion in network as page response is sent to network through SDCCH.

e) Eliminate Abis /A interface congestion/error.

f) Correcting the various Paging/Location Update timers/parameters in MSC/BSC/Cell.

g) Poor Paging Success rate is also observed due to poor RF environment (Site outage/ Poor Signal Level etc.).

h) Use correct paging strategy according to network size and topology.

10.3.5 RACH SUCCESS RATE

Random Access Channel (RACH) is used by the MS on the “uplink” to request for allocation of an SDCCH. This request from the MS on the uplink could either be as a page response (MS being paged by the BSS in response to an incoming call) or due to user trying to access the network to establish a call. For all services there will CH REQ (Channel Request) from MS and in the response of CH REQ if MS will get the IMM ASS CMD (Signalling Ch) Access to system is successful. Nature of this Access REQ is random so it is call Random Access Channel Request.

Process of optimisation

a) Identify the Bad performing Cells for RACH Success Rate

b) Take detailed report and analyze for no of failure of Request and failures.

c) The main reasons for bad RACH success rate could be access from very distant place with very low coverage; Parameters Configuration discrepancies.

d) First Check for Parameters Configuration discrepancies and correct as per standard parameter set.

e) **The main parameters to be verified are**:

I. "MS MAX Retrans" allows the MS to retransmit again for AGCH by not incrementing the RACH access failure counter. It can set depending upon Traffic and Clutter.

II. "Tx-Interger" will reduce the RACH collision and can improve RACH success rate.

III. "T3122" waiting time for next network access.

IV. "RACH Min.Access Level (dbm)" very important parameter for low coverage rural areas.

V. "CCCH conf" & "BS_AG_BLKS_RES" check properly defined or not? Because if you have overload with AGCH "IMM ASS" can't be send in the response of CH REQ.

f) Check for Hardware Issues (Ex. BTS sensitivity has very crucial role to play here)

g) Check for Uplink Interference and quality.

h) Check for UL-DL imbalance and correct if any problem.

10.4 DATA KPI IMPROVEMENT

10.4.1 TBF SUCCESS RATE

Temporary Block Flow (TBF) is a physical connection used by the two Radio Resource entities to support the unidirectional transfer of PDUs on packet data physical channels. The TBF is allocated radio resource on one or more PDCHs and comprises a number of RLC/MAC blocks carrying one or more LLC PDU. TBF Success Rate is when during a data session, TBFs are successfully established on UL and DL.

Process of optimisation

a) Identify the Bad performing Cells for TBF Success Rate.

b) Identify the bifurcation of Poor TBF Success Rate: whether UL or DL is poor or it is poor in both directions.

c) Take the detailed report showing (Ex. Total TBF Requests, Total TBF Success, Failure reasons)

d) Identify the failure reasons after analyzing detailed report and follow the below mentioned process.

Failure is mainly due to TBF Congestion or MS No response.

10.4.2 TBF CONGESTION:

i. Check the Static and Dynamic PDCH definition from BSC Configuration data) If you find Zero Static or Dynamic PDCH, define the same.

ii. If PDCH definition is sufficient as per the guidelines, then check whether the TBF requests are high. If requests are high, then we need to define more PDCHs in the cell. But before defining more PDCHs, check whether the Voice Utilization is not high and there is no TCH Congestion in the cell.

iii. Check Hardware/TRX alarms; Resolve if find any.

iv. Audit for any parameters related discrepancies and define as per standard parameters set.

MS No Response: RF and Environmental Factors:

i. Low Coverage Areas (Try to reduce low coverage patches with physical optimization; New sites)
ii. Interference/ Bad quality/ UL-DL Imbalance;
iii. Check the states for TRx on which PDCH is configured can be issue of TRx also; Change TRx if you found random behavior of TRx.

10.4.3 AVERAGE GPRS/EDGE RLC THROUGHPUT

Throughput is the amount of data uploaded/downloaded per unit of time.

Process of optimisation

a) Identify the Bad performing Cells for Poor GPRS/EDGE Throughput.
b) Identify the bifurcation of Poor Throughput: whether UL or DL is poor or it is poor in both directions.
c) Take the detailed report showing (Ex. Total TBF Requests, Coding Scheme Utilization)
d) Identify the cells after analyzing detailed report and follow the below mentioned process.
e) Take the configuration dump of the poor cells:
   I. Check The Static and Dynamic PDCH definition from BSC Configuration data)
   II. If you find Zero Static or Dynamic PDCH, define the same.
   III. If PDCH definition is sufficient as per the guidelines, then check whether the TBF requests are high. If requests are high, then we need to define more PDCHs in the cell. But before defining more PDCHs, check whether the Voice Utilization is not high and there is no TCH Congestion in the cell.
   IV. Check whether there are enough Idle TS defined at the site. If not, definition to be done.
f) Check whether it is due to poor radio conditions/interference; check C/I. Perform a drive test to analyze the cell in more detail.
g) Check Gb Congestion/Utilization at the BSC/PCU.
h) Check Hardware/TRX alarms; Resolve if find any.
i) Audit for any parameters related discrepancies and define as per standard parameters set.

10.4.4 DOWNLINK MULTI SLOT ASSIGNMENT SUCCESS RATE

User timeslot request based on traffic types and MS multi-timeslot capability and the actual timeslot allocated by the system which can also be termed as Downlink Multislot Assignment Success rate.

Process of optimisation

a) Identify the Bad performing Cells for Poor Poor DL Multislot Assignment.
b) Take the detailed report showing (Ex. Total TBF Requests, Failure in terms of TS requests)
c) Identify the cells after analyzing detailed report and follow the below mentioned process.
d) Take the configuration dump of the poor cells:
   I. Check The Static and Dynamic PDCH definition from BSC Configuration data)
   II. If you find Zero Static or Dynamic PDCH, define the same.
   III. If PDCH definition is sufficient as per the guidelines, then check whether the TBF requests are high. If requests are high, then we need to define more PDCHs in the cell.

But before defining more PDCHs, check whether the Voice Utilization is not high and there is no TCH Congestion in the cell.

IV. Check the multiplexing thresholds and upgrade/downgrade reports.

e) Check whether it is due to poor radio conditions/interference; check C/I. Perform a drive test to analyze the cell in more detail.
f) Check Gb Congestion/Utilization at the BSC/PCU.
g) Check Hardware/TRX alarms; Resolve if find any.
h) Audit for any parameters related discrepancies and define as per standard parameters set.

10.5 3G UMTS KPI

10.5.1 3G KPIS ARCHITECTURE

Figure 152: 3G KPI Structure

RAN KPI Class :

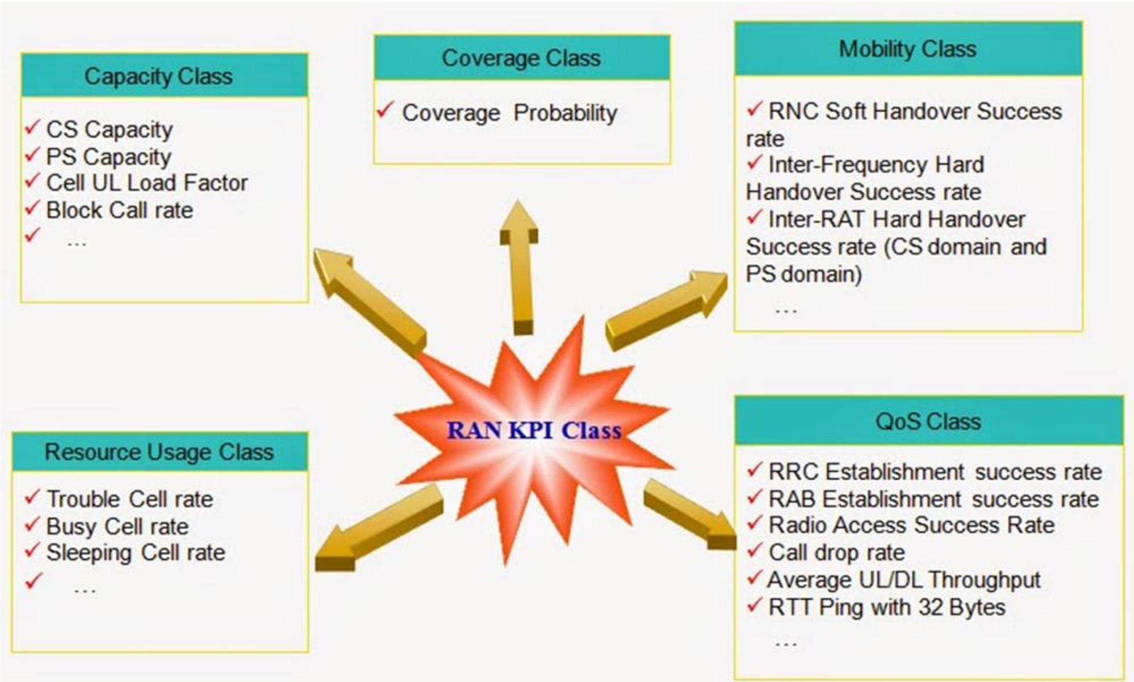


Figure 153: 3G KPI Class

10.5.2 RAB ESTABLISHMENT SUCCESS RATE

This KPI describes the ratio of all successful RAB establishments to RAB establishment attempts for UTRAN network and is used to evaluate service accessibility across UTRAN. This KPI is obtained by the number of all successful RAB establishments divided by the total number of attempted RAB establishments.

RAB Assignment is the last step of the service connection. If it is successfully assigned, the connection to the user plane is successfully setup.

RAB setup procedure is the process that establishes the higher-layer connection between UE and CN that is used to transfer the user data only (not signalling). When the RNC receives the RAB ASSIGNMENT REQUEST allocates the necessary resources for the requested service, after successful call admission. Resources include Codes, CE, Power, IUB bandwidth. Then the RB is setup which is the UTRAN part of the RAB.

Upon successful completion of the RB setup, the RNC responds to the CN with the RAB ASSIGNMET RESPOND message.

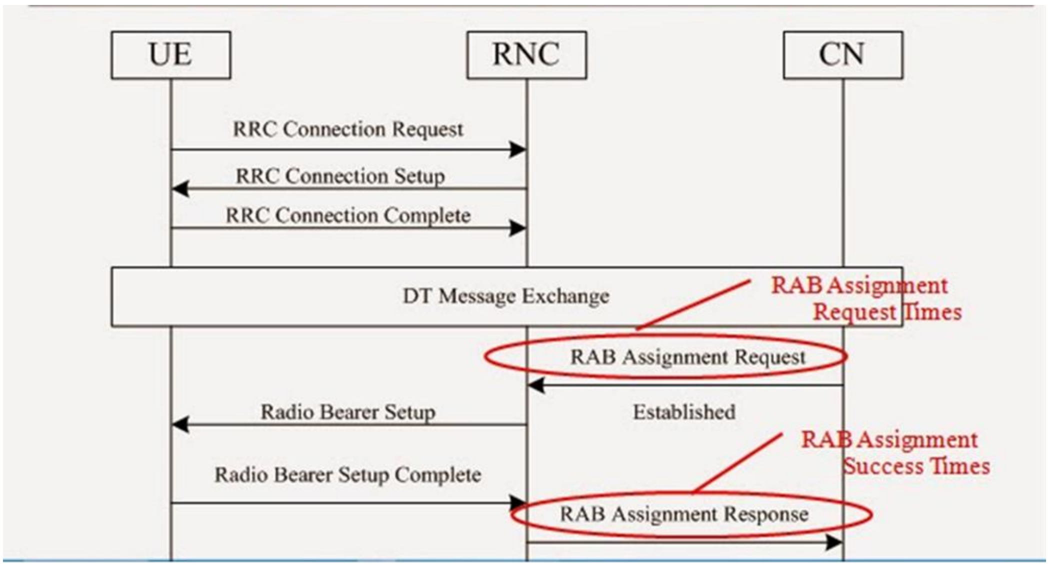


Figure 154: RAB Establishment

10.5.3 RRC CONNECTION ESTABLISHMENT SUCCESS RATE

This KPI describes the ratio of all successful RRC establishments to RRC establishment attempts for UTRAN network, and is used to evaluate UTRAN and RNC or cell admission capacity for UE and/or system load. This KPI is obtained by the number of all successful RRC establishments divided by the total number of attempted RRC establishments.

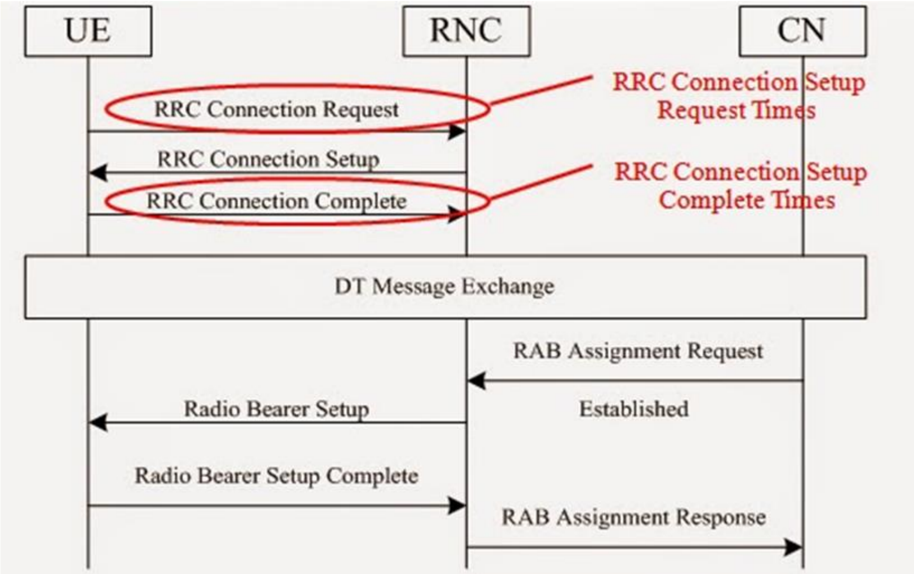


Figure 155: RRC Establishment

RRC setup procedure is the process that establishes the L3connection between UE and RNC that is used for signalling traffic only. After RNC receives the RRC CONNECTION REQUEST, processes it and allocates relevant resources on L1, L2 and L3 ofthe air interface for this signalling connection. The RNC notifies the UE for the prepared configuration with the RRC CONNECTION SETUP message. The UE reports its capabilities to the RNC with the RRCCONNECTION SETUP COMPLETE

10.5.4 CALL SETUP SUCCESS RATE/ SERVICE ACCESS SUCCESS RATE:

This KPI describes the ratio of successful call establishments. It is based on the Successful RRC Connection Establishment Rate for callsetup purposes and the RAB Establishment Success Rate for all RAB types. Both KPIs are multiplied.

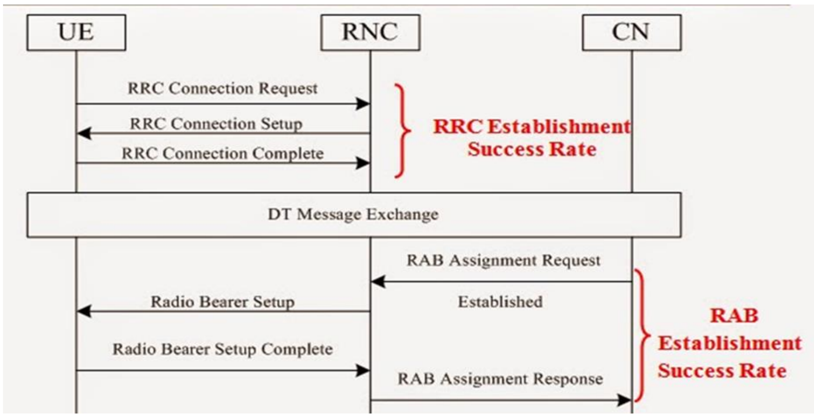


Figure 156: RAB & RRC Establishment

The Call Set up Success Rate (CSSR) is one of the most important Key Performance Indicators (KPIs) used by all mobile operators. The CSSR in general is a term in telecommunications denoting the fraction of the attempts to make a call which result in a connection to the dialled number.

10.5.5 UTRAN SERVICE ACCESS SUCCESS RATE

UTRAN service access success rate for idle mode UEs describes the ratio of all successful UTRAN access to UTRAN access attempts for UTRAN network and is used to evaluate service accessibility provided by UTRAN. Successful RRC set up repetition and/or cell re-selections during RRC setup should be excluded, namely only service related RRC setup should be considered.

This KPI is obtained by the Successful RRC Connection Establishment Rate for UTRAN access purposes multiplied by the RAB Establishment Success Rate for all RAB types.

10.5.6 UMTS PDP CONTEXT ACTIVATION SUCCESS RATE

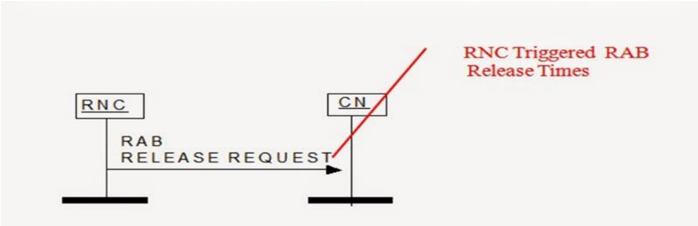
This KPI describes the ratio of the number of successfully performed PDP context activation procedures to the number of attempted PDP context activation procedures for UMTS PS core network and is used to evaluate service accessibility provided by UMTS and network performance to provide GPRS.

This KPI is obtained by successful PDP context activation procedures initiated by MS divided by attempted PDP context activation procedures initiated by MS.

10.5.7 CALL DROP RATE

It is the most important indicators of the customers experience. It reflects the retainability of the network.

The Call Drop Rate (CDR) is the fraction of the telephone calls which, due to technical reasons, were cut off before the speaking parties had finished their conversation and before one of them had hung up (dropped calls), this fraction is usually measured as a percentage of all calls. This KPI describes the ratio of RAB release requests related to the number of successful RAB establishment (per CS/PS domain).



Drops are derived from "IU Release Request" and "RAB Release Request "messages sent from UTRAN to the CN as calculated by the formula:

Call Drop Rate

＝（RNC Triggered CS RAB Release Number
＋RNC Triggered PS RAB Release Number）
/(Total RAB Release number for CS
＋Total RAB Release number for PS)
×100%

10.5.8 CALL BLOCKING RATE :

This KPI indicate rate of blocked calls due to resource shortage. This KPI partially reflects the degree of congestion in the cell.

Call Blocking Rate

＝The number of blocked calls
/The number of call admission requests Times×100%

10.6 MOBILITY KPI

10.6.1 SOFT HANDOVER SUCCESS RATE

This Indicate Radio link addition success rate. This KPI describes the ratio of number of successful radio link additions to the total number of radio link addition attempts.

This KPI is obtained by the number of successful radio link additions divided by the total number of radio link.

Soft Handover Success Rate

＝（Soft Handover Attempted Times
—Soft Handover Failure Times）
/Soft Handover Attempted Times×100%

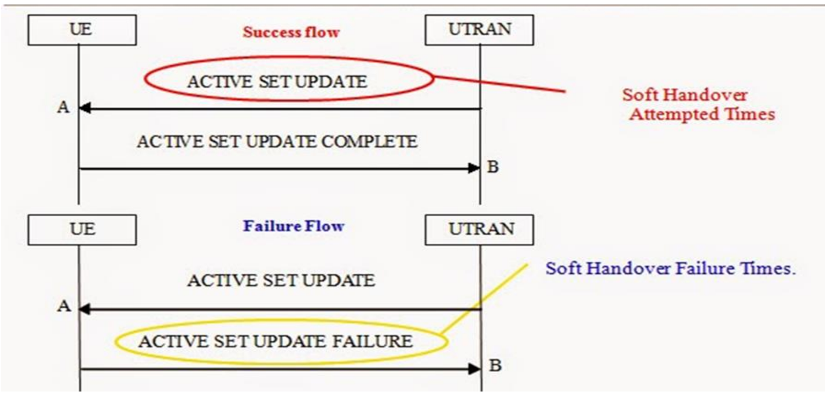


Figure 157: Soft Handover

This indicator reflects the soft handover mobility in the RNC control area.

10.6.2 OUTGOING INTER RAT HANDOVER SUCCESS RATE (CS)

This KPI describes the ratio of number of successful inter RAT handover to the total number of the attempted inter RAT handover from UMTS to GSM for CS domain.

This KPI is obtained by the number of successful inter RAT handover divided by the total number of the attempted inter RAT handover from UMTS to GSM for CS domain.

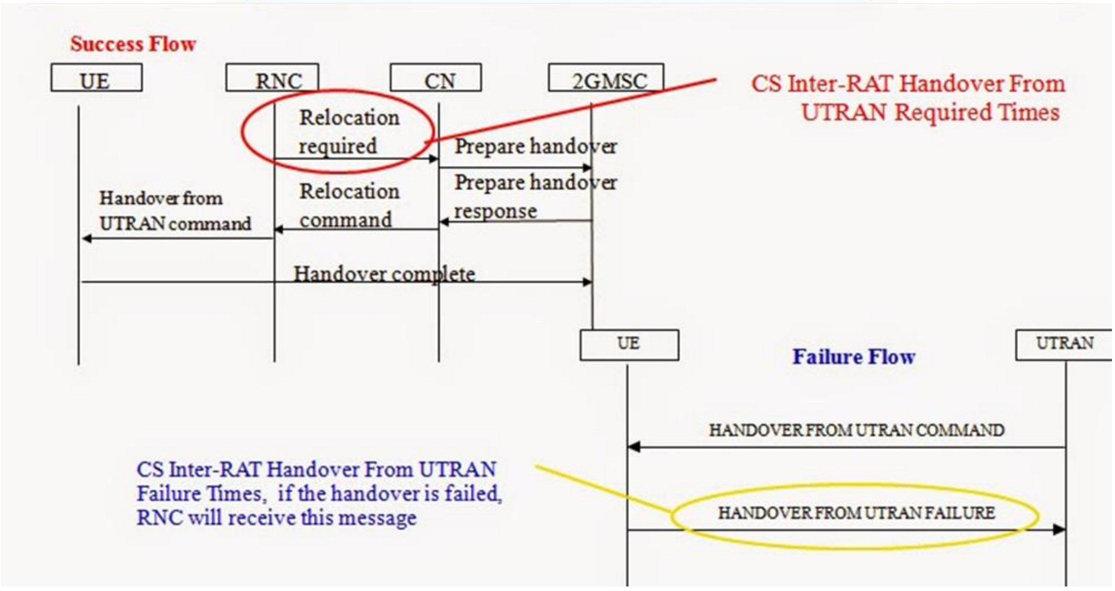


Figure 158: CS Outgoing Inter RAT Handover (UMTS to GSM)

10.6.3 OUTGOING INTER RAT HANDOVER SUCCESS RATE (PS)

This KPI describes the ratio of number of successful inter RAT handover to the total number of the attempted inter RAT handover from UMTS to GSM for PS domain.

PS Inter-RAT Handover Success Rate（UMTS->GPRS）

＝1－PS Inter-RAT Handover From UTRAN Failure Times /PS Inter-RAT Handover From UTRAN Required Times×100%

This KPI is obtained by the number of successful inter RAT handover divided by the total number of the attempted inter RAT handover from UMTS to GSM/GPRS for PS domain respectively.

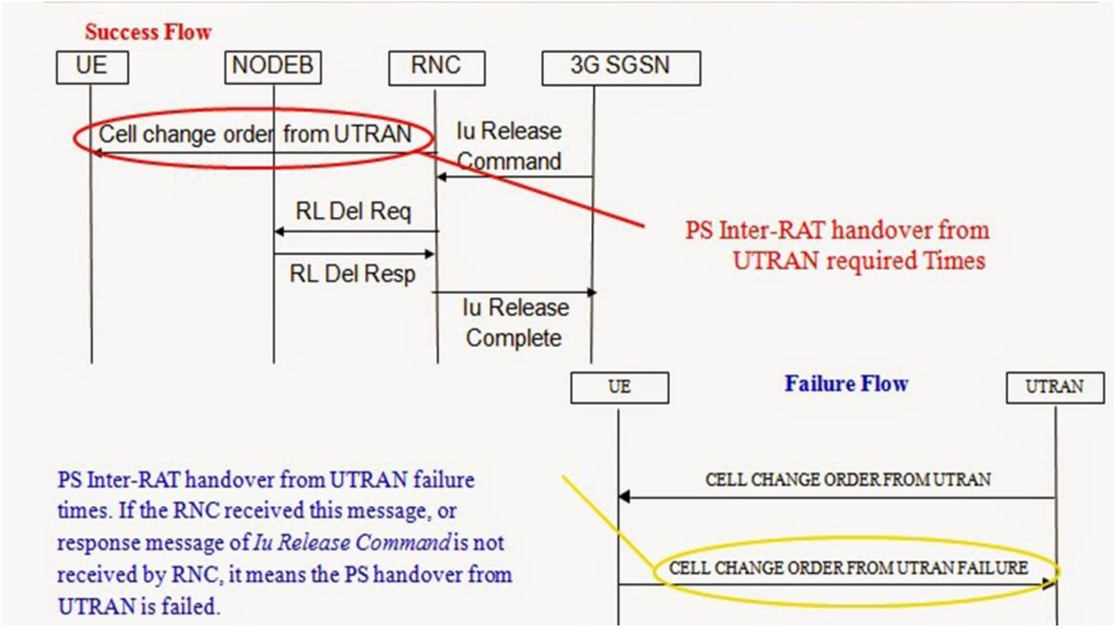


Figure 159: PS Outgoing Inter RAT Handover (UMTS to GSM)

10.6.4 INTER RAT INCOMING HANDOVER (PS)

This indicates the Inter-RAT handover mobility, the handover is from GPRS system to UMTS system.

PS Inter-RAT Handover to UTRAN Success rate（GPRS->UMTS）

＝PS Inter-RAT Handover to UTRAN Success Times /PS Inter-RAT Handover to UTRAN Attempted Times×100%

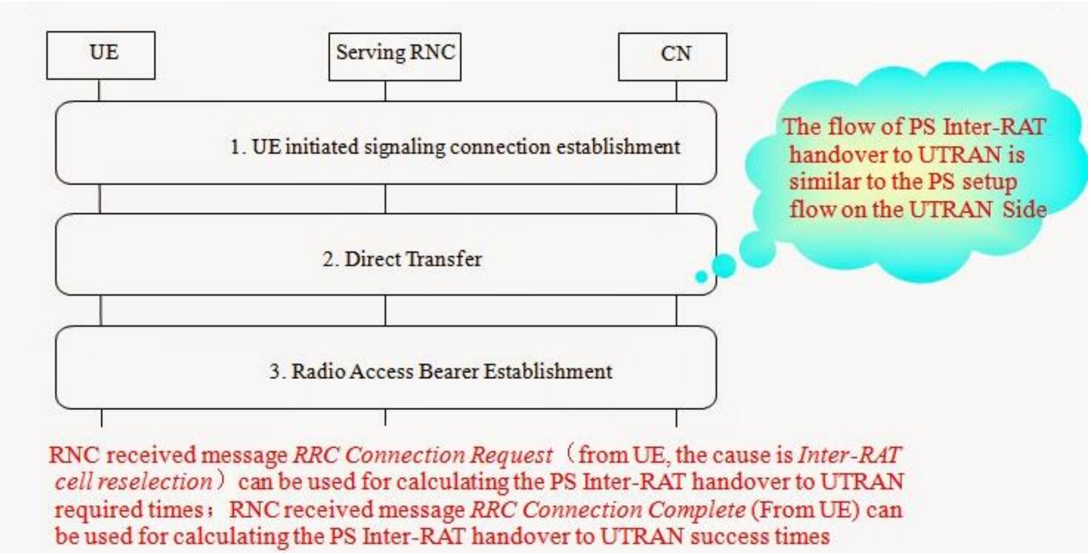
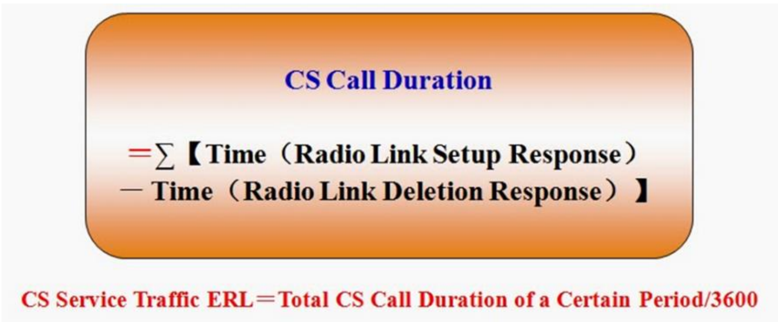


Figure 160: Incoming Inter RAT Handover (GPRS to UMTS)

10.7 UTILISATION KPI

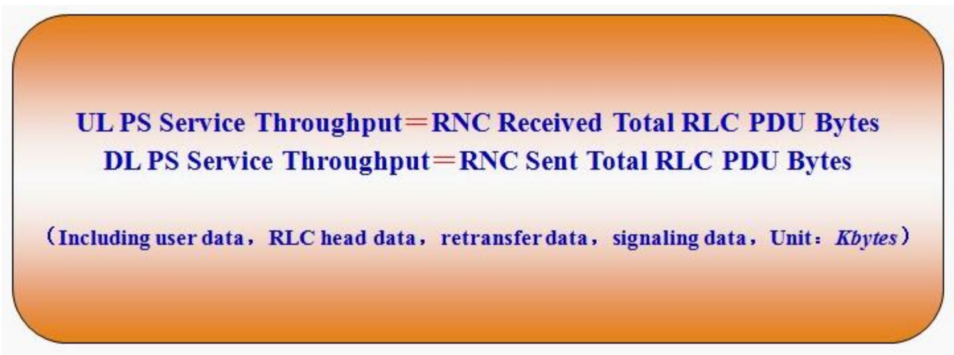
10.7.1 CS SERVICE TRAFFIC ERLANG

This indicator reflects the traffic Erlang of CS conversation service.



10.7.2 PS SERVICE THROUGHPUT

This indicator reflects total throughput of PS service.



10.7.3 UTRAN CELL AVAILABILITY.

A KPI that shows Availability of UTRAN Cell.Percentage of time that the cell is considered available.

10.8 4G LTE KPI

As specified in the 3GPP TS 32.451 document, there are several types of KPI parameters that are integral to any LTE network, depending on the target they measure:

- Accessibility
- Retainability
- Integrity
- Availability
- Mobility

Others can be added depending on the the network's need, such as:

- Utilization
- Traffic
- Latency

Accessibility

Accessibility is a measurement that allows operators to know information related to the mobile services accessibility for the subscriber. The measurement is performed through E-UTRAN's E-RAB service.

Retainability

Retainability measures how many times a service was interrupted or dropped during use, thus preventing the subscriber to benefit from it or making it difficult for the operator to charge for it. Therefore, a high retainability is very important from a business stand point.The measurement is performed through E-UTRAN's E-RAB service.

I**ntegrity**

Integrity measures the high or low quality of a service while the subscriber is using it.The measurement is performed through E-UTRAN's delivery of IP packets.

Availabilit*y*

Availability measures a service's availability for the subscriber. The measurement is performed by determining the percentage of time that the service was available for the subscribers served by a specific cell. The measurement can also aggregate data from more cells or from the whole network.

Mobility

Mobility measures how many times a service was interrupted or dropped during a subscriber's handover or mobility from on cell to another. The measurement is performed in the E-UTRAN and will include Intra E-UTRAN and Inter RAT handovers.

KPIs for LTE RAN (Radio Access Network)

LTE KPI	INDICATORS
Accessibility KPI	• RRC setup success rate • ERAB setup success rate • Call Setup Success Rate Are used to measure properly of whether services requested by users can be accessed in given condition, also refers to the quality of being available when users needed. eg. user request to access the network, access the voice call, data call, ...
Retainability KPI	• Call drop rate • Service Call drop rate *Are used to measure how the network keep user's possession or able to hold and provide the services for the users*
Mobility KPI	• Intra-Frequency Handover Out Success Rate • Inter-Frequency Handover Out Success Rate • Inter-RAT Handover Out Success Rate (LTE to WCDMA) *Are used to measure the performance of network which can handle the movement of users and still retain the service for the user, such as handover,...*
Integrity KPI	• E-UTRAN IP Throughput • IP Throughput in DL • E-UTRAN IP Latency *Are used to measure the character or honesty of network to its user, such as what is the throughput, latency which users were served.*
Availability KPI	• E-UTRAN Cell Availability Partial cell availability (node restarts excluded) *Are used to measure how the network keep user's possession or able to hold and provide the services for the users*
Utilization KPI	• Mean Active Dedicated EPS Bearer Utilization *Are used to measure the utilization of network, whether the network capacity is reached its resource.*

Table 12. LTE KPI

10.8.1 RRC SETUP SUCCESS RATE

RRC setup success rate is calculated based on the counter at the e-NodeB when the e-NodeB received the RRC connection request from UE. Number of RRC connection attempt is collected by the e-NodeB to the measurement at point A, and the number of successful RRC connection calculated at point C. Here's an illustration:

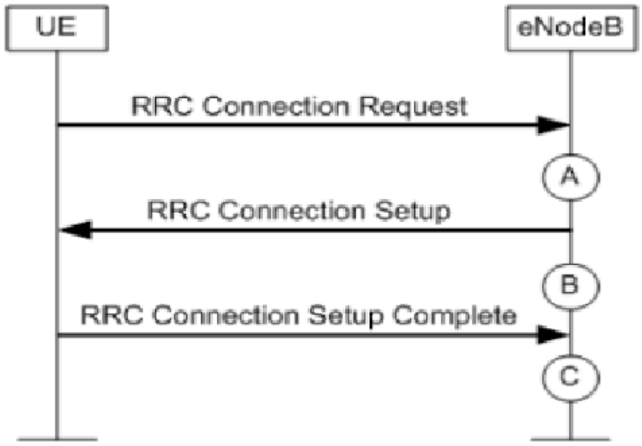


Figure 161: RRC Setup

KPI Name	RRC Setup Success Rate (Service)
Measurement Scope	Cell or radio network
Formula	$RRCS\_SR_{service} = \frac{RRCConnectionSuccess_{service}}{RRCConnectionAttempt_{service}} \times 100\%$
Unit	Percentage (%)

Table 13. RRC Setup Success Rate

10.8.2 ERAB SETUP SUCCESS RATE

ERAB setup success rate KPI shows the probability of success ERAB to access all services including VoIP in a cell or radio network. KPI is calculated based counter ERAB connection setup attempt (point A) and successful ERAB setup (point B). The explanation is as given in the following illustration:

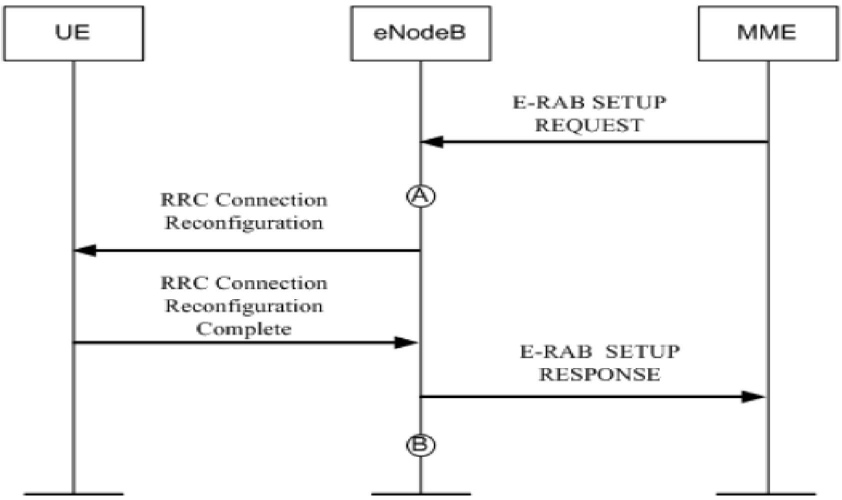


Figure 162: ERAB Setup

KPI Name	E-RAB Setup Success Rate (All)
Measurement Scope	Cell or radio network
Formula	$ERABS\_SR = \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$
Unit	Percentage (%)

10.8.3 CALL SETUP SUCCESS RATE

Call Setup Success Rate KPI call setup indicates the probability of success for all service on the cell or radio network. KPI is calculated by multiplying the RRC setup success rate KPI, S1 signalling connection success rate KPI, and ERAB success rate KPI. The table below describes the definition Call Setup Success Rate:

KPI Name	Call Setup Success Rate
Measurement Scope	Cell or radio network
Formula	$CSSR = \frac{RRCConnectionSuccess_{service}}{RRCConnectionAttempt_{service}} \times \frac{S1SIGConnectionEstablishSuccess}{S1SIGConnectionEstablishAttempt} \times \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$
Unit	Percentage (%)

Table 14. CSSR

10.8.4 CALL DROP

VoIP call drop arise when VoIP ERAB release is not normal. Each ERAB associated with QoS information. Here's an illustration of two procedures being done to release ERAB namely: ERAB release indication and the UE context release request:

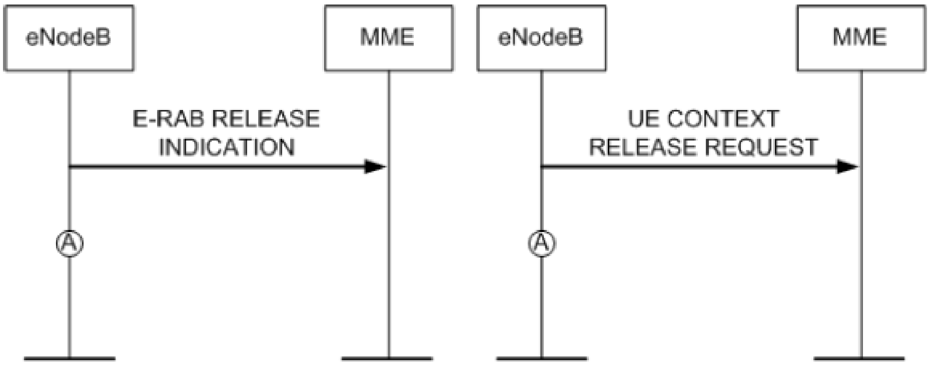


Figure 163: ERAB Setup

KPI Name	Service Drop Rate (All)
Measurement Scope	Cell or radio network
Formula	$Service\_CDR = \frac{ERABAbnormalRelease}{ERABRelease} \times 100\%$
Unit	Percentage (%)

10.8.5 INTRA-FREQUENCY HANDOVER OUT SUCCESS RATE

Intra-Frequency Handover Success Rate Our KPI shows intra-frequency handover success rate of local cell or radio network to the intra-frequency neighboring cell or radio network. Intra-frequency HO included in a single cell e-NodeB or different e-NodeB. Intra-frequency HO scenario shown in the figure below:

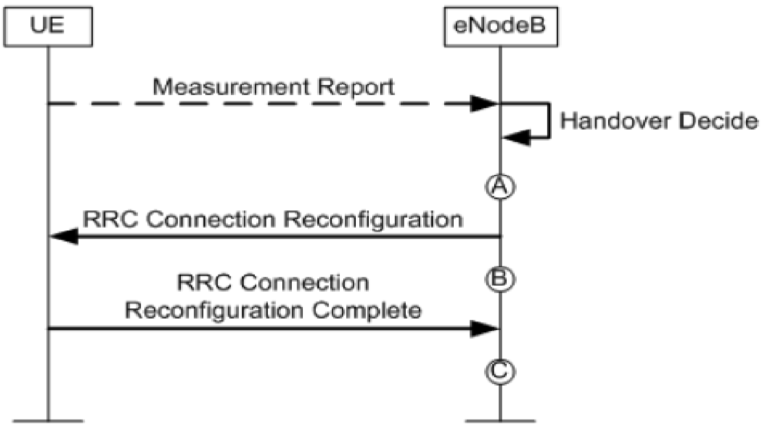


Figure 164: Intra-Frequency Handover Out

No attempt HO calculations at point B. When E-NodeB sending RRC connection reconfiguration message to the EU, he will do the handover. E-NodeB will count the number of times the HO attempt at the source cell. HO calculation of success is at point C. The HO E-NodeB count the number of the source cell when E-NodeB receive RRC connection reconfiguration message complete of the EU. Here's a scenario intra-frequency handover inter E-NodeB

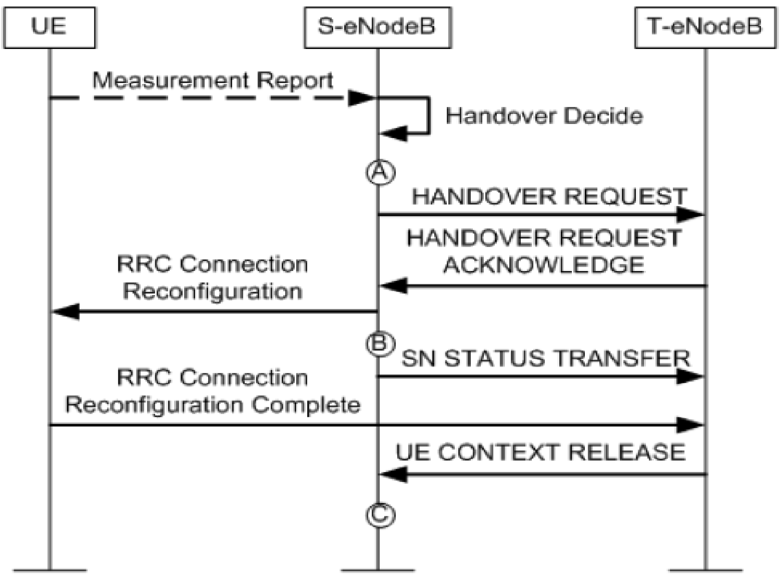


Figure 165: Intra-Frequency Handover inter E-NodeB

Handover attempt occurs at point B, when the source E-NodeB (S-e-NodeB) sends RRC connection reconfiguration message to the UE. He decided to conduct inter E-NodeB HO. in this KPI, the source and the target cell work on the same frequency. The number of the attempt HO calculated at the source cell. The number of successful HO occurs at point C. During HO, HO amount which success is measured in the cell sauce. This measurement appears typing S-e-NodeB received a UE context release message from the target eNode B (T-e-NodeB), or the UE context release command from the MME, which shows that the UE-e-NodeB T has successfully attach at the T-e-NodeB. The following scenarios illustrate intra frequency B HO - inter E-NodeB:

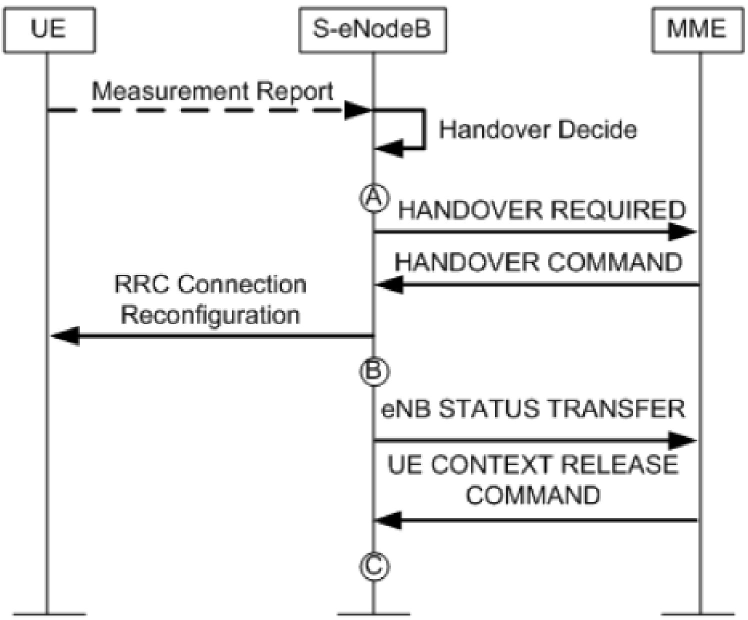


Figure 166: Intra-Frequency Handover inter E-NodeB

Following the definition of Intra Frequency Out Handover Success Rate KPI:

KPI Name	Intra-Frequency Handover Out Success Rate
Measurement Scope	Cell or radio network
Formula	$IntraFreqHOOut\_SR = \frac{IntraFreqHOOutSuccess}{IntraFreqHOOutAttempt} \times 100\%$
Unit	Percentage (%)

10.8.6 INTER-RAT HANDOVER OUT SUCCESS RATE (LTE TO WCDMA)

Inter RAT Handover Out Success rate shows the success rate KPI HO from LTE cell or radio network to a WCDMA cell.
Here's a scenario out inter RAT handover success rate:

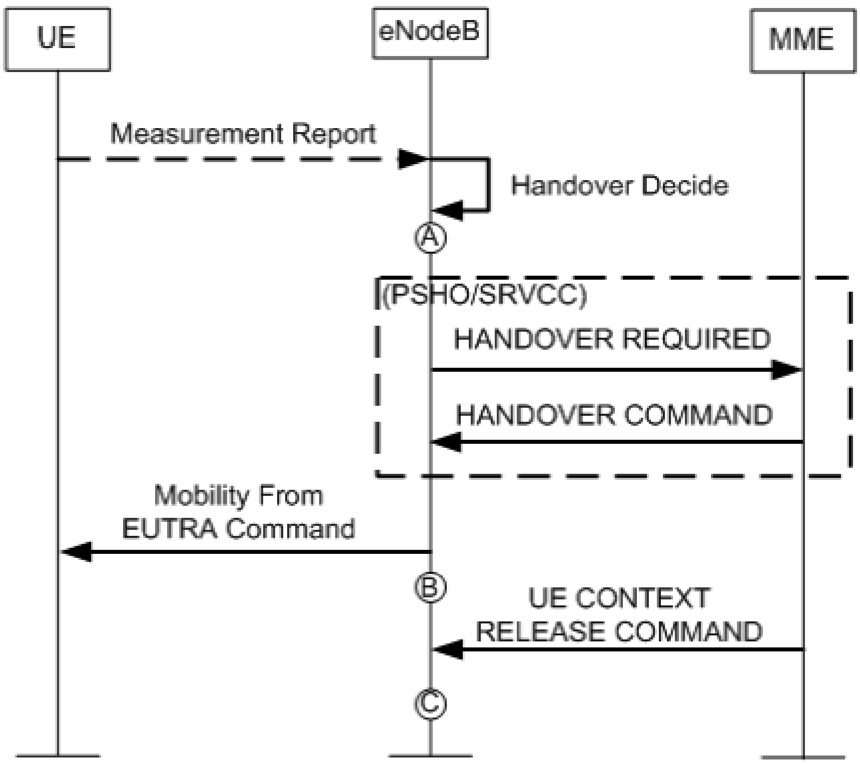


Figure 167: out inter RAT handover

Inter RAT handover success rate out

KPI Name	Inter-RAT Handover Out Success Rate (LTE to WCDMA)
Measurement Scope	Cell or radio network
Formula	$IRATHO\_L2W\_SR = \frac{IRATHO\_L2W\_Success}{IRATHO\_L2W\_Attempt} \times 100\%$
Unit	Percentage (%)

10.8.7 E-UTRAN IP THROUGHPUT

A KPI that shows how E-UTRAN impacts the service quality provided to an end-user. Payload data volume on IP level per elapsed time unit on the Uu interface. IP Throughput for a single QCI:

$$Downlink \quad Thp_{QCI=x} = DRB.IPThpDl_{QCI=x}$$

$$Uplink \quad Thp_{QCI=x} = DRB.IPThpUl_{QCI=x}$$

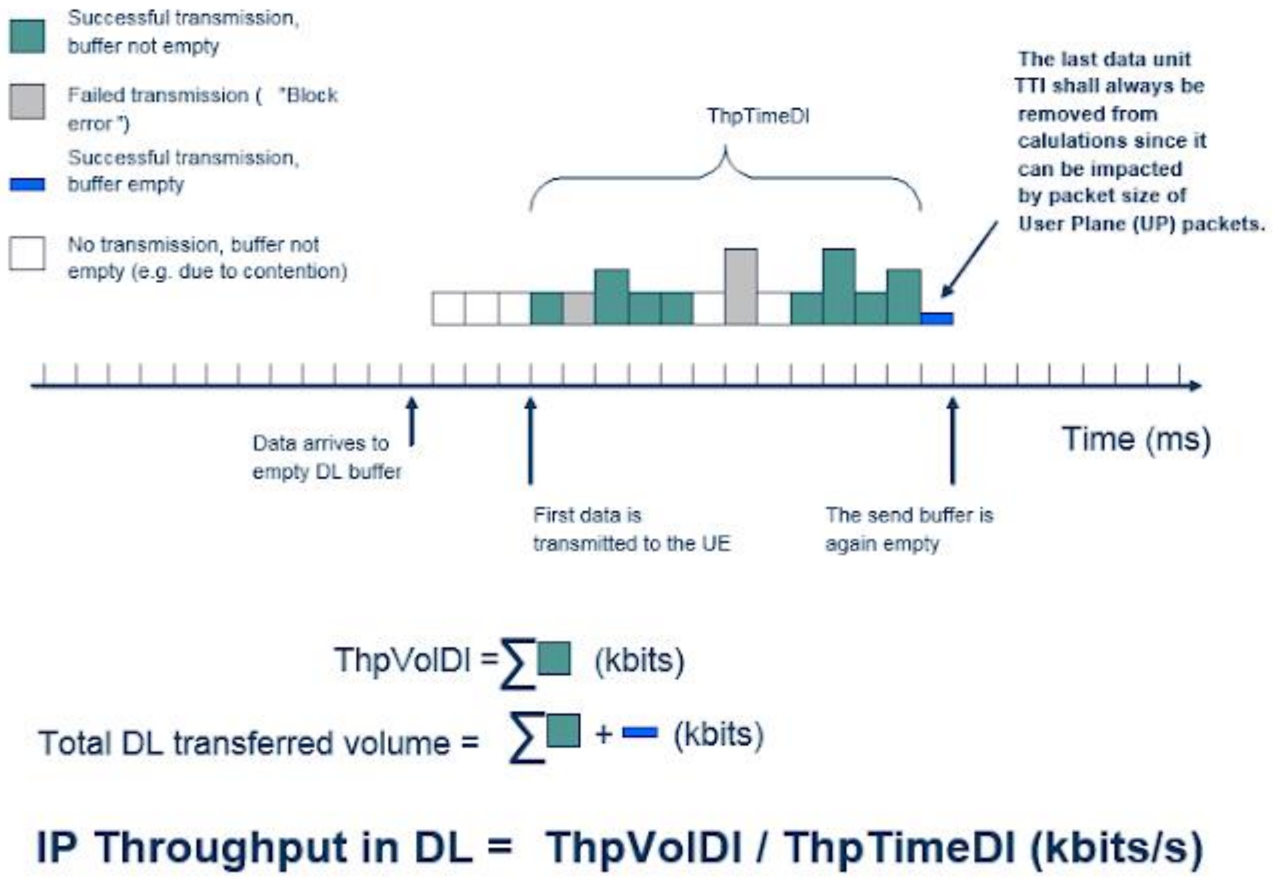
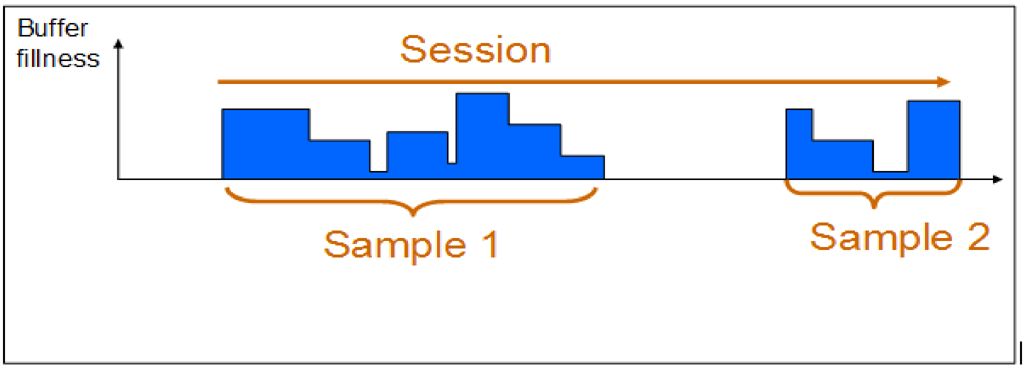


Figure 168: E-UTRAN IP Throughput

To achieve a throughput measurement that is independent of bursty traffic pattern, it is important to make sure that idle gaps between incoming data is not included in the measurements. That shall be done as considering each burst of data as one sample. ThpVolDl is the volume on IP level and the ThpTimeDl is the time elapsed on Uu for transmission of the volume included in ThpVolDl.



$$IP\ Throughput\ DL = \frac{\sum_{Samples} \mathrm{ThpVolDl}}{\sum_{Samples} \mathrm{ThpTimeDl}}$$

Figure 169: E-UTRAN IP Throughput

10.8.8 E-UTRAN IP LATENCY

A measurement that shows how E-UTRAN impacts on the delay experienced by an end-user. Time from reception of IP packet to transmission of first packet over the Uu. To achieve a delay measurement that is independent of IP data block size only the first packet sent to Uu is measured. To find the delay for a certain packet size the IP Throughput measure can be used together with IP Latency (after the first block on the Uu, the remaining time of the packet can be calculated with the IP Throughput measure).

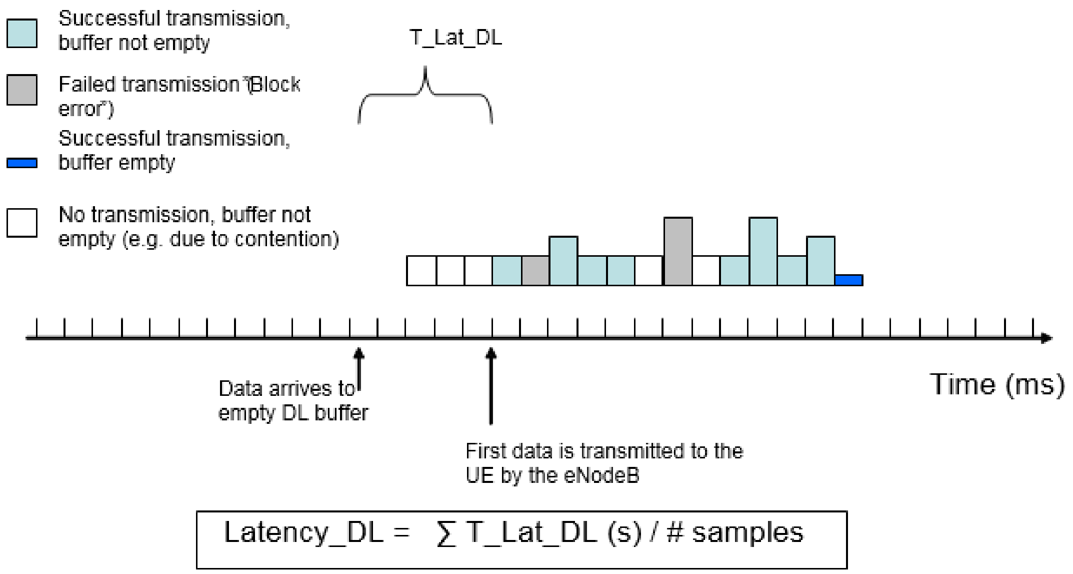


Figure 170: E-UTRAN IP Latency

T_Lat is defined as the time between receiption of IP packet and the time when the e-NodeB transmits the first block to Uu. Since services can be mapped towards different kind of E-RABs, the Latency measure shall be available per QoS group.

AVAILABILITY KPI:

10.8.9 E-UTRAN CELL AVAILABILITY.

A KPI that shows Availability of E-UTRAN Cell.Percentage of time that the cell is considered available.

$$\text{Availability} = \frac{\text{Time that cell is available}}{\text{Measurement Time}} * 100\ [\%]$$

As for defining the cell as available, it shall be considered available when the e-NodeB can provide E-RAB service in the cell.

10.9 CONCLUSION

It is very important to manage KPI of radio network in order to have best of radio network performance.

11 RF PLANNING AND OPTIMIZATION TOOLS

11.1 LEARNING OBJECTIVE

After completion of this chapter participant will come to know:

- Process of RNP
- RF Planning Tools and digital map
- Radio Network Optimization
- Drive Test Tool and its connectivity
- 2G/3G/4G Drive Test Parameters

11.2 PLANNING PRINCIPLES

11.2.1 PURPOSE

- Reach good quality
- Required radio coverage
- Maximum use of resources
- Maintaining high level of system quality
- Provide both increased capacity and the improvement in required network quality

11.2.2 INPUT TO NETWORK PLANNING

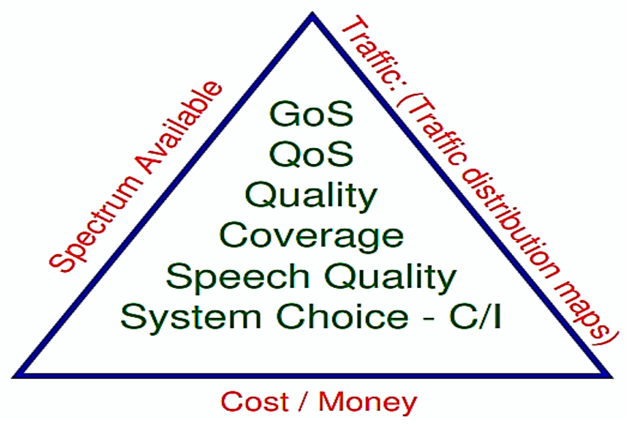


Figure 171: Input to network planning

11.2.3 MAIN FEATURES OF RADIO PLANNING

The basic decisions that must be taken during the radio planning phase are**:**

- Where to install base stations.
- How to configure base stations (antenna type, height, sectors orientation, tilt, maximum power, device capacity, etc.)
- FDMA/TDMA/OFDMA cellular systems adopt a two phases radio planning

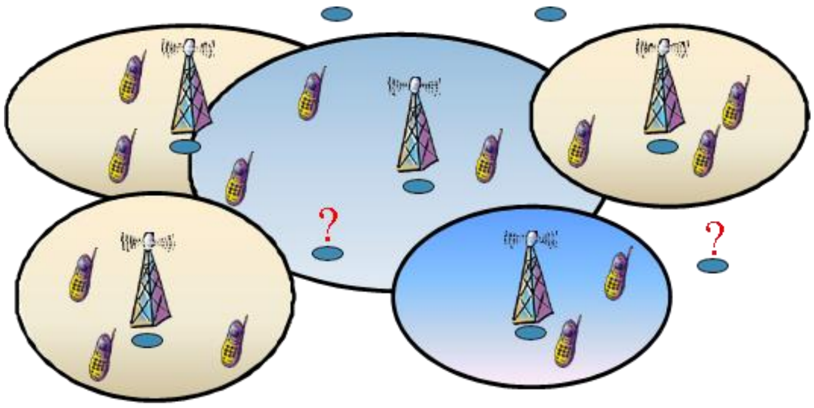


Figure 172: Main features of radio planning

Coverage planning:

Percentage of the geographical area covered by the cellular service where mobile telephony is available. Guarantee the signal strength in the service area.

- Select where to install base stations
- Select antenna configurations
- Constraints on signal level in the area

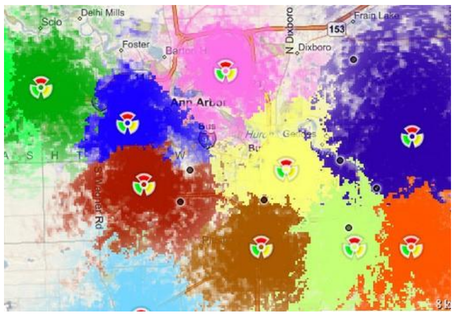


Figure 173: Coverage planning

Depending on the following factors

- Natural: geographical aspect/propagation conditions
- Human: landscape (urban, suburban, rural)

Methods

- Theoretically through link budget calculation and computer.
- Simulation and optimization through the drive test and other measurements.

Capacity Planning*:*

- Number of calls that can be handled in a certain area within a certain period of time.
- Probability that users will be denied access to a system due to unavailability of radio channels.
- Define which radio resource scan be used by each cell.

Essential parameters:

- Estimated traffic
- Antenna parameters (height, tilt, azimuth, aperture, gain, …)
- Frequency reuse factor

11.3 PROCESS OF RADIO NETWORK PLANNING:

- Collection of the input parameters like requirement of capacity, coverage and quality.
- Pre planning is done (which involves calculation of no. of BTS's with the objective to obtain maximum coverage at minimum cost.)
- Site survey involves selection of candidate sites based on feasibility study of constructing by Civil engineers
- Frequency allocation is done on the basis of Cell-to-Cell channel to interference ratio(C/I)
- Parameter planning is done which involves channel configurations, power control and network specific parameters
- The final radio network plan involves rest of the parameters like power budget calculations and considering path loss calculations.

11.4 RF PLANNING TOOLS:

RNP tools are software packages that help for Radio network planning. These are normally licensed software and require hardware key/Dongle. By using RNP tool many essential planning, optimization and management tasks can be performed, which are:

- Network calculations, dimensioning and analysis
- Site planning for base stations; database for existing radio sites
- Automatic Frequency Planning (AFP) and Neighbor planning
- Making different types of prediction plots
- Management of sites and network elements
- Acquisition and maintenance of geo-data
- Terrain and field-strength profiles

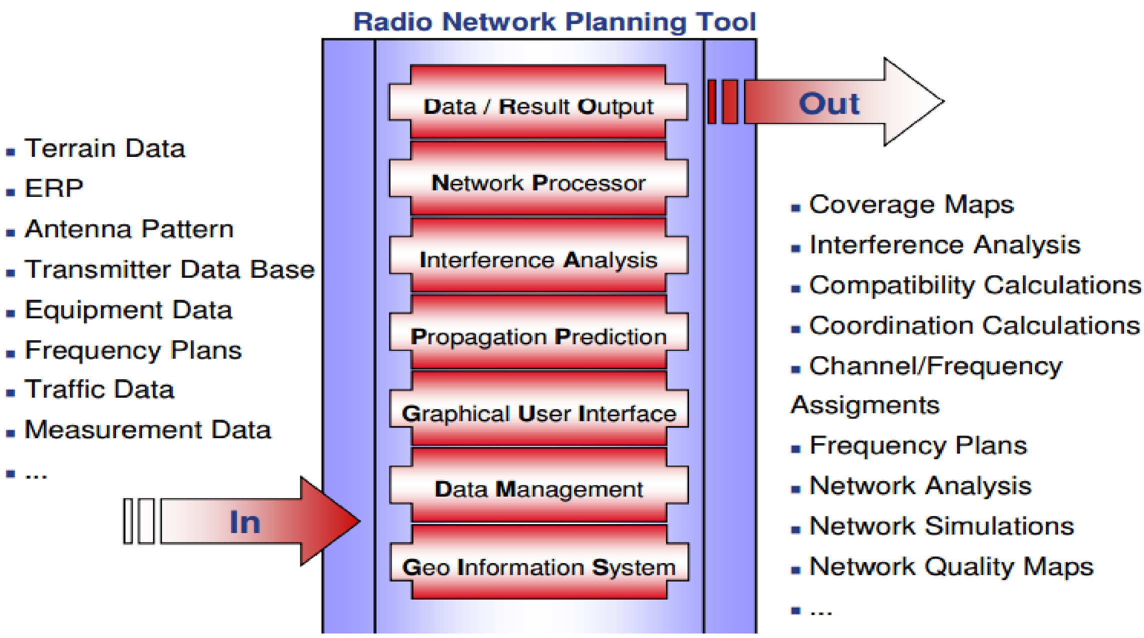


Figure 174: RF Planning Tool Input and Output

As shown in above figure we input Terrain Data (by importing Digital map having clutter, Altitude, vector, places information of the area), Site and transmitter data, Available spectrum, Antenna Patterns etc. in the RNP tool to get required output like Prediction Maps (Plots),Automatic frequency planning etc.

11.4.1 RESOURCES REQUIRED FOR RNP TOOL SETUP

- RNP Tool with License
- Digital map of concerned area
- Details of existing cells (If any): Latitude/longitude, antenna height/tilt/ azimuth and different logical parameters of the existing cells.

11.4.2 DATA IN DIGITAL MAP

- Clutter: It shows type of clutter e.g Urban/Rural/Water/Forest/Open etc.
- Altitude: Shows altitude variations and Height above sea level.
- Vector: It shows Roads/Highways /Railway line etc.
- Places :It shows Cities/Villages.

Clutter and Altitude is called Raster Data and these are taken for different calculations by the tool

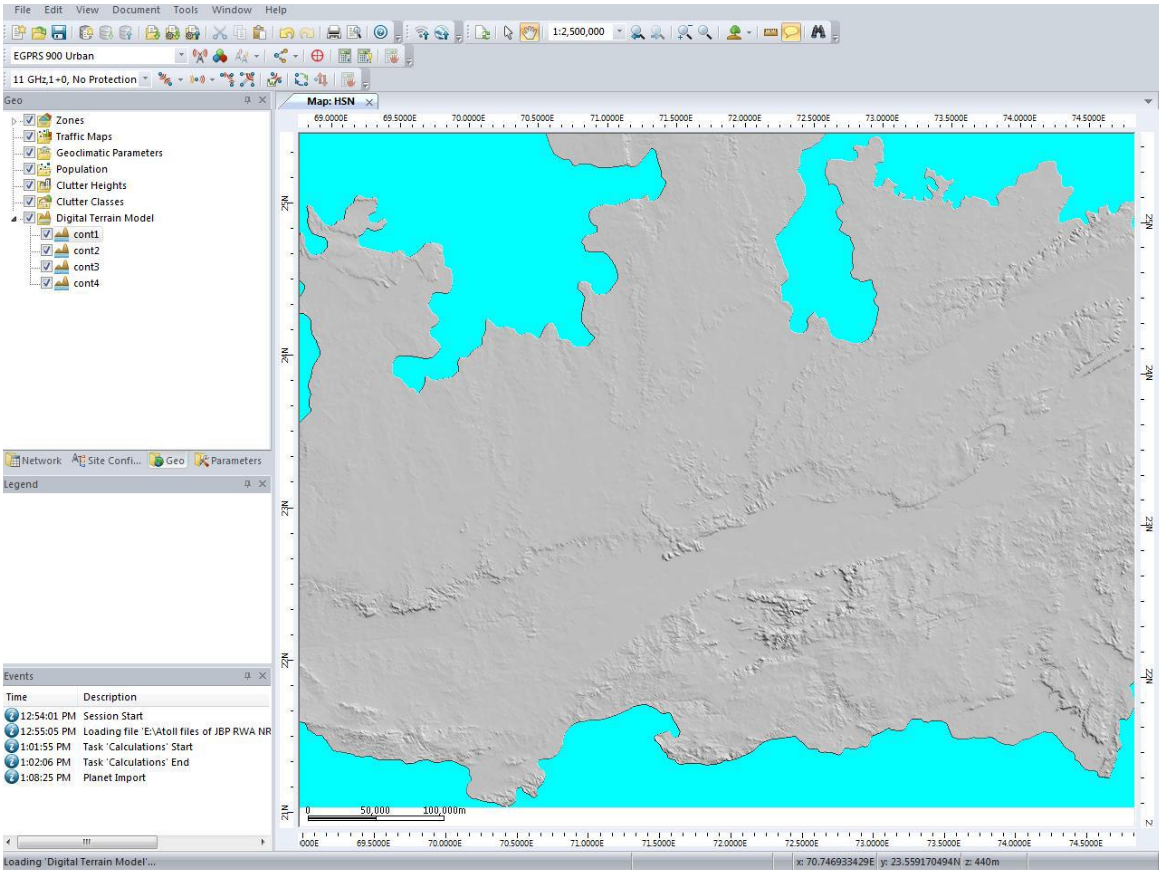


Figure 175: Digital Map showing altitude in RNP Tool

11.4.3 MAIN APPLICATIONS/USAGE OF RNP TOOL

- Prediction of coverage (RxLevel (2G)/RSCP (3G)/RSRP(4G))
- Automatic Neighbour planning
- AFP (Automatic Frequency Planning) in GSM
- PSC Planning in WCDMA

- PCI Planning in LTE
- Audit of Existing Network with analysis of different parameters e.g. BCCH/BSIC in GSM,PSC in WCDMA,PCI in LTE etc.
- Automatic Cell Planning

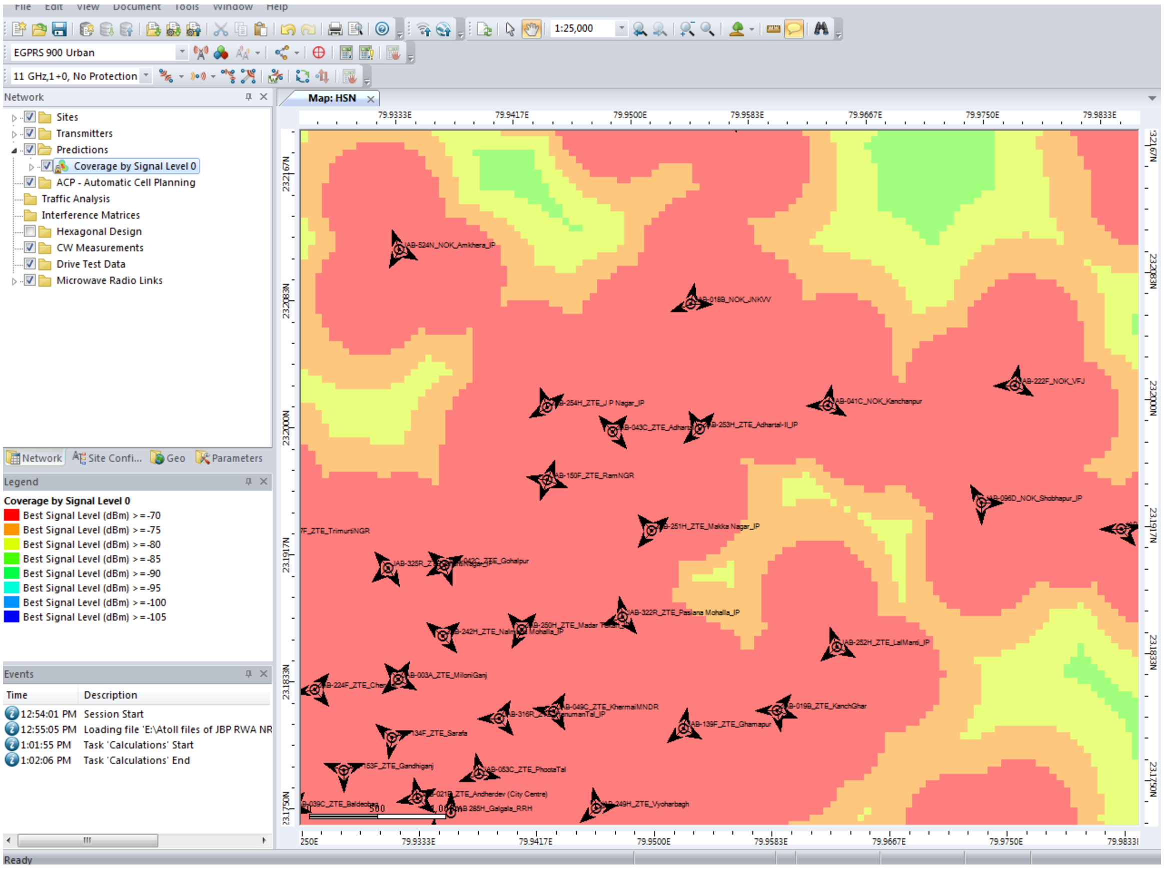


Figure 176: Prediction Plot of Coverage

11.4.4 MAIN PLANNING TOOLS

- Aircom Asset
- Mentum Planet
- Atoll FORSK
- ATDI
- WinProp
- EDX Signal Pro
- CelPlan
- Siradel
- Capesso
- MapInfo RF Tool

11.4.5 RF PLANNING TOOL : ATOLL

Atoll is a scalable and flexible multi-technology network design and optimization platform that supports wireless operators throughout the network lifecycle, from initial design to densification and optimization.

Atoll is also an open technical information system that easily integrates with other IT applications and increases productivity. It features advanced development tools and open interfaces that enable the integration of customized or commercially available complementary modules.

Atoll is designed to work in a wide range of implementation scenarios, from standalone to enterprise-wide server-based configurations using distributed and parallel computing.

Atoll includes advanced multi-technology network planning features (e.g. GSM/UMTS/LTE, CDMA2000/ LTE). It includes a set of fully integrated AFP (Automatic Frequency Planning) tools and ACP (Automatic Cell Planning) tools.

Atoll supports multi-user environments through a database architecture that provides user rights management, data sharing, data integrity management, and easy integration with other IT systems. Atoll enables task automation through a standard macro language, and includes an advanced C++ Software Development Kit (SDK) that facilitates customization and IT integration. Atoll also has the largest range of compatible 3rd party products on the market.

Atoll supports multi-format/multi-resolution geographical data. High-resolution urban and country-wide datasets are supported and displayed interactively as multiple layers including engineering and prediction plots. Atoll also features an integrated vector/raster cartography editor and integrates with leading GIS (Geographical Information System) tools such as MapInfo and Arc View.

Atoll allows distributing calculations over several workstations and supports parallel computing on multi-processor servers, thus dramatically reducing calculation times and getting the most out of hardware.

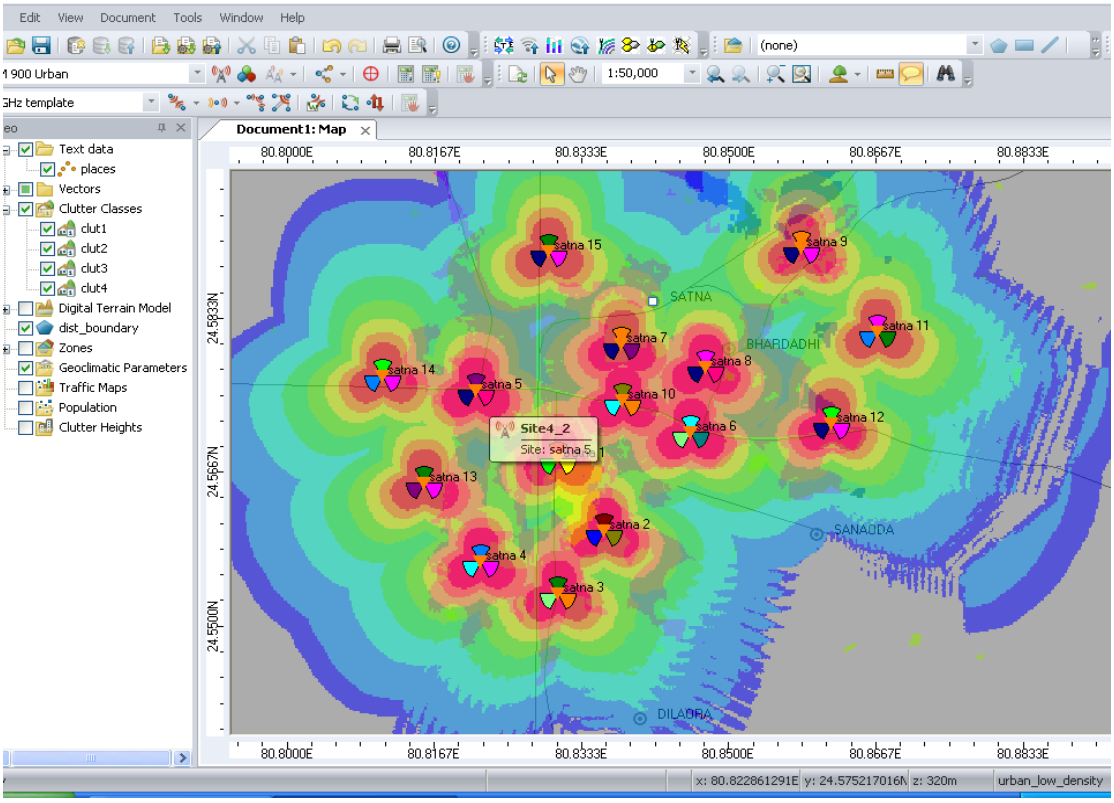


Figure 177: Atoll

11.5 RADIO NETWORK OPTIMIZATION

Once some hundreds of sites are on air, it becomes necessary to perform optimization on the network in order to maximize benefits while minimizing capital and operation costs for operators. This section, in fact, deals with all aspects of optimizing a GSM network starting from standard operations and ending with specific trials, studies and fine-tuning. Before the network is commercially launched, the radio network optimization process starts and then continues during the life of the network.

Depending on the type of network management system, either in the BSC or in the BTS, each cell reports thousands of statistics about all relevant behaviors (number of attempts, failures, successes, during call, handover, setup, etc.). These statistics are reported to the Network Management System (NMS) as counters. To facilitate interpretation of the behavior, a set of key performance indicators (KPIs) is defined out of formulas using pure counters. Each operator chooses its own KPIs and sets, according to specific criteria, some objectives to be met in order to achieve a good end user perception of the service offered and also in order to benchmark one network with other operators.

Another aspect that is important in the optimization phase deals with drive tests. In fact, while statistics give a general idea of the cell's behavior at a certain period, field measurements give a one instant scenario of one area's behavior during a call. Different tools can be used to perform drive tests. Each specific tool is able to standard reporting at the signal level, quality and site information (cell identity, BCCH, mobile allocation list, best neighbors, etc.).

Statistics and drive tests are the main methods used to monitor the network's performance. However, other specific methods can also be used. Tracing catches one object's behavior (TRX, cell, BTS or BSC) during a certain period and regardinga specific event (SDCCH allocation, conversation phase of a voice call, etc.) or a set of successful events (IMSI attach, paging, call setup, location update, etc.). Alarm monitoring, transmission network auditing and network switching subsystem (NSS) performance follow-up are also important in the sense that they give an idea of hardware problems or parameter errors.

After deep analysis, actions are then taken to correct and improve performance. All the above-described methods help the optimization engineers to identify the origin of the problem from the office while applying several analysis methods. Another aspect is, however, very important: field knowledge. Correct site re-engineering is the basis for a good performing network. Frequency planning review is also a key step in the process.

Network planning optimization consists of various operations, all leading to the improvement of KPIs. input data for starting optimization are KPI values in a certain area. Depending on whether the area KPI is greater or less than the target, troubleshooting on a cell basis starts and statistics can be extracted weekly, daily or even on an hourly basis from the NMS. The Call Setup Success Rate (CSSR) and dropcall rate (DCR) are the main KPIs relevant to operator losses.

11.6 DRIVE TESTING

11.6.1 WHAT IS DRIVE TEST

Drive Testing is a method of measuring and assessing the coverage, capacity and Quality of Service (QoS) of a mobile radio network. Drive testing is principally applied in both the planning and optimization stage of network development. Drive tests are the most common measurement tool used by operators, to probe the quality status and solve network problems.

11.6.2 DRIVE TESTING

The technique consists of using a motor vehicle containing mobile radio network air interface measurement equipment that can detect and record a wide variety of the physical and virtual parameters of mobile cellular service in a given geographical area.

It is conducted for checking the coverage criteria of the cell site with the RF drive test tool.

The data collected by drive test tool in form of Log files are assessed to evaluate the various RF parameters of the network.

11.6.3 DATA ACQUIRED FROM DRIVE TEST:

The dataset collected during drive testing field measurements can include information such as

- Signal intensity
- Signal quality
- Interference
- Dropped calls
- Blocked calls
- Call statistics
- Service level statistics
- QoS information
- Handover information
- Neighbouring cell information
- GPS location co-ordinates

11.6.4 TYPES OF DRIVE TESTING

- Network Benchmarking
- Optimization & Troubleshooting
- Service Quality Monitoring

Network Benchmarking

Sophisticated multi-channel tools are used to measure several network technologies and service types simultaneously to very high accuracy and collect accurate competitive data on the true level of their own and their competitors technical performance and quality levels

Optimization & Troubleshooting

Optimization and troubleshooting information is more typically used to aid in finding specific problems during the rollout phases of new networks or to observe specific problems reported by consumers during the operational phase of the network lifecycle.

Service Quality Monitoring

Service quality monitoring typically involves making test calls across the network to a fixed test unit to assess the relative quality of various services using Mean opinion score (MOS).Service quality monitoring is typically carried out in an automated fashion.

The results produced by drive testing for each of these purposes is different.

11.6.5 DRIVE TEST EQUIPMENT

Following Resources/Equipments are required for drive test

- A Laptop
- Drive Test software with Dongle/License Key
- GPS (Global Positioning system) to provide location information
- One or Multiple Handsets Compatible with the Drive Test Software
- Scanner (Optional)
- Database of Existing Network (Cell site database)
- A Suitable Vehicle

11.6.6 CONNECTIVITY OF DRIVE TEST TOOL

As shown in figure, all the equipments (GPS, Mobile Handsets, Dongle) are connected to Laptop via USB ports. Normally antenna type GPS (with magnetic base to stick on top of vehicle) is used with drive test tool.

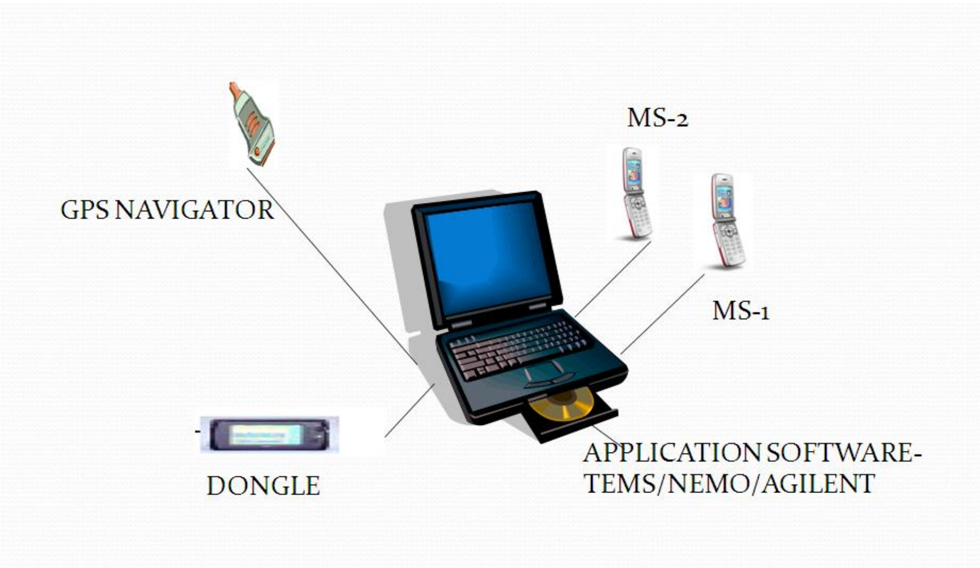


Figure 178: Connectivity of Drive Test Tool

11.6.7 DRIVE TEST TOOLS

Data Collection Tools

- TEMS Investigation

- Nemo Outdoor
- JDSU E6474A
- Accuver XCAL

Post-processing tools

- Actix Analyzer/Spotlight
- Accuver XCAP
- TEMS Discovery LTE

11.6.8 LTE DRIVE TEST PARAMETERS

- RSRP: Reference Signal Received Power.
- RSRQ: Reference Signal Received Quality.
- RSSI: Received Signal Strength Indicator.
- SINR : Signal to Interference Noise Ratio
- CQI: Channel Quality Index.
- PCI: Physical Cell Identity.
- BLER: Block Error Ratio.
- DL Throughput: Down Link Throughput.
- UL Throughput : Up Link Throughput

This is the common key performance parameters for LTE drive test parameter we have to work out for LTE drive test task.

RSRP:

It indicates coverage. RSRP is the average power received from a single Reference signal, and its typical range is around -44dbm (good) to -140dbm (bad).

RSRQ:

RSRQ – Indicates quality of the received signal and its range is typically -19.5dB (bad) to -3dB (good).

RSSI:

RSSI (Received Signal Strength Indicator) is a parameter which provides information about total received wide-band power (measure in all symbols) including all interference and thermal noise.
RSSI = wideband power = noise + serving cell power + interference power

RSSI is related to the other parameters through the following formula:

$$RSRQ=N*(RSRP/RSSI)$$

Where N is the number of Resource Blocks of the E-UTRA carrier RSSI measurement bandwidth.

SINR:

SINR is the reference value used in the system simulation and can be defined:

- Wide band SINR
- SINR for a specific sub-carriers (or for a specific resource elements)

All measured over the same bandwidth!

$$SINR = \frac{S}{I + N}$$

RSSP vs RSRQ vs RSSI vs SINR

Below is a chart that shows what values are considered good and bad for the LTE signal strength values:

		RSRP (dBm)	RSRQ (dB)	SINR (dB)
RF Conditions	Excellent	>=-80	>=-10	>=20
	Good	-80 to -90	-10 to -15	13 to 20
	Mid Cell	-90 to -100	-15 to -20	0 to 13
	Cell Edge	<=-100	<-20	<=0

CQI:

The Channel Quality Indicator (CQI) contains information sent from a UE to the eNode-B to indicate a suitable downlink transmission data rate, i.e., a Modulation and Coding Scheme (MCS) value. CQI is a 4-bit integer and is based on the observed signal-to-interference-plus-noise ratio (SINR) at the UE. The CQI estimation process takes into account the UE capability such as the number of antennas and the type of receiver used for detection. This is important since for the same SINR value the MCS level that can be supported by a UE depends on these various UE capabilities, which needs to be taken into account in order for the eNode-B to select an optimum MCS level for the transmission. The CQI reported values are used by the eNode-B for downlink scheduling and link adaptation, which are important features of LTE.

In LTE, there are 15 different CQI values ranging from 1 to 15 and mapping between CQI and modulation scheme, transport block size is defined as follows (36.213)

CQI index	modulation	code rate x 1024	efficiency
0	out of range		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

CQI	Modulation	Bits/Symbol	REs/PRB	N_RB	MCS	TBS	Code Rate
1	QPSK	2	138	20	0	536	0.101449
2	QPSK	2	138	20	0	536	0.101449
3	QPSK	2	138	20	2	872	0.162319
4	QPSK	2	138	20	5	1736	0.318841
5	QPSK	2	138	20	7	2417	0.442210
6	QPSK	2	138	20	9	3112	0.568116
7	16QAM	4	138	20	12	4008	0.365217
8	16QAM	4	138	20	14	5160	0.469565
9	16QAM	4	138	20	16	6200	0.563768
10	64QAM	6	138	20	20	7992	0.484058
11	64QAM	6	138	20	23	9912	0.600000
12	64QAM	6	138	20	25	11448	0.692754
13	64QAM	6	138	20	27	12576	0.760870
14	64QAM	6	138	20	28	14688	0.888406
15	64QAM	6	138	20	28	14688	0.888406

BLER:

A Block Error Ratio is defined as the ratio of the number of erroneous blocks received to the total number of blocks sent. An erroneous block is defined as a Transport Block, the cyclic redundancy check (CRC) of which is wrong.

11.6.9 WCDMA (3G) DRIVE TEST PARAMETERS

RSCP (Received Signal Code Power)

The received power on one code measured on the Primary CPICH. Unit is dbm. It shows signal strength of a cell. It Indicates Coverage.

RSSI (Received Signal Strength Indicator)

It is the wide-band received power within the relevant channel bandwidth. It is a parameter in dbm that describes the total signal strength of a UTRA carrier frequency i.e. signal strength of all cells of same frequency at a certain location.

Ec/No

It is a parameter in dB that describes the received energy per chip divided by the power density in the band. Measurement shall be performed on the Primary CPICH.It shows signal quality. Value of Ec/No>-15dB is considered good, between -15db and -18 dB is poor and less than -18dB is very poor.

Main reasons of poor Ec/Io are poor RSCP, missing neighbours, overshooting, pilot pollution etc.

11.6.10 ACTIVE, MONITORED AND DETECTED SETS

Cells that the UE is monitoring are grouped in the UE into three mutually exclusive categories:

Active Set: Active Set is defined as the set of cells the UE is simultaneously connected to (i.e., the UTRA cells currently assigning a downlink DPCH to the UE constitute the active set).

Monitored Set: Cells, which are not included in the active set, but are included in the CELL_INFO_LIST belong to the Monitored Set i.e. shows probable candidate sectors for handovers. If one of the active cells becomes weak, it is replaced by a candidate cell having highest signal strength from monitored set.

Detected Set: Cells detected by the UE, which are neither in the CELL_INFO_LIST nor in the active set belong to the Detected Set. All the missing neighbors appear in detected set. These must not have high signal strengths otherwise they will degrade the aggregate Ec/No & lead to call drops.

Pilot Pollution

When the number of strong cells exceeds the active set size, there is "Pilot Pollution" in the area. Pilot pollution is the detection of many high power pilots as compared to Best Serving Pilot that do not contribute to improve the signal strength. It ultimately degrades the aggregate Ec/Io leading to call drop. All other strong signals received when Active Set Size is full, act as interference which degrades the performance of the system. Physical optimization should be done so that there should not be many Pilots available at same spot with equally high signal strengths.

11.6.11 GSM (2G) DRIVE TEST PARAMETERS

- Rx level : Indicates received signal strength in dbm
- Rx Quality: Indicates Quality of voice, which is measured on the basis of BER (Range 0-7 where value 0 denotes minimum BER.
- C/I: The carrier-over-interference ratio is the ratio between the signal strength of the current serving cell and the signal strength of undesired (interfering) signal components (Unit is dB)
- FER: Frame Erasure Rate it represents the percentage of frames being dropped due to high number of bit errors in the frame. It is indication of voice quality in network.

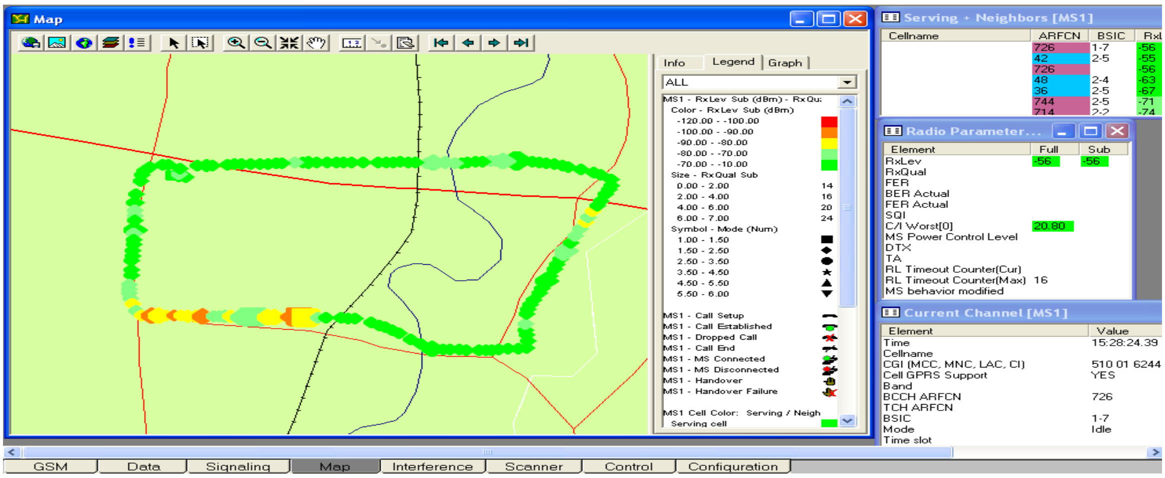


Figure 179: Screenshot of a Drive test window

11.7 CONCLUSION

RF Planning and Optimization plays a vital role in mobile radio network without it is merely impossible to rollout and manage radio network.