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1 CELLULAR CONCEPT, GSM ARCHITECTURE AND GSM RADIO

1.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- Cellular Concept
- Cells, Cluster, Concept of frequency reuse
- Types of Cell
- GSM Architecture
- GSM Radio

1.2 CELLULAR CONCEPT

Traditional mobile service was structured similar to television broadcasting. One very powerful transmitter located at the highest spot in an area would broadcast in a radius of up to fifty kilometers. The Cellular concept structured the mobile telephone network in a different way. Instead of using one powerful transmitter many low-powered transmitter were placed throughout a coverage area. In a cellular system, the covering area of an operator is divided into cells. A cell corresponds to the covering area of one transmitter or a small collection of transmitters. The cellular concept employs variable low power levels, which allows cells to be sized according to subscriber density and demand of a given area. As the population grows, cells can be added to accommodate that growth. Frequencies used in a cell will be reused several cells away. The distance between the cells using the same frequency must be sufficient to avoid interference. The frequency reuse will increase considerably the capacity in number of users.

Conversations can be handed over from cell to cell to maintain constant phone service as the user moves between cells. The cellular system design was pioneered by during '70s by Bell Laboratories in the United States, and the initial realization was known as AMPS (Advanced Mobile Phone Service). The AMPS cellular service was available in United States in 1983. AMPS is essentially generation 1 analog cellular system in contrast to generation 2 digital cellular systems of GSM and CDMA (1S-95).

1.2.1 CELLS

A cell is the basic geographic unit of cellular system. The term cellular comes from the honeycomb areas into which a coverage region is divided. Cells are base stations transmitting over small geographic areas that are represented as hexagons as shown in Figure. Each cell size varies depending upon landscape. Because of constraint imposed by natural terrain and man-made structures, the true shape of cell is not a perfect hexagon. In order to work properly, a cellular system must verify the following two main conditions:

- The power level of a transmitter within a single cell must be limited in order to reduce the interference with the transmitters of neighboring cells. The interference will not produce any damage to the system if a distance of about 2.5 to 3 times the diameter of a cell is reserved between transmitters.
- Neighboring cells can not share the same channels. In order to reduce the interference, the frequencies must be reused only within a certain pattern.

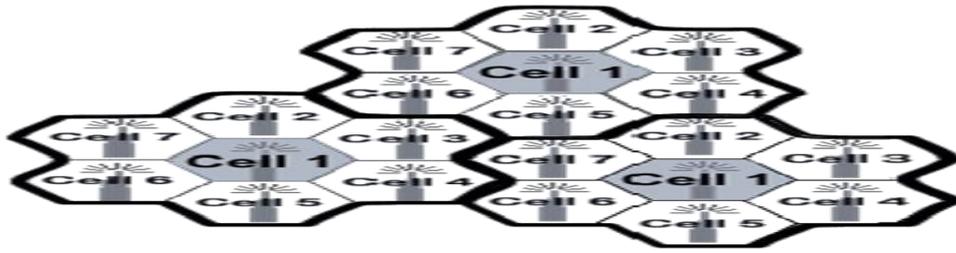


Figure 1: Cellular Network

1.2.2 CLUSTER

The spectrum allocated for a cellular network is limited. As a result there is a limit to the number of frequencies or channels that can be used. The cells are grouped into clusters. Group of cells in which no frequencies are reused is termed as a **cluster**.

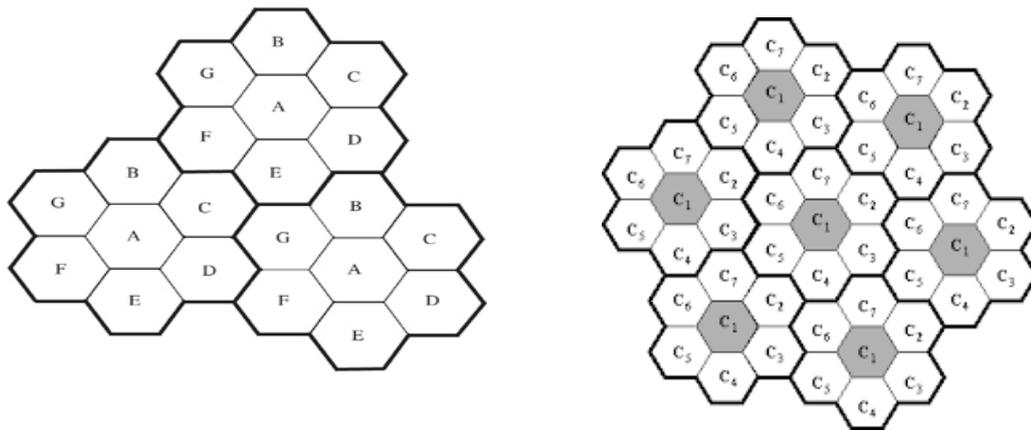


Figure 2: Cell Clustering and Co-channel cells

The number of cells in a cluster must be determined so that the cluster can be repeated continuously within the covering area of an operator. A cellular network can only provide service to a large number of subscribers, if the channels allocated to it can be reused. Channel reuse is implemented by using the same channels within cells located at different positions in the cellular network service area. Cells using the same channel set are called **co-channel** cells. Cell clustering and co-channel cells (Shaded cells) are shown in Figure.

Within the service area (PLMN), specific channel sets are reused at a different location (another cell). In the Figure, there are 7 channel sets: A through G. Neighboring cells are not allowed to use the same frequencies. For this reason all channel sets are used in a cluster of neighboring cells. As there are 7 channel sets, the PLMN can be divided into clusters of 7 cells each. The figure shows three clusters.

The number of channel sets is represented by **K**. **K** is also called the reuse factor. In the figure, $K=7$. Valid values of K can be found using equation (where i and j are integers):

$$K = i^2 + j^2 + i \times j; \quad \text{where } i \text{ and } j \text{ are integers}$$

Here cells are shaped ideally (hexagons). The distance between cells using the same channel set is always the same. The typical clusters contain 4, 7, 12 or 21 cells. The

number of cells in each cluster is very important. The smaller the number of cells per cluster is, the bigger the number of channels per cell will be. The capacity of each cell will be therefore increased. However a balance must be found in order to avoid the interference that could occur between neighboring clusters. This interference is produced by the small size of the clusters (the size of the cluster is defined by the number of cells per cluster). The total number of channels per cell depends on the number of available channels and the type of cluster used.

Signal attenuation with distance

Frequencies can be reused throughout a service area because radio signals typically attenuate with distance to the base station (or mobile station). When the distance between cells using the same frequencies becomes too small, co-channel interference might occur and lead to service interruption or unacceptable quality of service.

As long as the ratio

$$\frac{\text{Frequency reuse distance}}{\text{Cell radius}} = \frac{D}{R}$$

is greater than some specified value, the ratio

$$\frac{\text{Received radio carrier power}}{\text{Received interferer radio carrier power}} = \frac{C}{I}$$

will be greater than some given amount for small as well as large cell sizes when all signals are transmitted at the same power level.

Relationship between K and D/R

There is a relationship between K and ratio D/R, shown by the following equation:

$$D/R = \sqrt{3K}$$

Relationship between K and Performance

The performance of a cellular network can be expressed in quality of service. An acceptable quality of service means a low (co-channel) interference level in the network.

The relationship between the reuse factor K and the network performance is: if K increases, then the co-channel interference decreases, and so the performance increases (note that there is a fixed relationship between K and ratio D/R).

Relationship between K and Cell Capacity

The other key relationship in cellular networks is the one between the reuse factor K and call capacity. First of all, call capacity depends on the number of available channels. In GSM, a limited number of frequencies is available (for GSM: 124 frequencies, and for GSM-1800: 374 frequencies). The frequencies are grouped into frequency sets. If K increases, the number of frequencies per set (and so per cell) decreases, and so the call capacity per cell.

Capacity/Performance Trade-offs

- If K increases, then performance increases
- If K increases, then call capacity decreases per cell

The number of sites to cover a given area with a given high traffic density, and hence the cost of the infrastructure, is determined directly by the reuse factor and the number of traffic channels that can be extracted from the available spectrum. These two factors are compounded in what is called spectral efficiency of the system.

Many techniques are used to reduce interference and enhance spectral efficiency like-

- Power Control
- Use of directional Antennas (3 sector configuration)
- Mobile Assisted Handover (MAHO).

1.3 TYPES OF CELLS

The density of population in a country is so varied that different types of cells are used:

1.3.1 MACRO CELLS

The macro cells are large cells for remote and sparsely populated areas.

1.3.2 MICRO CELLS

These cells are used for densely populated areas. By splitting the existing areas into smaller cells, the number of channels available is increased as well as the capacity of the cells. The power level of the transmitters used in these cells is then decreased, reducing the possibility of interference between neighboring cells.

1.3.3 PICO CELLS

Pico cells are small cells whose diameter is only few dozen meters; they are used mainly in indoor applications. It can cover e.g. a floor of a building or an entire building like shopping centers, Airports etc.

1.3.4 SELECTIVE CELLS

It is not always useful to define a cell with a full coverage of 360 degrees. In some cases, cells with a particular shape and coverage are needed. These cells are called selective cells. Typical examples of selective cells are the cells that may be located at the entrances of tunnels where coverage of 360 degrees is not needed. In this case, a selective cell with coverage of 120 degrees is used.

1.3.5 UMBRELLA CELLS

A freeway crossing very small cells produces an important number of handovers among the different small neighboring cells in case of a fast moving mobile subscriber. In order to solve this problem, the concept of umbrella cells is introduced. An umbrella cell covers several micro cells. The power level inside an umbrella cell is increased comparing to the power levels used in the micro cells that form the umbrella cell. When the speed of the mobile is too high, the mobile is handed over to the umbrella cell. The mobile will then stay longer in the same cell (in this case the umbrella cell). This will reduce the number of handovers and the work of the network.

1.3.6 CELL SECTORISING

One way of reducing the level of interference is to use directional antenna at base stations, with each antenna illuminating a sector of the cell, and with a separate channel set allocated to each sector. There are two commonly used methods of Sectorisation either using 120° sector or 60° sector, both of which reduce the number of prime interference sources. The three sector case is generally used with a seven cell pattern, giving an overall requirement for 21 channel sets as shown in Figure. The main drawbacks of cell sectoring are increase in number of antennas at each base station. The number of handovers increases as the mobile move from one sector to another.

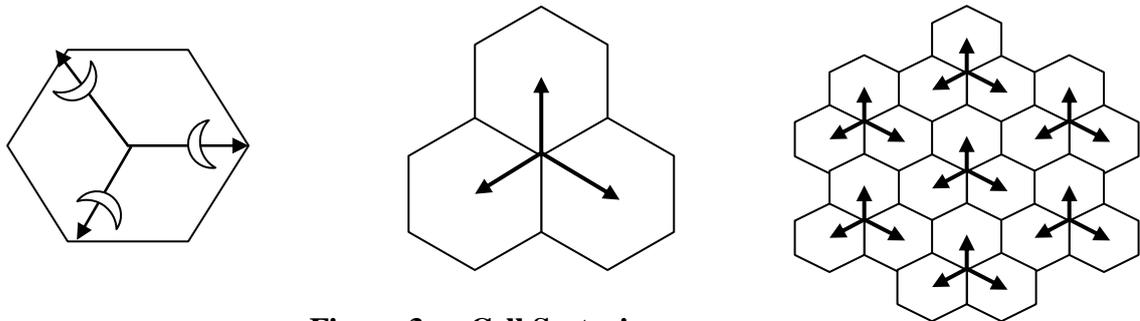


Figure 3: Cell Sectoring

Concept of Frequency Assignment

The cell layout (4-Cell, 3-Sector) and the corresponding frequency planning is shown in Figure.

Frequency Planning Aspects											
A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3
1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32	33	34	35	36

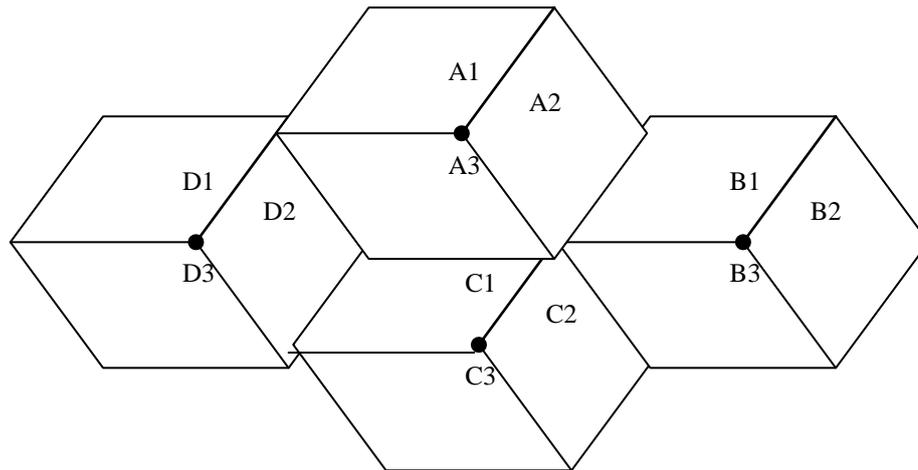


Figure 4: Frequency Planning in Sectored Cells

1.3.7 FEATURES OF DIGITAL SYSTEM

Small cells: A cellular system uses many base stations with relatively small coverage radii (on the order of a 100 m to 30 km).

Frequency reuse: The spectrum allocated for a cellular network is limited. As a result there is a limit to the number of channels or frequencies that can be used. For this reason each frequency is used simultaneously by multiple base-mobile pairs. This frequency reuse allows a much higher subscriber density per MHz of spectrum than other systems.

Small, battery-powered handsets: In addition to supporting much higher densities than previous systems, this approach enables the use of small, battery-powered handsets with a radio frequency that is lower than the large mobile units used in earlier systems.

Performance of handovers: In cellular systems, continuous coverage is achieved by executing a “handover” (the seamless transfer of the call from one base station to another) as the mobile unit crosses cell boundaries. This requires the mobile to change frequencies under control of the cellular network.

1.4 GSM ARCHITECTURE

A GSM system is basically designed as a combination of three major subsystems: the network subsystem, the radio subsystem, and the operation support subsystem. In order to ensure that network operators will have several sources of cellular infrastructure equipment, GSM decided to specify not only the air interface, but also the main interfaces that identify different parts. There are three dominant interfaces, namely, an interface between MSC and the base Transceiver Station (BTS), and an Um interface between the BTS and MS.

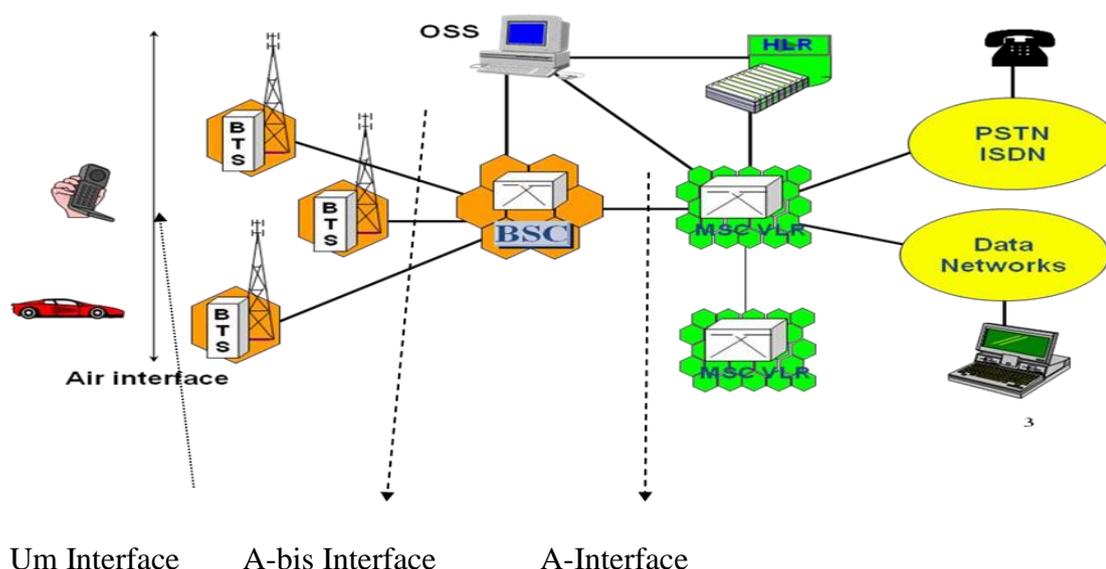


Figure 5: GSM Architecture

1.4.1 GSM NETWORK STRUCTURE

Every telephone network needs a well-designed structure in order to route incoming calls to the correct exchange and finally to the called subscriber. In a mobile network, this structure is of great importance because of the mobility of all its subscribers. In the GSM system, the network is divided into the following partitioned areas.

- GSM service area;
- PLMN service area;
- MSC service area;
- Location area;
- Cells.

The GSM service is the total area served by the combination of all member countries where a mobile can be serviced. The next level is the PLMN service area. There can be several within a country, based on its size. The next level of division is the MSC/VLR service area. In one PLMN there can be several MSC/VLR service areas. MSC/VLR is a sole controller of calls within its jurisdiction.

The next division level is that of the LA's within a MSC/VLR combination. There are several LA's within one MSC/VLR combination. A LA is a part of the MSC/VLR service area in which a MS may move freely without updating location information to the MSC/VLR exchange that control the LA.

Lastly, a LA is divided into many cells. A cell is an identity served by one BTS.

1.4.2 MOBILE STATION

The MS includes radio equipment and the man machine interface (MMI) that a subscriber needs in order to access the services provided by the GSM PLMN. MS can be installed in Vehicles or can be portable or handheld stations. The MS includes provisions for data communication as well as voice. A mobile transmits and receives messages to and from the GSM system over the air interface to establish and continue connections through the system.

Each MS is identified by an IMEI that is permanently stored in the mobile unit. Upon request, the MS sends this number over the signaling channel to the MSC. The IMEI can be used to identify mobile units that are reported stolen or operating incorrectly.

Just as the IMEI identifies the mobile equipment, other numbers are used to identify the mobile subscriber. Different subscriber identities are used in different phases of call setup. The Mobile Subscriber ISDN Number (MSISDN) is the number that the calling party dials in order to reach the subscriber. It is used by the land network to route calls toward an appropriate MSC. The international mobile subscriber identity (IMSI) is the primary function of the subscriber within the mobile network and is permanently assigned to him. The GSM system can also assign a Temporary Mobile Subscriber Identity (TMSI) to identify a mobile. This number can be periodically changed by the system and protect the subscriber from being identified by those attempting to monitor the radio channel.

Functions of MS

The primary functions of MS are to transmit and receive voice and data over the air interface of the GSM system. MS performs the signal processing function of digitizing, encoding, error protecting, encrypting, and modulating the transmitted signals. It also performs the inverse functions on the received signals from the BS.

In order to transmit voice and data signals, the mobile must be in synchronization with the system so that the messages are transmitted and received by the mobile at the correct instant. To achieve this, the MS automatically tunes and synchronizes to the frequency and TDMA timeslot specified by the BSC.

MS monitors the power level and signal quality, determined by the BER for known receiver bit sequences (synchronization sequence), from both its current BTS and up to six surrounding BTSs. This data is received on the downlink broadcast control channel. The MS determines and send to the current BTS a list of the six best-received BTS signals. The measurement results from MS on downlink quality and surrounding BTS signal levels are sent to BSC and processed within the BSC. The system then uses this list for best cell handover decisions. MS keeps the GSM network informed of its location during both national and international roaming, even when it is inactive. This enables the System to page in its present LA. The MS includes an equalizer that compensates for multi-path distortion on the received signal. This reduces inter-symbol interference that would otherwise degrade the BER.

Finally, MS can store and display short received alphanumeric messages on the liquid crystal display (LCD) that is used to show call dialing and status information. These messages are limited to 160 characters in length.

SIM Card

GSM subscribers are provided with a SIM card with its unique identification at the very beginning of the service. The subscriber is identified in the system when he inserts the SIM card in the mobile equipment. This provides an enormous amount of flexibility to the subscribers since they can now use any GSM-specified mobile equipment.

The SIM is a removable SC, the size of a credit card, and contains an integrated circuit chip with a microprocessor, random access memory (RAM), and read only memory (ROM). It is inserted in the MS unit by the subscriber when he or she wants to use the MS to make or receive a call.

International Mobile Subscriber Identity (IMSI)

An IMSI is assigned to each authorized GSM user. It consists of a mobile country code (MCC), mobile network code (MNC), and a PLMN unique mobile subscriber identification number (MSIN).

Temporary Mobile Subscriber Identity (TMSI)

A TMSI is a MSC-VLR specific alias that is designed to maintain user confidentiality. It is assigned only after successful subscriber authentication.

The Mobile Station Roaming Number (MSRN)

The MSRN is allocated on temporary basis when the MS roams into another numbering area. The MSRN number is used by the HLR for rerouting calls to the MS. It is assigned upon demand by the HLR on a per-call basis.

International Mobile Equipment Identity (IMEI)

The IMEI is the unique identity of the equipment used by a subscriber by each PLMN and is used to determine authorized (white), unauthorized (black), and malfunctioning (gray) GSM hardware. In conjunction with the IMSI, it is used to ensure that only authorized users are granted access to the system. An IMEI is never sent in cipher mode by MS.

1.4.3 BASE STATION SYSTEM

The BSS is a set of BS equipment (such as transceivers and controllers) that is in view by the MSC through a single A interface as being the entity responsible for communicating with MSs in a certain area. The radio equipment of a BSS may be composed of one or more cells. A BSS may consist of one or more BS. The interface between BSC and BTS is designed as an A-bis interface. The BSS includes two types of machines: the BTS in contact with the MSs through the radio interface and the BSC, the latter being in contact with the MSC.

A BTS is a network component that serves one cell and is controlled by a BSC. BTS is typically able to handle three to five radio carries, carrying between 24 and 40 simultaneous communication. Reducing the BTS volume is important to keeping down the cost of the cell sites.

An important component of the BSS that is considered in the GSM architecture as a part of the BTS is the Transcoder/Rate Adapter Unit (TRAU). The TRAU is the equipment in which coding and decoding is carried out as well as rate adoption in case of data. Although the specifications consider the TRAU as a subpart of the BTS, it can be sited away from the BTS (at MSC), and even between the BSC and the MSC.

The interface between the MSC and the BSS is a standardized SS7 interface (A-interface). This allows the system operator to purchase switching equipment from one supplier and radio equipment and the controller from another. The interface between the BSC and a remote BTS likewise is a standard the A-bis.

1.4.4 FUNCTIONS OF BTS

The primary responsibility of the BTS is to transmit and receive radio signals from a mobile unit over an air interface. To perform this function completely, the signals are encoded, encrypted, multiplexed, modulated, and then fed to the antenna system at the cell site. Transcoding to bring 13-kbps speech to a standard data rate of 16 kbps and then combining four of these signals to 64 kbps is essentially a part of BTS, though, it can be done at BSC or at MSC.

Random access detection is made by BTS, which then sends the message to BSC. The channel subsequent assignment is made by BSC. Timing advance is determined by BTS. BTS signals the mobile for proper timing adjustment. Uplink radio channel measurement corresponding to the downlink measurements made by MS has to be made by BTS.

1.4.5 TRANSCODER

The transcoder is the device that takes 13-Kbps speech or 3.6/6/12Kbps data multiplexes and four of them to convert into standard 64-Kbps data. First, the 13 Kbps or the data at 3.6/6/12 Kbps are brought up to the level of 16 Kbps by inserting additional synchronizing data to make up the difference between a 13-Kbps speech or lower rate data, and then four of them are combined in the transcoder to provide 64 Kpbs channel within the BSS. Four traffic channels can then be multiplexed on one 64-Kpbs circuit. Thus, the TRAU output data rate is 64 Kpbs. Then, up to 30 such 64-Kpbs channels are multiplexed onto a 2.048 Mpbs if a CEPT1 channel is provided on the A-bis interface. This channel can carry up to 120-(16x 120) traffic and control signals. Since the data rate to the PSTN is normally at 2 Mbps, which is the result of combining 30-Kbps by 64-Kbph channels, or 120- Kbps by 16-Kpbs channels.

1.4.6 BSC

The BSC, as discussed, is connected to the MSC on one side and to the BTS on the other. The BSC performs the Radio Resource (RR) management for the cells under its control. It assigns and release frequencies and timeslots for all MSs in its own area. The BSC performs the intercell handover for MSs moving between BTS in its control. It also reallocates frequencies to the BTSs in its area to meet locally heavy demands during peak hours or on special events. The BSC controls the power transmission of both BSSs and MSs in its area. The minimum power level for a mobile unit is broadcast over the BCCH. The BSC provides the time and frequency synchronization reference signals broadcast by its BTSs.

1.4.7 SWITCHING SUBSYSTEMS: MOBILE SWITCHING CENTER AND GATEWAY SWITCHING CENTER

The main role of the MSC is to manage the communications between the GSM users and other telecommunication network users. The basic switching function of performed by the MSC, whose main function is to coordinate setting up calls to and from GSM users. The MSC has interface with the BSS on one side (through which MSC VLR

is in contact with GSM users) and the external networks on the other (ISDN/PSTN/PSPDN). The main difference between a MSC and an exchange in a fixed network is that the MSC has to take into account the impact of the allocation of RRs and the mobile nature of the subscribers and has to perform, in addition, at least, activities required for the location registration and handover.

The MSC is a telephony switch that performs all the switching functions for MSs located in a geographical area as the MSC area. The MSC must also handle different types of numbers and identities related to the same MS and contained in different registers: IMSI, TMSI, ISDN number, and MSRN. In general identities are used in the interface between the MSC and the MS, while numbers are used in the fixed part of the network, such as, for routing.

1.4.8 FUNCTIONS OF MSC

The main function of the MSC is to coordinate the set up of calls between GSM mobile and PSTN users. Specifically, it performs functions such as paging, resource allocation, location registration, and encryption.

This is ensured if the two BSSs are connected to the same MSC but also when they are not. In this latter case the procedure is more complex, since more than one MSC is involved. The MSC performs billing on calls for all subscribers based in its areas. When the subscriber is roaming elsewhere, the MSC obtains data for the call billing from the visited MSC. Encryption parameters transfers from VLR to BSS to facilitate ciphering on the radio interface are done by MSC. The exchange of signaling information on the various interface toward the other network elements and the management of the interface themselves are all controlled by the MSC. Finally, the MSC serves as a SMS gateway to forward SMS messages from Short Message Service Centers (SMSC) to the subscribers and from the subscribers to the SMSCs. It thus acts as a message mailbox and delivery system.

1.4.9 VLR

The VLR is collocated with an MSC. A MS roaming in an MSC area is controlled by the VLR responsible for that area. When a MS appears in a LA, it starts a registration procedure. The MSC for that area notices this registration and transfers to the VLR the identity of the LA where the MS is situated. A VLR may be in charge of one or several MSC LA's. The VLR constitutes the databases that support the MSC in the storage and retrieval of the data of subscribers present in its area. When an MS enters the MSC area borders, it signals its arrival to the MSC that stores its identity in the VLR. The information necessary to manage the MS is contained in the HLR and is transferred to the VLR so that they can be easily retrieved if so required.

1.4.10 DATA STORED IN VLR

The data contained in the VLR and in the HLR are more or less the same. Nevertheless the data are present in the VLR only as long as the MS is registered in the area related to that VLR. Data associated with the movement of mobile are IMSI, MSISDN, MSRN, and TMSI.

1.4.11 HOME LOCATION REGISTER

The HLR is a database that permanently stores data related to a given set of subscribers. The HLR is the reference database for subscriber parameters. Various identification numbers and addresses as well as authentication parameters, services subscribed, and special routing information are stored. Current subscriber status including a subscriber's temporary roaming number and associated VLR if the mobile is roaming, are maintained.

The HLR maintains record of which supplementary service each user has subscribed to and provides permission control in granting services. The HLR stores the identification of SMS gateways that have messages for the subscriber under the SMS until they can be transmitted to the subscriber and receipt is knowledge.

1.4.12 AUTHENTICATION CENTER

The AUC stores information that is necessary to protect communication through the air interface against intrusions, to which the mobile is vulnerable. The legitimacy of the subscriber is established through authentication and ciphering, which protects the user information against unwanted disclosure. Authentication information and ciphering keys are stored in a database within the AUC, which protects the user information against unwanted disclosure and access.

1.4.13 EQUIPMENT IDENTIFY REGISTER

EIR is a database that stores the IMEI numbers for all registered ME units. The IMEI uniquely identifies all registered ME. There is generally one EIR per PLMN. It interfaces to the various HLR in the PLMN. The EIR keeps track of all ME units in the PLMN. There are three classes of ME that are stored in the database, and each group has different characteristics.

- White List: contains those IMEIs that are known to have been assigned to valid MS's. This is the category of genuine equipment.
- Black List: contains IMEIs of mobiles that have been reported stolen.
- Gray List: contains IMEIs of mobiles that have problems (for example, faulty software and wrong make of the equipment). This list contains all MEs with faults not important enough for barring.

1.4.14 INTERWORKING FUNCTION

The IWF, which in essence is a part of MSC, provides the subscriber with access to data rate and protocol conversion facilities so that data can be transmitted between GSM Data Terminal Equipment (DTE) and a land-line DTE.

1.4.15 ECHO CANCELER (EC)

EC is used on the PSTN side of the MSC for all voice circuits. The EC is required at the MSC PSTN interface to reduce the effect of GSM delay when the mobile is connected to the PSTN circuit. The total round-trip delay introduced by the GSM system, which is the result of speech encoding, decoding and signal processing, is of the order of 180 ms. Normally this delay would not be an annoying factor to the mobile, except when communicating to PSTN as it requires a two-wire to four-wire hybrid transformer in the

circuit. This hybrid is required at the local switching office because the standard local loop is a two-wire circuit. Due to the presence of this hybrid, some of the energy at its four-wire receive side from the mobile is coupled to the four-wire transmit side and thus retransmitted to the mobile. This causes the echo, which does not affect the land subscriber but is an annoying factor to the mobile. The standard EC cancels about 70 ms of delay.

During a normal PSTN (land-to-land call), no echo is apparent because the delay is too short and the land user is unable to distinguish between the echo and the normal telephone “side tones” However, with the GSM round-trip delay added and without the EC, the effect would be irritating to the MS subscriber.

1.4.16 OPERATION AND MAINTENANCE CENTER (OMC)

The OMC provides alarm-handling functions to report and log alarms generated by the other network entities. The maintenance personnel at the OMC can define that criticality of the alarm. Maintenance cover both technical and administrative actions to maintain and correct the system operation, or to restore normal operations after a breakdown, in the shortest possible time.

The OMC provides system change control for the software revisions and configuration data bases in the network entities or uploaded to the OMC. The OMC also keeps track of the different software versions running on different subsystem of the GSM.

1.5 GSM RADIO

The radio interface is the interface between the mobile stations and the fixed infrastructure. It is one of the most important interfaces of the GSM system. One of the main objectives of GSM is roaming. Therefore, in order to obtain a complete compatibility between mobile stations and networks of different manufacturers and operators, the radio interface must be completely defined. The spectrum efficiency depends on the radio interface and the transmission, more particularly in aspects such as the capacity of the system and the techniques used in order to decrease the interference and to improve the frequency reuse scheme. The specification of the radio interface has then an important influence on the spectrum efficiency.

The specifications of GSM radio interface:

- Frequency Band
- FDMA and TDMA
- Uplink and Downlink
- Physical and Logical Channel
- Multiplexing Logical Channels
- Frame Types in Radio Interface
- GSM Radio Link Processes
- Low Bit Rate Speech coding
- Channel coding
- Bit Interleaving
- Burst assembling

1.5.1 FREQUENCY ALLOCATION

GSM 900 MHz

Two frequency bands, of 25 MHz each one, have been allocated for the GSM system:

The band 890-915 MHz has been allocated for the uplink direction (transmitting from the mobile station to the base station).

The band 935-960 MHz has been allocated for the downlink direction (transmitting from the base station to the mobile station).

But not all the countries can use the whole GSM frequency bands. This is due principally to military reasons and to the existence of previous analog systems using part of the two 25 MHz frequency bands.

GSM 1800 MHz

Two frequency bands, of 75 MHz each one, have been allocated for the GSM system:

The band 1710 to 1785 MHz has been allocated for the uplink direction (transmitting from the mobile station to the base station).

The band 1805 to 1880 has been allocated for the downlink direction (transmitting from the base station to the mobile station).

1.3.2 FDMA and TDMA methods

To achieve a high spectral efficiency in the cellular network a combination of FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) is used. The FDMA part involves the division by frequency of the 25 MHz bandwidth into 124 carrier frequencies spaced 200 KHz for GSM-900. For GSM-1800 the frequency spectrum of the 75 MHz bandwidth is divided into 374 carrier frequencies spaced 200 KHz. One or more frequencies are assigned to each BTS. Each of these carrier frequencies is then divided in time, using a TDMA scheme to increase the number of channels per carrier frequency.

1.5.2 UPLINK AND DOWNLINK

In the frequency range specified for the GSM-900 mobile radio networks, 124 frequency channels with a bandwidth of 200 KHz are available for both the uplink and downlink direction. The uplink (mobile station to BTS) uses the frequencies between 890 MHz and 915 MHz and the downlink (BTS to mobile station) uses the frequencies between 935 MHz and 960 MHz. The duplex spacing, the spacing between the uplink and downlink channel, is 45 MHz.

GSM-1800 uses a similar scheme. The difference is that for GSM-1800 the uplink uses the frequencies between 1710 MHz and 1785 MHz and the downlink the frequencies between 1805 MHz and 1880 MHz. The duplex spacing is 95 MHz.

1.5.3 PHYSICAL AND LOGICAL CHANNEL

One GSM carrier of 200 KHz is divided in 8 time slots and access by various users is in TDMA mode. Calls to and from subscribers in a cell coverage area are

facilitated by various logical channels. Logical channels are mapped onto physical channel which is one time slot of a GSM carrier.

A **physical channel** is determined by the carrier frequency (or a number of carrier frequencies and a defined hopping sequence) and the timeslot number. A mobile station can transmit speech data only during its assigned timeslot.

Types of Logical Channels:

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

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

1.5.4 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.

The following traffic channels are provided:

- **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.
- **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.

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.

1.5.5 BROADCAST CHANNELS

The information distributed over the broadcast channels helps the mobile stations to orient themselves in the mobile radio 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:

- **BCCH (Broadcast Control Channel)** : Via the BCCH the mobile station is informed about the system configuration parameters (for example Local Area Identification, Cell Identity and Neighbor Cells). Using this information the mobile stations can choose the best cell to attach to. The BCCH is also known as beacon.

- **FCCH (Frequency Correction Channel)** :To communicate with the BTS the mobile station must tune to the BTS. The FCC transmits a constant frequency shift of the radio frequency carrier that can be used by the mobile station for frequency correction.
- **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).
- **CBCCH (Cell Broadcast Channel)** :The CBCCH is used for the transmission of generally accessible information (Short Message Service messages) in a cell, which can be polled by the mobile station.

1.5.6 COMMON CONTROL CHANNEL

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. The following channels are provided:

- **PCH (Paging Channel)** : The PCH is used in the downlink direction for paging the mobile stations.
- **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.
- **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.

1.5.7 DEDICATED CONTROL CHANNELS

Dedicated control channels are full-duplex, point-to-point Channels. They are used for signaling between the BTS and a certain mobile station. They are divided into:

- **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.
- **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.
- **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 0.8kbit/s.

1.5.8 MULTIPLEXING LOGICAL CHANNELS ONTO PHYSICAL CHANNELS

Several of the above-mentioned types of logical channels can be transmitted over one single physical channel (timeslot). 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.

Channel Combination

The channel combinations are:

- TCH/F + FACCH/F + SACCH/F
- TCH/H + FACCH/H + SACCH/H
- (TCH/F + FACCH/F + SACCH/F) or (TCH/H + FACCH/H + SACCH/H)
- FCCH + SCH + CCCH + BCCH
- FCCH + SCH + CCCH + BCCH + SDCCH/4 + SACCH/4
- CCCH + BCCH
- SDCCH/8 + SACCH/8

The CCCH is a channel that carries both the PCH and the AGCH on the downlink, and the RACH on the uplink. The extensions “/4” and “/8” in the above mentioned terms mean, respectively, that four and eight logical channels are mapped onto one physical channel (timeslot). Note that the BCCH is always transmitted in timeslot 0 on the first defined frequency.

1.5.9 FRAME TYPES ON THE RADIO INTERFACE

The GSM specifications define several types of frames, which are:

- **TDMA frame:** 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.

- **26-TDMA multiframe :** This multiframe is defined as a succession of 26 TDMA frames, and corresponds to the 26 x 8 BP or 120 ms cycle used in the definition of the TCH/F and TCH/H.
- **51-TDMA multiframe :** This multiframe is defined as a succession of 51 TDMA frames, and corresponds to the 51 x 8 BP cycle used in the definition of the TCH/F, TCH/H and of the common channels.

- **Superframe** : The superframe 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.
- **Hyperframe** : The hyperframe is the numbering period. It is 2048 x 51 x 26 x 8 BP long, or 3 hours, 28 minutes, 53 seconds and 760 milliseconds. It is a multiple of all previously cited cycles, and determines all the cycles in the transmission of the radio path. It is in particular the smallest cycle for frequency hopping and for ciphering.

1.5.10 BURST ASSEMBLING

- The burst assembling procedure is in charge of grouping the bits into bursts.
- GSM radio transmission is accomplished by sending data in burst.
- Burst is the physical content of a time slot.
- Each burst consists of 148 usable bits of each 3.69 msec.
- Guard period between the bursts is 30.5 msec. (=8.25 bits) to distinguish consecutive burst.
- Hence each time slot has a fixed length of 156.25 bits (0.577 m sec.)
- Different parts of a burst have special function.
- E.g. of burst part are training sequence, encrypted bits, tail bit, guard period & stealing bit.



Figure 6: Organization of a burst

- **Training sequence bits** Fixed (26 or 41 or 64) bit pattern to train the MS in predicting and correcting signal distortions (due to multi path effects) in the demodulation process.
- **Encrypted bits** - Represents the useful bits of speech, data or signaling to transmit.
- **Tail bits** - To indicate the start (3bits) and end (3bits) of a burst.
- **Stealing Flag bits** - Two bits (Hl and Hu) are located just before and after the TSC in normal burst. To identify the data contained in the bursts Indicate

whether adjacent 57 bits in associated data field contain speech/data or are 'stolen' from the traffic channel for carrying FACCH signaling Information.

- **Guard period (8.25 bits)** - Necessary for switching the transmitter on and off for MS. (Switching off will reduce interference to RF channel)

1.5.11 BURST TYPES

Normal Burst - Two Packets Of 58 encrypted bits (57 data bits+1 stealing bit) are carried for the traffic channel (TCH) or for the control channel (BCCH and CCCH)

Dummy Burst - Transmitted in idle Time slots on the BCCH carrier which ensures that the BCCH is always present. This makes it easier for the MS to find the BCCH carrier and permits assessment of the neighbor cell. It provides two packets of fixed bit pattern without information content.

Synchronization burst - First Burst in the down link direction that a MS needs to process, used on the SCH. Provides a unique 64 bit TSC in order to facilitate the initial demodulation for the MS. The encrypted bit field contain Base Station Identity Code (BSIC) and the TDMA frame Number. Frame Number continuously counted in a Hyper Frame are run from (0 to 2715647)

Access Burst - Short burst used by MS in the Uplink direction at an initial phase of a call when the propagation delay between MS and BTS is not known. Occurs during a first access on the RACH and sometimes upon a hand over to a new cell.

Frequency Correction Burst - Used by the MS to correct its Transmit and Receive Frequency. Sent in down link direction as FCCH. Consists of a bit string of all logical 0's

1.6 RADIO RESOURCE MANAGEMENT

GSM network has adopted various Radio Resource management techniques such as Discontinuous Transmission, Discontinuous Reception, Power Control, Timing Advance and Frequency Hopping.

1.6.1 DISCONTINUOUS TRANSMISSION (DTX)

This is another aspect of GSM that could have been included as one of the requirements of the GSM speech codec. The function of the DTX is to suspend the radio transmission during the silence periods. This can become quite interesting if we take into consideration the fact that a person speaks less than 40 or 50 percent during a conversation. The DTX helps then to reduce interference between different cells and to increase the capacity of the system. It also extends the life of a mobile's battery. The DTX function is performed thanks to two main features:

The Voice Activity Detection (VAD), which has to determine whether the sound represents speech or noise, even if the background noise is very important. If the voice signal is considered as noise, the transmitter is turned off producing then, an unpleasant effect called clipping.

The comfort noise, an inconvenient of the DTX function is that when the signal is considered as noise, the transmitter is turned off and therefore, a total silence is heard at

the receiver. This can be very annoying to the user at the reception because it seems that the connection is dead. In order to overcome this problem, the receiver creates a minimum of background noise called comfort noise. The comfort noise eliminates the impression that the connection is dead.

1.6.2 TIMING ADVANCE

The timing of the bursts transmissions is very important. Mobiles are at different distances from the base stations. Their delay depends, consequently, on their distance. The aim of the timing advance is that the signals coming from the different mobile stations arrive to the base station at the right time. The base station measures the timing delay of the mobile stations. If the bursts corresponding to a mobile station arrive too late and overlap with other bursts, the base station tells, this mobile, to advance the transmission of its bursts.

1.6.3 POWER CONTROL

This is a feature of the GSM air interface which allows the network provider to not only compensate for the distance from MS to BTS as regards timing, but can also cause the BTS and MS to adjust their power output to take account of that distance also. The closer the MS is to the BTS, the less the power it and the BTS will be required to transmit. This feature saves radio battery power at the MS, and helps to reduce co-channel and adjacent channel interference. Both uplink and downlink power settings can be controlled independently and individually at the discretion of the network provider. Initial power setting for the MS is set by the information provided on the Broadcast Control Channel (BCCH) for a particular cell. The BSS controls the transmit power of both the MS and the BTS. The received MS power is monitored by the BSS and the receive BTS power is monitored by the MS and then reported to the BSS. Using these measurements the power of both MS and BTS can be adjusted accordingly

1.6.4 DISCONTINUOUS RECEPTION

DRX allows the MS to effectively “switch off” during times when reception is deemed unnecessary. By monitoring the Broadcast Control Channel (BCCH), the Frequency Correction Control Channel (FCCH) and the Synchronization Control Channel (SCCH) the MS is aware of the Frame Number and repetition format for Frame Synchronization. It can therefore, after initially locking on to a BCCH, determine when the next relevant information is to be transmitted. This allows the MS to ‘go to sleep’ and listen-in only when necessary, with the effective saving in power usage. DRX may only be used when a MS is not in a call. When DRX is employed, the MS using information broadcast on the BCCH determines its “paging group”. The paging group may appear once during a control channel multiframe, or may only be scheduled to appear once over several multiframe – the rate of repetition is determined by the network provider and it is this information which is broadcast over the BCCH, which allows the MS to determine its paging group

1.6.5 FREQUENCY HOPPING

Frequency hopping allows the RF channel used for carrying signaling channel timeslots or traffic channel (TCH) timeslots to change frequency every frame (or 4.615

msec). This capability provides a high degree of immunity to interference, due to the effect of interference averaging, as well as providing protection against signal fading.

The effective “radio channel interference averaging” assumes that radio channel interference does not exist on every allocated channel and the RF channel carrying TCH timeslots changes to a new allocated RF channel every frame. Therefore, the overall received data communication experiences interference only part of the time.

All mobile subscribers are capable of frequency hopping under the control of the BSS.

To implement this feature, the BSS software must include the frequency hopping option. Cyclic or pseudo random frequency hopping patterns are possible, by network provider selection

1.6.6 MULTIPATH AND EQUALISATION

At the GSM frequency bands, radio waves reflect from buildings, cars, hills, etc. So not only the 'right' signal (the output signal of the emitter) is received by an antenna, but also many reflected signals, which corrupt the information, with different phases.

An equalizer is in charge of extracting the 'right' signal from the received signal. It estimates the channel impulse response of the GSM system and then constructs an inverse filter. The receiver knows which training sequence it must wait for. The equalizer will then, comparing the received training sequence with the training sequence it was expecting, compute the coefficients of the channel impulse response. In order to extract the 'right' signal, the received signal is passed through the inverse filter.

1.7 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 delivers very less data rates. Thus GSM has been migrated to newer technologies such as GPRS and EDGE.

2 MAINTENANCE ISSUES OF BTS, NODE-B, AND E-NODE-B

2.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- Functioning of BTS, Node-B, e Node-B
- Common faults in base stations
- Resolution of common fault such as VSWR, Cable Swamping etc
- VSWR Meter functioning
- Alarm Handling
- E node B Troubleshooting

2.2 INTRODUCTION

Traditional mobile service was structured similar to television broadcasting. One very powerful transmitter located at the highest spot in an area would broadcast in a radius of up to fifty kilometers. The Cellular concept structured the mobile telephone network in a different way. Instead of using one powerful transmitter many low-powered transmitters were placed throughout a coverage area. For example, by dividing metropolitan region into one hundred different areas (cells) with low power transmitters using twelve conversations (channels) each, the system capacity could theoretically be increased from twelve conversations using one hundred low power transmitters.

The cellular concept employs variable low power levels, which allows cells to be sized according to subscriber density and demand of a given area. As the populations grow, cells can be added to accommodate that growth. Frequencies used in one cell cluster can be reused in other cells. Conversations can be handed over from cell to cell to maintain constant phone service as the user moves between cells.

2.3 CELLS

A cell is the basic geographic unit of cellular system. The term cellular comes from the honeycomb areas into which a coverage region is divided. Cells are base stations transmitting over small geographic areas that are represented as hexagons. Each cell size varies depending upon landscape. Because of constraint imposed by natural terrain and man-made structures, the true shape of cell is not a perfect hexagon.

A group of cells is called a cluster. No frequencies are reused in a cluster. Features of Digital Cellular Systems:

- Small cells
- Frequency reuse
- Small, battery-powered handsets
- Performance of handovers

2.4 FUNCTIONS OF BTS

- The BTS provides the physical connection of an MS to the network in form of the Air-interface.
- On the other side, toward the NSS, the BTS is connected to the BSC via the Abis-interface.
- The GSM recommendations allow for one BTS to host up to 18 TRXs.

- Each frequency is given a number called as ARFCN (Absolute Radio Frequency Carrier Number).
- In the field, the majority of the BTSs host between one and twelve TRXs. (4+4+4) (3 Sector each with 3 frequencies).
- Radio transmission & reception (TRX).
- Modulation, demodulation, equalization and digitalization of voice and data signals coming from air interface.
- Combining and coupling of RF Signals to antenna.
- Mapping & Transmission of information from BTS to BSC side.
- Alarms generation and Control of over all BTS system.

2.5 MAINTENANCE

STEP-1

- Enter into the BTS room or the shelter (outdoor BTS).
- Do Physical examination of the environment of BTS, Check for fire, smoke, humidity and physical damage to BTS or infrastructure. (Also check alarms).
- If OK proceeds further.

STEP-2

- If alarms are available, go to subsequent step or go sequence by sequence.
- First check the control card and its LEDs. Generally, it contains the media termination also. So, check for media LED if media is down.
- Verify by giving the loop in both the directions.
- If OK, go to check TRX step

STEP-3

- If Control Card itself is faulty, replace it with new one or tested card from other site. Also try to reset the control card so that software can be reloaded to it. If possible, locally access the control card and try to identify the fault.

STEP-4

- If media and control card both is OK, then proceed to the TRX cards.
- Check the LEDs on TRX card (on all cards).
- Mark the TRX card which is showing fault.

STEP-5

- If TRX Card itself is faulty then only in one sector some frequency will not work or sector will not work if BCCH carrier is down, replace it with new one or from tested card from other site.
- If not possible, replace it with other TRX card of same BTS of other sector or same sector but it should not contain the BCCH channel carrier. Also check the cable connection of TRX card and coupler.
- If this occurs frequently check the temperature.

STEP-6

- If TRX Cards are OK, check the coupler card and also the status of RF jumper cable connecting the output of TRX or coupler to the antenna. Look out for VSWR reports.

- Consult with the OMC-R team for physical test and media test. Now if configuration is proper, the BTS should be up and radiating.
- Look out for all LEDs and alarms and take subsequent action.

STEP-7

- If BTS is radiating and calls are not landing
- Check whether BCCH channel is assigned or not.
- If not assigned, assign it. Also check the BCCH channel should not be on hopping frequency.
- Check the availability of SDCCH channel. Sometime TRX is also faulty.

STEP-8

- If BTS is radiating, calls land but are not maturing, there is crosstalk, call drop, interference.
- Check whether BCCH channel is assigned or not. If not assigned, assign it.
- Also check the BCCH channel should not be on hopping frequency and whether the cable has not been swapped. Also check HSN & MAIO with adjacent sector.

2.6 ALARMS IN BTS

There are two classes of alarms in BTS.

- **External Alarms:** These alarms are external in nature and are caused due to environmental conditions or infrastructural failure.
- **Internal Alarms:** They are internal to the BTS system.

2.6.1 EXTERNAL ALARMS

- **Power plant & Battery:** Generally BTS are inside other exchanges so they take power from existing power plant. If not at least 25-50 A module power plant with 200 AH battery set must be provided. The health of the battery is very crucial as at most of the site it is seen that BTS is off due to no battery backup and DG.
- **Engine Alternator:** Ensure the working of engine alternator. Make sure that battery of DG set is working properly and ensure the starting of DG when mains fail. Timely check the DG (periodically test).
- **Air-conditioning:** Check the site condition. Recommended Temperature is 23oC+ 3oC.
- Fire detection system should be available.
- Tower earthing should be proper and separated from DC earth.
- Earthing: Measure earth resistance range <0.5ohms.
- Media: Check the PCM. If possible, give a redundant PCM (optional).
- Shelter: Cleaning of shelter. It should be dust free. No additional items should be available in shelter as it causes troubles.
- VSWR

2.6.2 INTERNAL ALARMS

- BTS fail
- TRX card faulty
- Combiner faulty
- Combiner loss
- Swapping of feeder cable with adjacent sector

- BCCH TRX failure
- High BER in PCM
- Power failure
- Media failure
- Fan failure

2.7 MAINTENANCE ISSUES OF NODE-B

Node B is the telecommunications node in particular mobile communication networks, namely those that adhere to the UMTS standard. The Node B provides the connection between mobile phones (UEs) and the wider telephone network. Node B corresponds to BTS (Base Transceiver station) in GSM. e Node Bs have minimum functionality, and are controlled by an RNC (Radio Network Controller). However, this is changing with the emergence of High-Speed Downlink Packet Access (HSDPA), where some logic (e.g., retransmission) is handled on the Node B for lower response times. A full cell site has a cabinet, an antenna mast and actual antenna. An equipment cabinet contains e.g. RF power amplifiers, digital signal processors and backup batteries. A Node B can serve several cells, also called sectors, depending on the configuration and type of antenna. Common configuration is 3 sectors ($3 \times 120^\circ$).

2.7.1 LOCATING FAULTY EQUIPMENTS

- If RNC has fault, usually it will affect some Sites or all of Sites.
- If NodeB has fault, usually it just affects itself and the handover successful rate of adjacent cells.
- During implementation or expansion, we can “Interchange” NodeB and judge the fault is because of RNC or NodeB
- During maintenance, RNC faults don’t just affect one NodeB.

2.7.2 COMMON FAULT TYPES

RAN fault

- Cell
- Traffic
- Link
- Interconnection
- Clock
- Antenna & Feeder
- Transmission

Operation and maintenance fault

- OMC
- Software Loading

RNO fault

- Access
- Call drop
- Congestion
- Handover

Operation and Maintenance System Faults

Fundamental knowledge of Node-B provides two modes of operation and maintenance.

- Near end operation and maintenance
- Far end operation and maintenance

Case1: Downloading Software Package Lasts Too Long, Sometimes Software Downloading Fails

In the course of software upgrading, it takes several hours to download the software package , and sometimes, the software downloading procedure fails.

Troubleshooting methods

- For maintenance over IPoA through RNC, check whether the IPoA bandwidth on RNC Operation and Maintenance system is too narrow.
- Increase the IPoA bandwidth to speed up software downloading progress based on the actual situation.

Case2: Fail to Log in to NodeB by Near End Mode

In near end maintenance mode, the Operation and Maintenance system can log in to NodeB normally before downloading data configuration file. When NodeB restarts after the data configuration file downloading procedure finishes, the Operation and Maintenance system cannot log in to NodeB by near end mode, but can log in to it over IPoA. In this case, board indicators are normal.

Troubleshooting methods

The reason for this fault may be incorrect setting of IP address of near end maintenance channel.

- Step 1: Log into NodeB over IPoA link through Operation and Maintenance system, configure IP for near end maintenance channel by using the MML command SET IP. Query whether the setting is successful by using the MML command LST IP.
- Step 2: Open the data configuration file on the configuration management system to modify the NodeB property. Modify the local IP address as the value demanded, download the data configuration file again, and then restart the NodeB.

Cell Faults**Case1: No CELL SETUP REQUEST Message from RNC While NodeB in Normal State**

The logical cell cannot be setup. When you perform query with MML command on NodeB Operation and Maintenance system, the local cell resources are available, and both NCP and CCP states are normal. Upon receipt the request of resource audit from NodeB Operation and Maintenance system by MML command ADT RES, RNC delivers only a resource audit command but no CELL SETUP REQUEST message.

Troubleshooting methods

- Step 1: Check whether the maximum downlink power reported by NodeB in the audit message is smaller than the value configured by RNC.
- Step 2: On NodeB Operation and Maintenance system, use the MML command DSP CELL to view whether the local cell ID is consistent with that specified in RNC.

Case2: Cell Deleted and Setup Repeatedly, RNC Multi-Frame Out-of-Synchronization Alarm Occurs, Cell Setup Fails

From the message traced by Iub interface, cell is deleted and setup repeatedly. At the same time, there are multi-frame out-of-synchronization alarms unable to be cleared in RNC. But E1 cable state is available when queried by the MML command DSP E1T1 on NodeB Operation and Maintenance system.

Troubleshooting methods

The most possible cause for this fault is that E1 working mode for NodeB is not consistent with that for RNC, dual-frame for NodeB, and multi-frame for RNC.

Case3: Only One Cell Can Be Setup due to Modification of Cell Radius

Originally, cell 0 and cell 2 can be setup normally. After the radius of both cell 0 and cell 2 is modified from 256*78 m to 1536*78 m, cell 2 is failed to setup. The local cell is unavailable due to lack of baseband resources according to the query result with the corresponding MML command.

Troubleshooting methods

The fault must be caused by lack of access resources. A set of access resources includes an access ASIC and an access DSP. When the cell radius is smaller than or equal to 384*78 m, a set of access resources can support three cells. When the cell radius is greater than 384*78 m, it can support only one cell.

Case4: RNC Deletes Cell after NodeB Responds with Cell and Common Transport Channel Setup

RNC sends a CELL SETUP REQUEST message to NodeB, and NodeB reports a CELL SETUP RESPONSE message to RNC. Then RNC sends two COMMON TRANSPORT CHANNEL SETUP REQUEST messages. Upon receipt of the two COMMON TRANSPORT CHANNEL SETUP RESPONSE messages from NodeB, the RNC sends a CELL DELETION REQUEST message instead of a SYSTEM INFORMATION UPDATE REQUEST message. There is no alarm in NodeB or RNC.

Troubleshooting methods

The fault may be relative to Iub interface user plane. In this case, it is necessary to check the user plane of NodeB and RNC in data configuration and hardware connection to see whether they are consistent.

2.7.3 NODE B FAULT PREVENTION

Hardware installation specifications are most important

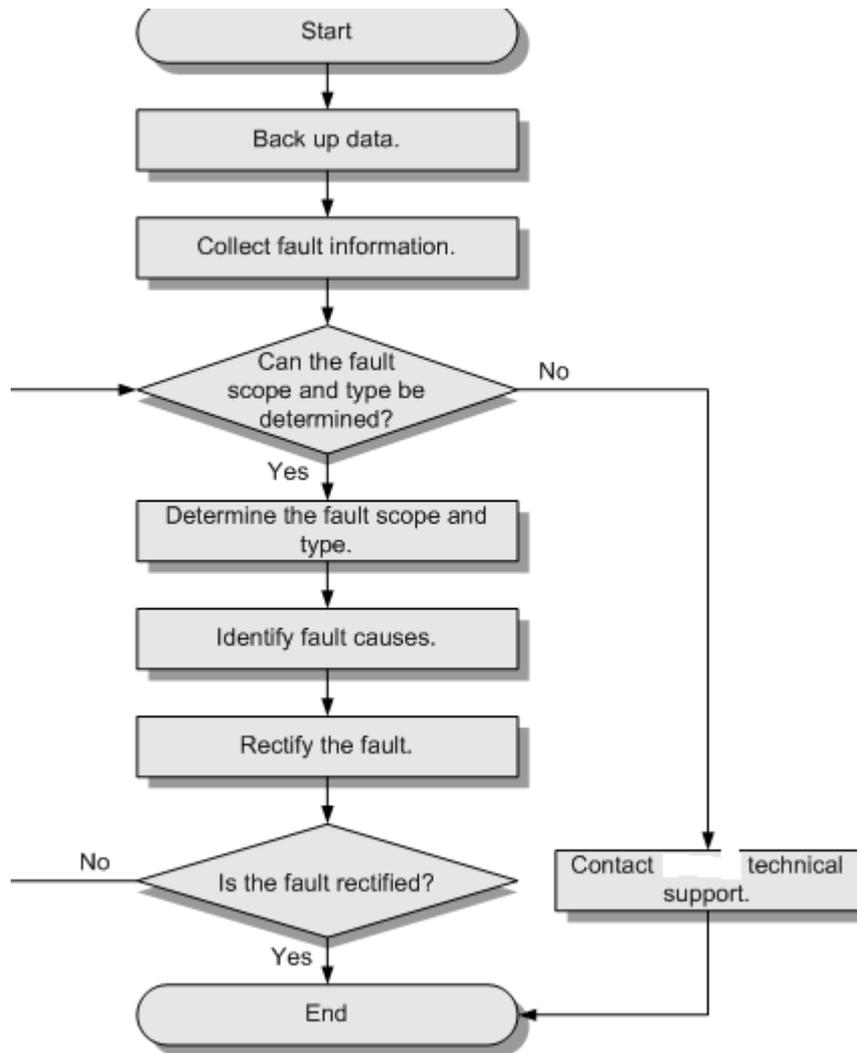
- Pay more attention to E1 connector
- Pay more attention to feeder connector
- Pay more attention to the waterproofed of antenna and feeder system
- Confirm the grounding and lightning protection

Checking Running status

- Node B maintenance console.
- First, do “multi-site fault query”.
- Then, try to remove the fault according to the alarm description and suggestion.
- If you cannot remove the fault provisionally, confirm the reason of every fault at least.

2.8 LTE E NODE B TROUBLESHOOTING

Troubleshooting process



2.8.1 LTE SERVICE FAULTS

Service faults are further classified into the following types:

- Access faults
 - User access fails.
 - The access success rate is low.
- Handover faults
 - The intra-frequency handover success rate is low.
 - The inter-frequency handover success rate is low.
- Service drop faults
 - Service drops occur during handovers.
 - Services are unexpectedly released.
- Inter-RAT interoperability faults
 - Inter-RAT handovers cannot be normally performed.
- Rate faults
 - Data rates are low.
 - There is no data rate.
 - Data rates fluctuate.

2.8.2 LTEQUIPMENT FAULTS

Equipment faults are further classified into the following types:

- Cell faults
 - Cell setup fails.
 - Cell activation fails.
- Operation and maintenance channel (OMCH) faults
 - The OMCH is interrupted or fails intermittently.
 - The CPRI link does not work properly.
 - The S1/X2/SCTP/IPPATH links do not work properly.
 - IP transport is abnormal.
- Clock faults
 - The clock source is faulty.
 - The IP clock link is faulty.
 - The system clock is out of lock.
- Security faults
 - The IPsec tunnel is abnormal.
 - SSL negotiation is abnormal.
 - Digital certificate processing is abnormal.
- Radio frequency faults
 - The standing wave is abnormal.
 - The received total wideband power (RTWP) on the RX channel is abnormal. The antenna line device (ALD) link does not work properly.
- License faults
 - License installation fails.
 - License modification fails.

2.8.3 RECTIFYING THE FAULT

To troubleshoot a fault, take proper measures to eliminate the fault and restore the system, including checking and repairing cables, replacing boards, modifying configuration data, switching over the system, and resetting boards. Maintenance personnel need to clear different faults using proper methods.

After the fault is cleared, be sure to perform the following:

- Perform testing to confirm that the fault has been rectified.
- Record the troubleshooting process and key points.
- Summarize measures of preventing or decreasing such faults. This helps to prevent similar faults from occurring in the future.

2.9 CONCLUSION

For proper working of network maintenance of radio network is very important. Day to day resolution of fault is of prime importance.

3 3G RADIO NETWORK

3.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- 3G Standards and Releases
- CDMA/WCDMA Concept
- WCDMA Codes
- Handovers in 3G
- WCDMA Channels

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 early 80'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 operators 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 2G systems, 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 and load 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 the 3GPP, 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 the 3GPP *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 2001 because 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 14Mbps.

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.

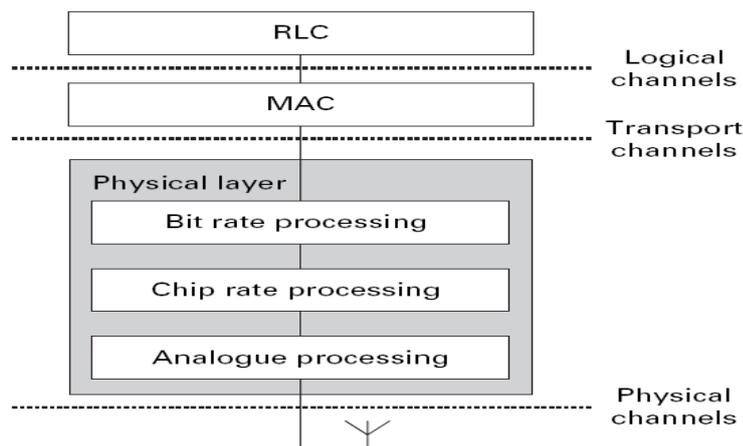


Figure 7: Architecture of the air interface’s transport protocols

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.

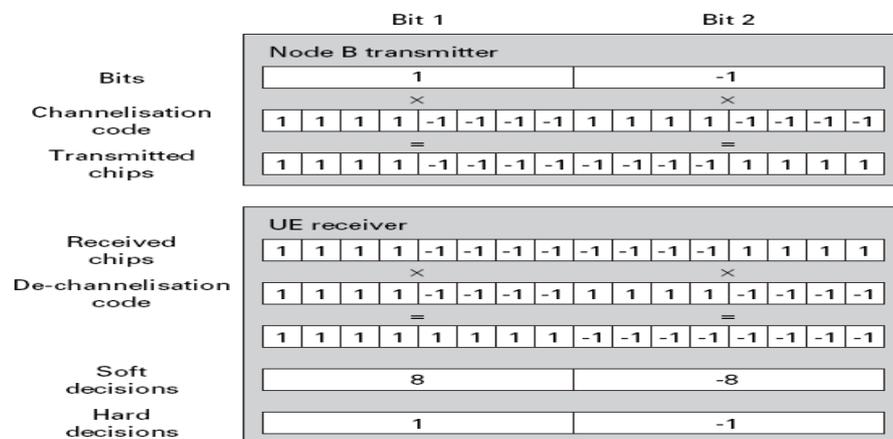


Figure 8: Downlink channelisation and de-channelisation, from a Base Station to a single mobile

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.

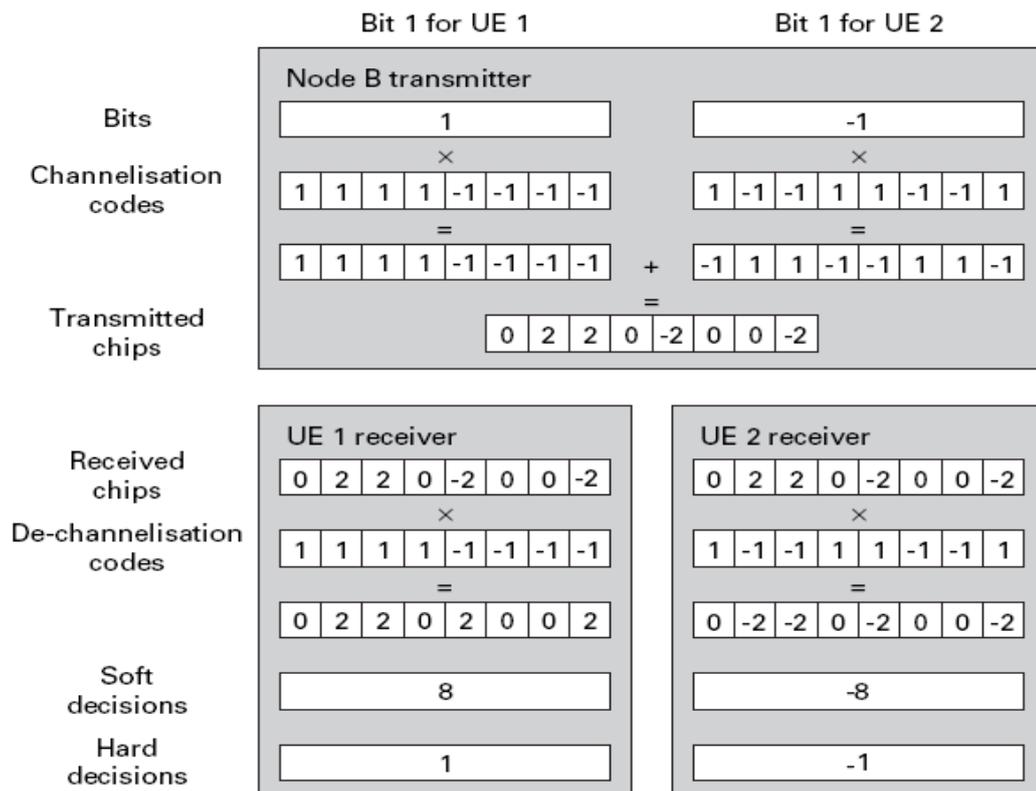


Figure 9: Downlink channelisation & de-channelisation, from a base station to two mobiles

Figure shows what happens if there are two mobiles in the cell. Here, the base station assigns a different channelisation 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 channelisation 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 channelisation 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 channelisation codes are orthogonal.

The complete processing procedures of a WCDMA system is shown in figure . 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.

Processing Procedure of WCDMA System

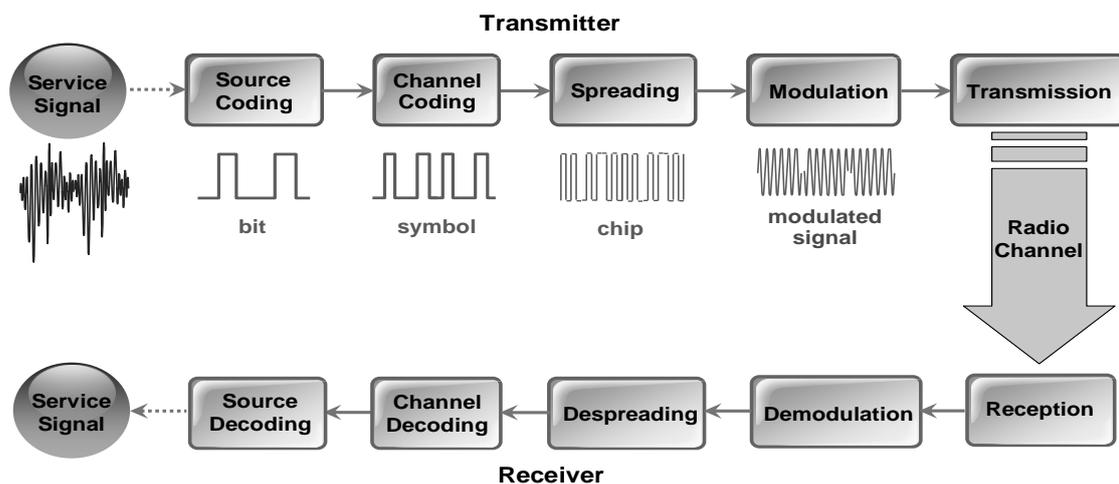


Figure 10: A WCDMA System

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.

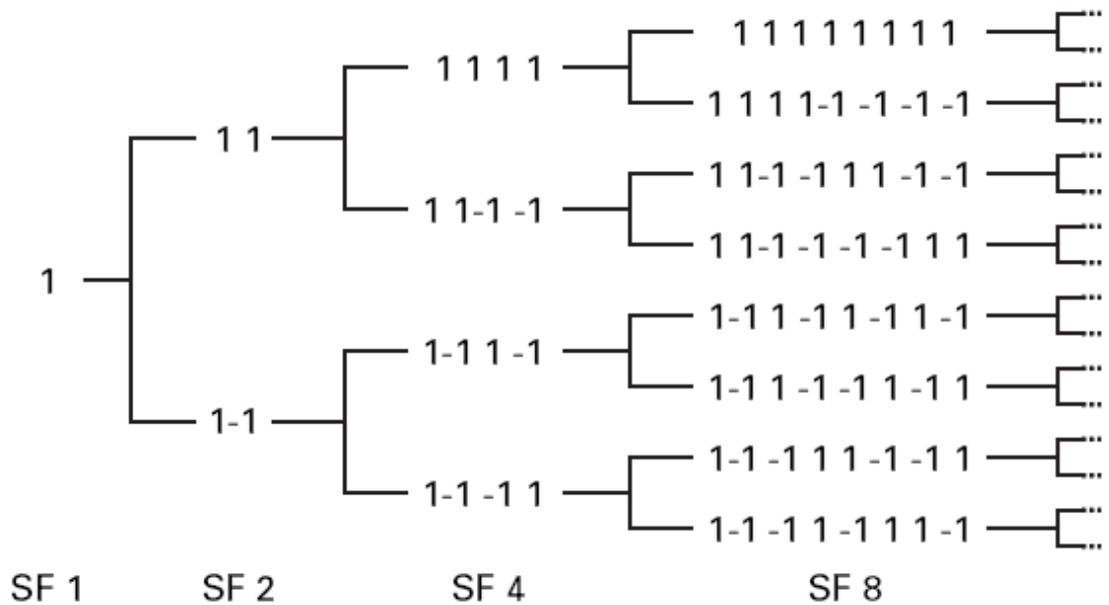


Figure 11: Code Tree

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.

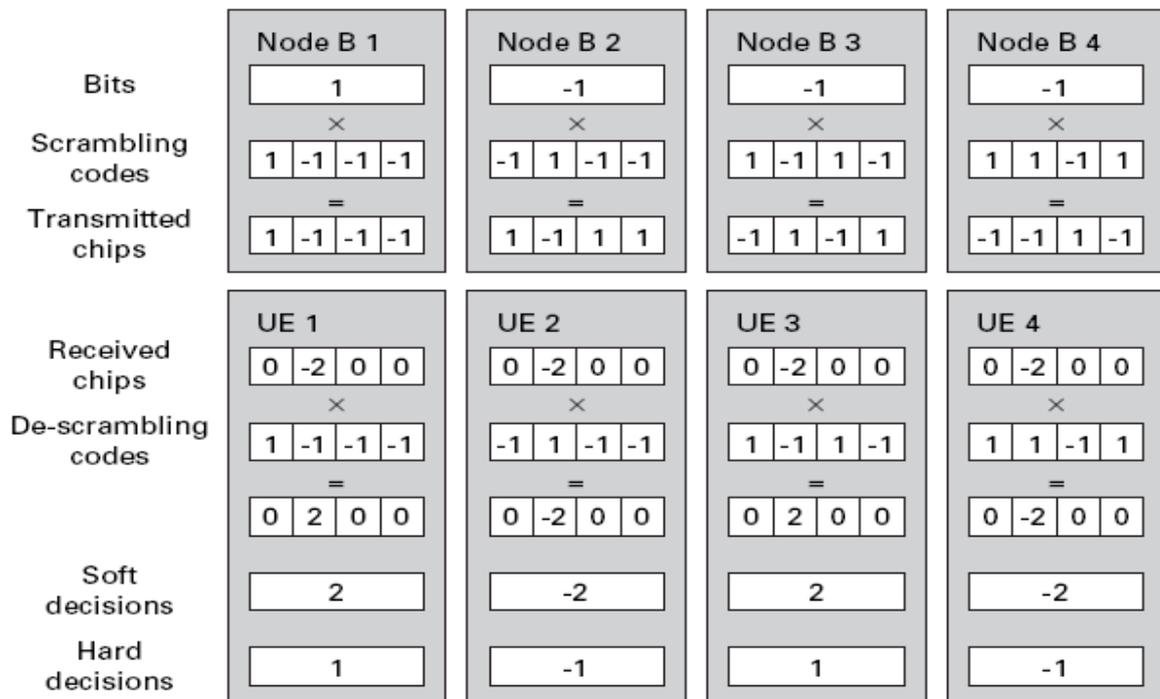


Figure 12: Scrambling and de-scrambling on the downlink

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:

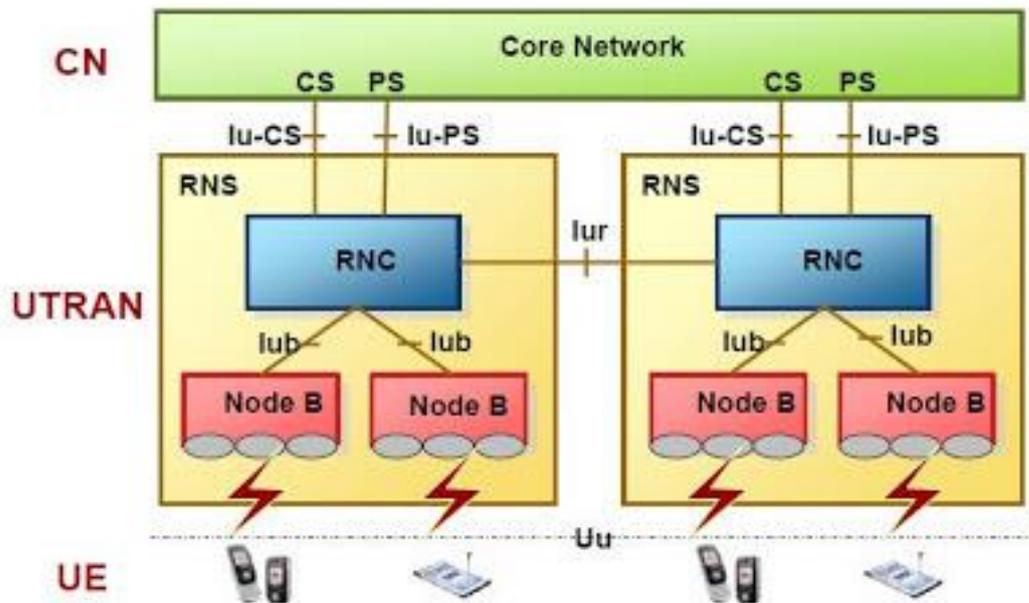


Figure 13: WCDMA Radio Access Network

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.

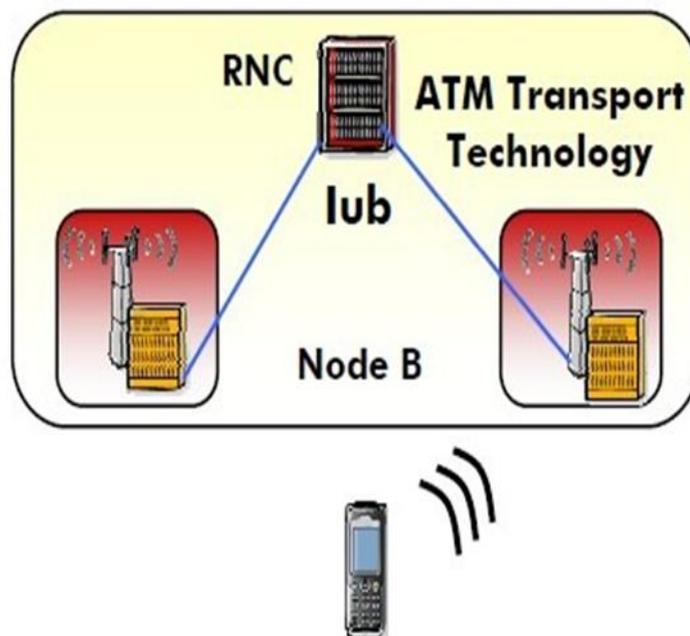


Figure 14: WCDMA Node B

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.

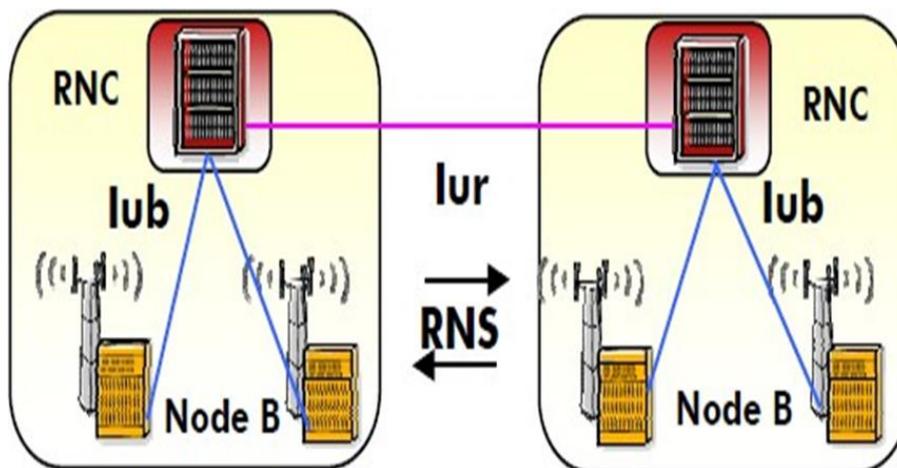


Figure 15: Radio Network Controller

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.

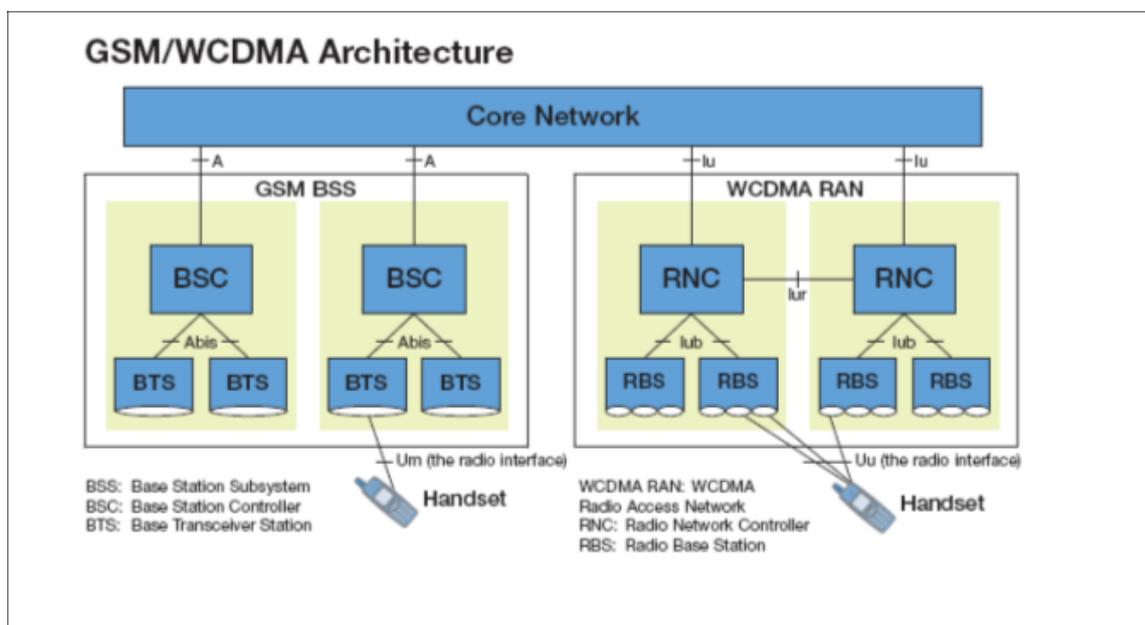


Figure 16: WCDMA Architecture

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 updates power levels 1500 times every second. By doing 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 17: 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.

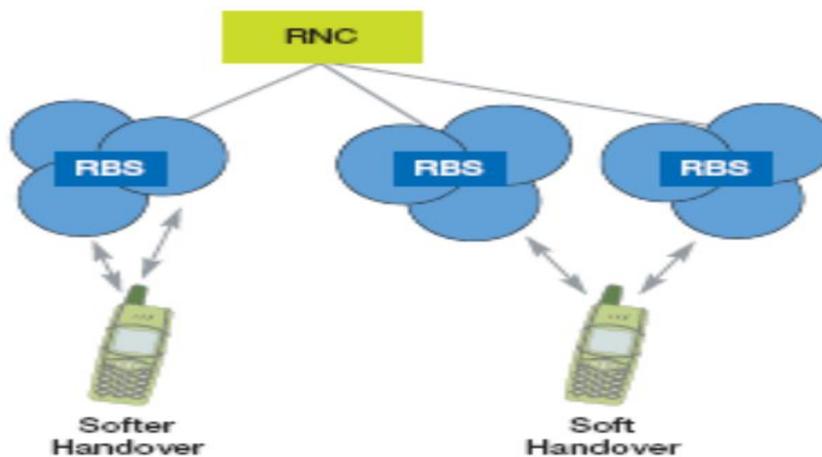


Figure 18: Inter System Handover

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 CONCLUSION

WCDMA is very successful technology due to its robust radio network design. 3G has got an add-on feature with the introduction of HSPA and HSPA+.

4 3G CORE NETWORK

4.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- UMTS Network Component
- 3G Core Network
- Elements of 3G Core
- Functionalities of 3G Core Network Elements

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,

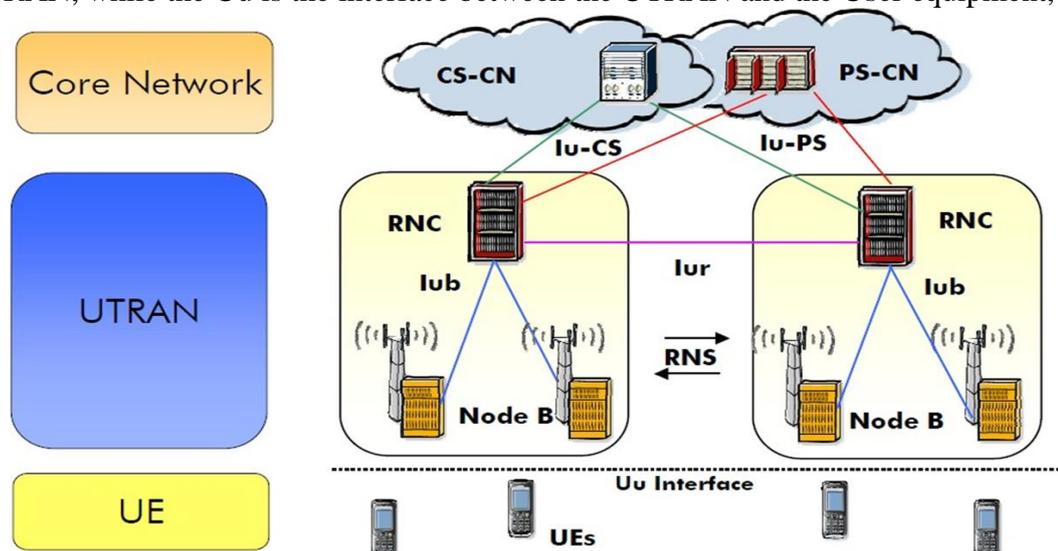


Figure 19: UMTS Release 99 Architecture

4.3 3G 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.

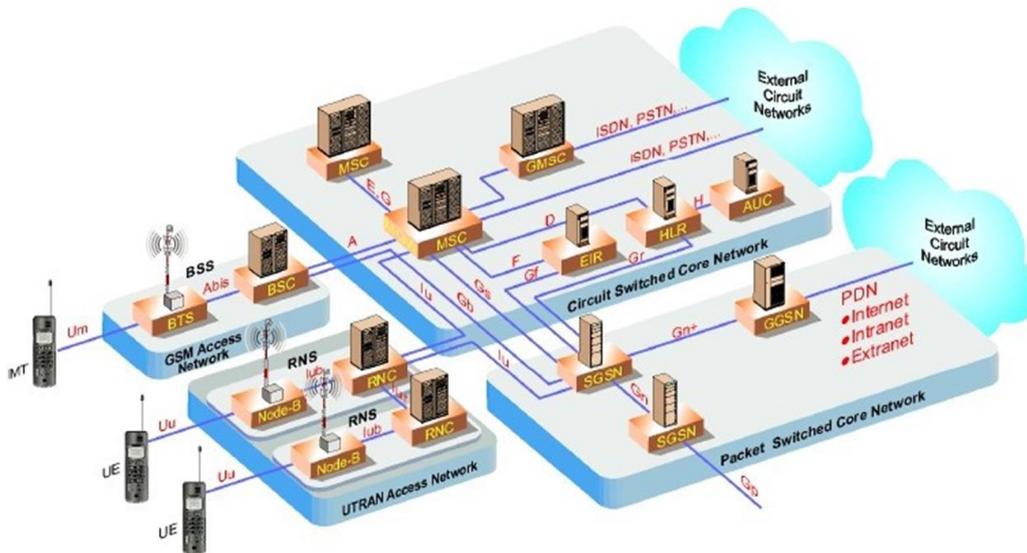


Figure 20: UMTS Core Network

4.4 CIRCUIT SWITCHED CORE NETWORK

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

4.4.1 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.

4.4.2 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.

4.5 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:

4.5.1 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).

4.5.2 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.

4.5.3 BORDER GATEWAY (BG)

The BG provides connectivity, and interworking and roaming capabilities between two different PLMNs.

4.6 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:

4.6.1 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.

4.6.2 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.

4.6.3 EQUIPMENT IDENTITY REGISTER (EIR)

The EIR is the entity that decides whether a 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.

4.6.4 AUTHENTICATION CENTRE (AUC)

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

4.6.5 EQUIPMENT IDENTITY REGISTER (EIR)

The EIR stores information on mobile equipment identities.

4.6.6 SMS MSCS

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

4.7 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).

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

Figure 21: 3GPP Releases

4.8 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:

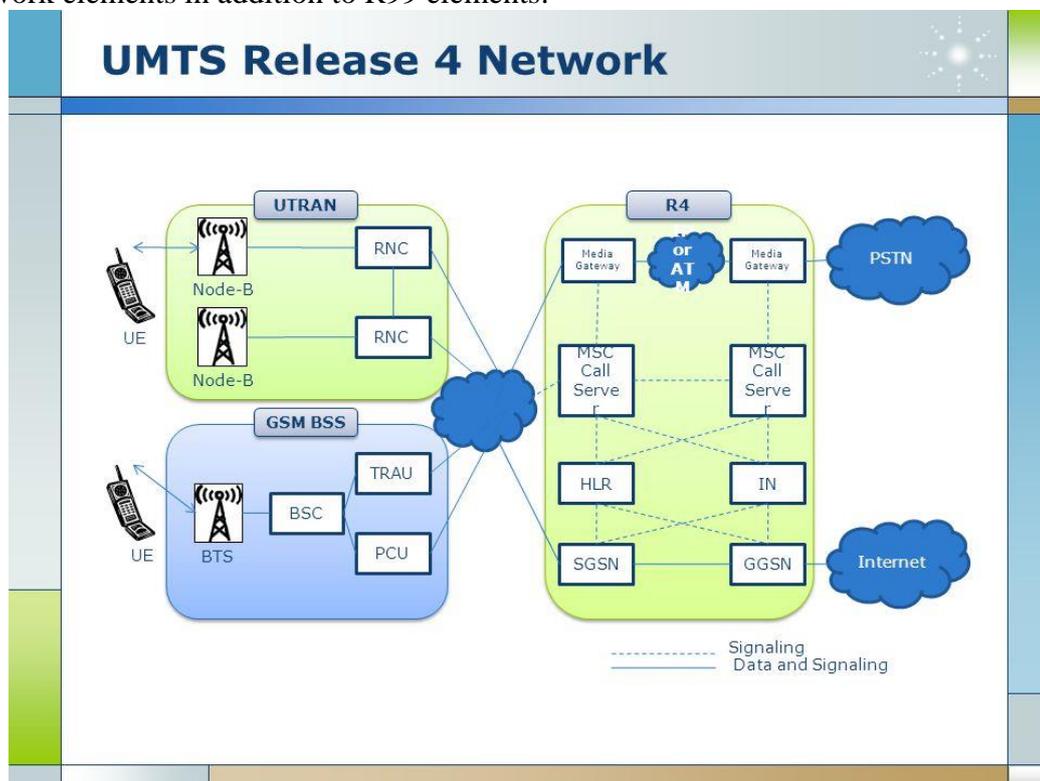


Figure 22: UMTS Release 4 Architecture

4.8.1 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.

4.8.2 GMSC SERVER

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

4.8.3 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 for an illustration of 3GPP Release 4 network architecture.

4.9 3GPP 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 ServerControl Function (CSCF), Media Gateway Control Function (MGCF) and the Multimedia Resource Function (MRF).

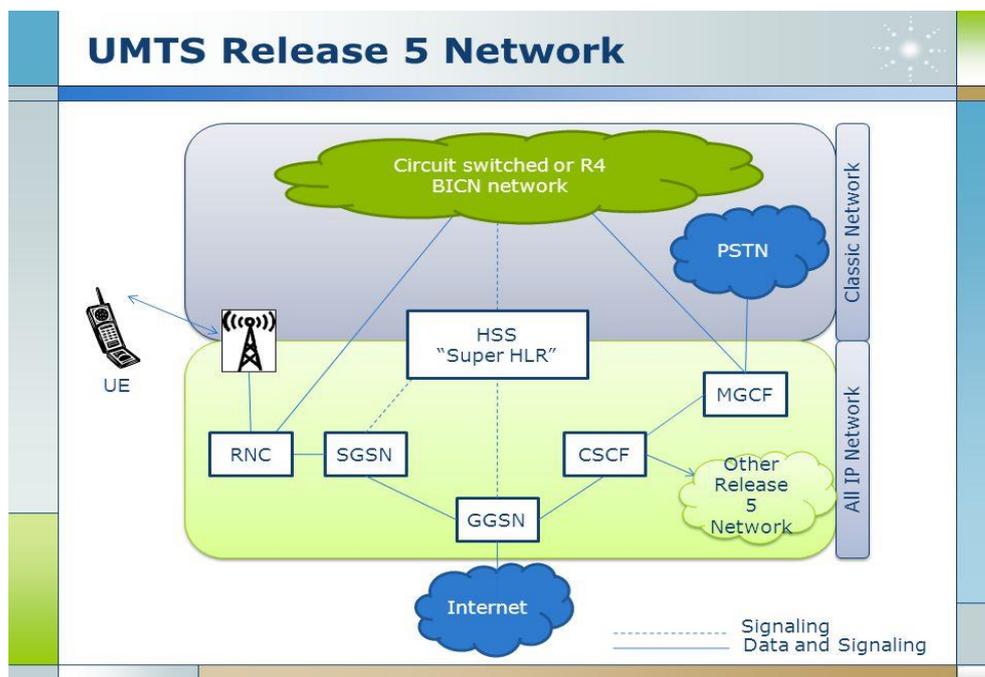


Figure 23: UMTS Release 5 Architecture

4.10 CONCLUSION

The 3G Network is designed for data delivery, but up to release 4 legacy network is also accommodated in the same. After release 5 core network is converted to complete IP based network.

5 3G CALL PROCESSING (VOICE AND DATA)

5.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- 3G Mobile Originated Call
- 3G Terminated Voice Call
- Data Attach/Detach processes
- 3G Data Call Flow.

5.2 ARCHITECTURE FOR UMTS 3G CALL HANDLING

The architecture for handling a basic Mobile Originated (MO) call and a basic Mobile Terminated Call (MT) are shown in Fig. A basic mobile-to-mobile call is treated as the concatenation of an MO call and an MT call.

5.2.1 ARCHITECTURE FOR AN MO CALL

A basic mobile originated call involves signaling between the MS and its Visiting MSC (VMSC) via the BSS, between the VMSC and the VLR and between the VMSC and the destination exchange, as indicated in figure

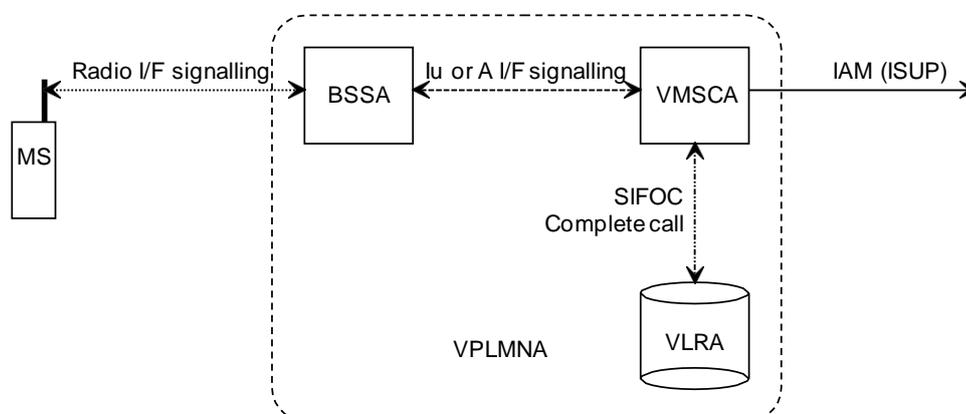


Figure 24: Architecture for a basic mobile originated call

The term BSS is used to denote a UTRAN BSS. The term ISUP is used to denote the telephony signaling system used between exchanges. In a given network, any telephony signaling system may be used.

When the user of an MS wishes to originate a call, the MS establishes communication with the network using radio interface signaling, and sends a message containing the address of the called party. VMSCA requests information to handle the outgoing call (SIFOC) from VLRA, over an internal interface of the MSC/VLR. If VLRA determines that the outgoing call is allowed, it responds with a Complete Call. VMSCA:

- establishes a traffic channel to the MS; and
- constructs an ISUP IAM using the called party address and sends it to the destination exchange.

5.2.2 ARCHITECTURE FOR AN MT CALL

A basic mobile terminated call involves signaling as indicated in figure below. Communication between VMSCB and the MS is via the BSS, as for the mobile originated case. If VPLMNB supports GPRS and the Gs interface between VLRB and the SGSN is implemented and there is an association between VLRB and the SGSN for the MS, the

paging signal towards the MS goes from VMSCB via VLRB and the SGSN to the BSS. The IPLMN(Interrogating PLMN) , containing GMSCB, is in principle distinct from HPLMNB (Home Public Land Mobile Network B), containing HLRB, but the practice for at least the majority of current UMTS or GSM networks is that a call to an MS will be routed to a GMSC in HPLMNB.

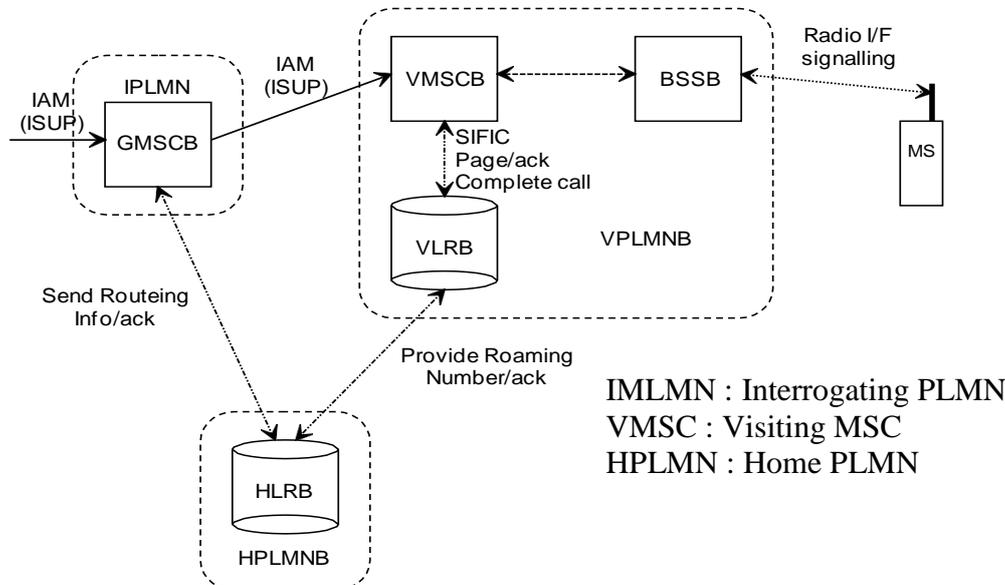


Figure 25: Architecture for a basic mobile terminated call

When GMSCB receives an ISUP IAM, it requests routing information from HLRB using the MAP protocol. HLRB requests a roaming number from VLRB, also using the MAP protocol, and VLRB returns a roaming number in the Provide Roaming Number Ack. HLRB returns the roaming number to GMSCB in the Send Routing Info ack. GMSCB uses the roaming number to construct an ISUP IAM, which it sends to VMSCB. When VMSCB receives the IAM, it requests information to handle the incoming call (SIFIC) from VLRB, over an internal interface of the MSC/VLR. If VLRB determines that the incoming call is allowed, it requests VMSCB to page the MS. VMSCB pages the MS using radio interface signalling. When the MS responds, VMSCB informs VLRB in the Page ack message. VLRB instructs VMSCB to connect the call in the Complete call, and VMSCB establishes a traffic channel to the MS.

5.2.3 ARCHITECTURE FOR A TO CALL

A basic trunk originated call involves signaling between the PSTN and the PLMN's MSC, as indicated in figure. The originating exchange may also be another MSC of the same or different PLMN.

The MSC may also be connected to PBX but that is outside the scope of this document. In the PBX case same modelling applies but the PBX signaling is different to ISUP.

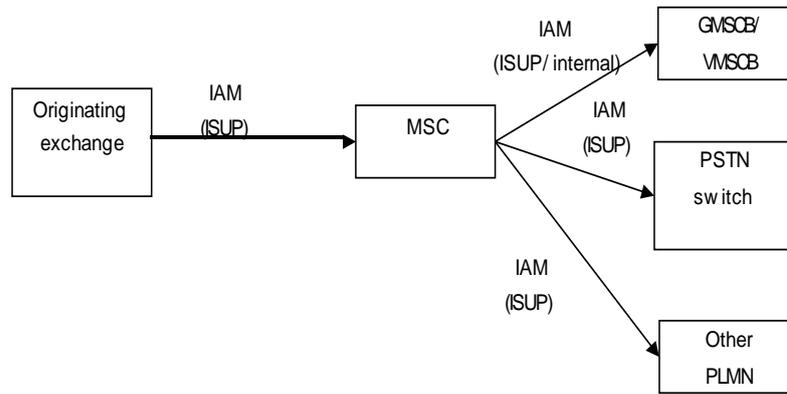


Figure 26: Architecture for a basic trunk originated call

The term ISUP is used to denote the telephony signaling system used between exchanges. In a given network, any telephony signaling system may be used.

The MSC receives a setup (IAM) message from the originating exchange. The MSC analyses the called party number and routes the call to an appropriate destination. If the called party number is an MSISDN the gateway MSC functionality is activated. If the MSISDN belongs to another PLMN (or is ported out), the call is routed to another PLMN. If the called number is a PSTN number then the call is routed to (appropriate) PSTN operator. There may be other destinations also.

5.2.4 INFORMATION FLOW FOR AN MO CALL

An example information flow for an MO call is shown in figure; many variations are possible. Signaling over the radio interface between MSA and BSSA or VMSCA is shown by dotted lines; signaling over the Iu interface (for UMTS) or the A interface (for GSM) between BSSA and VMSCA is shown by dashed lines; signaling over the B interface between VMSCA and VLRA is shown by chain lines; and ISUP signaling between VMSCA and the destination exchange is shown by solid lines.

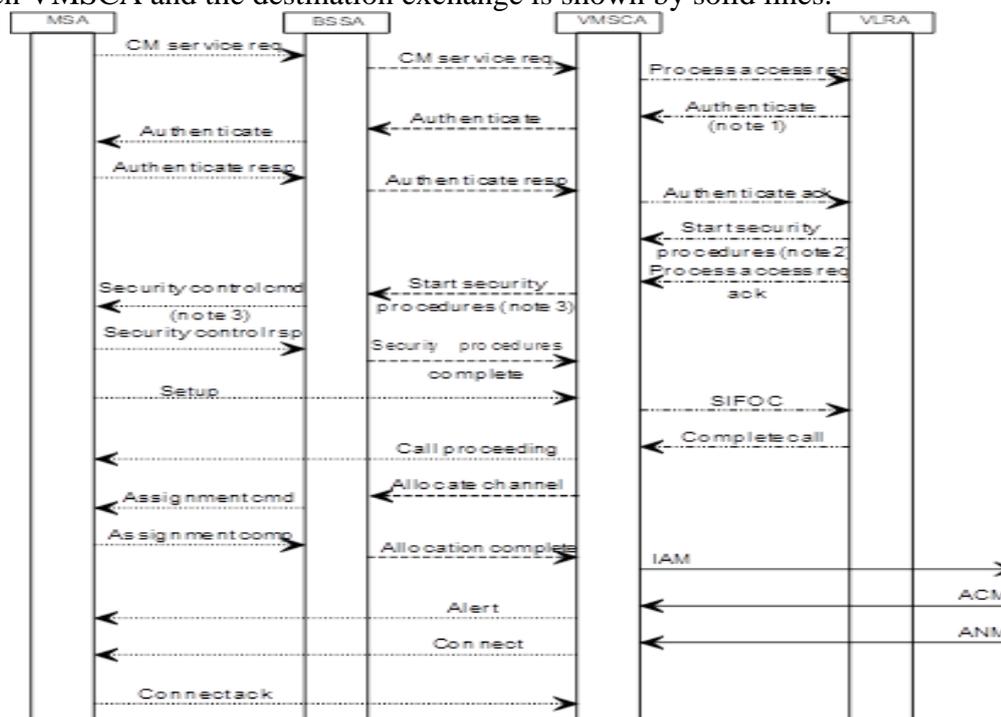


Figure 27: Information flow for a basic mobile originated call

NOTE 1: Authentication may occur at any stage during the establishment of an MO call; its position in this message flow diagram is an example.

NOTE 2: Security procedures may be initiated at any stage after authentication; the position in this message flow diagram is an example.

NOTE 3: If ciphering is not required for a GSM connection, the MSC may send a CM service accept towards the MS; optionally it may instead send a "start ciphering" request indicating that no ciphering is required. This option is not available for a UMTS connection.

NOTE 4: The network may request the IMEI from the MS, and may check the IMEI, at any stage during the establishment of an MO call, either as part of the procedure to start security procedures or explicitly after security procedures have started; this is not shown in this message flow diagram.

When the user wishes to originate a call, MSA establishes a signalling connection with BSSA, and sends a Connection Management (CM) service request to BSSA, which relays it to VMSCA. VMSCA sends a Process Access Request to VLRA. VLRA may then initiate authentication, as described in 3GPP TS 33.102 [32] for UMTS and 3GPP TS 43.020 [1] for GSM. VLRA may also initiate security procedures at this stage, as described in 3GPP TS 33.102 [32] for UMTS and 3GPP TS 43.020 [1] for GSM. If the user originates one or more new MO calls in a multical configuration, MSA sends a CM service request through the existing signalling connection for each new call.

If the MS has performed the Connection Management (CM) service request in a CSG cell, VLRA shall control if the CSG cell is allowed by the CSG subscription data stored in VLRA. If the CSG cell is not allowed, VLRA shall reject the Process Access Request.

If the MS has performed the Connection Management (CM) service request in a hybrid cell, VLRA shall set the CSG membership status in the Process Access Request ack according to the CSG subscription data stored in VLRA.

If VLRA determines that MSA is allowed service, it sends a Process Access Request ack to VMSCA. If VMSCA has received a Start security procedures message from VLRA, the Process Access Request ack message triggers a Start security procedures message towards BSSA; otherwise VMSCA sends a CM Service Accept message towards BSSA.

If BSSA receives a Start security procedures message from VMSCA, it initiates security procedures as described in 3GPP TS 33.102 [32] for UMTS and 3GPP TS 43.020 [1] for GSM; when security procedures have been successfully initiated, MSA interprets this in the same way as a CM Service Accept. If security procedures are not required at this stage, BSSA relays the CM Service Accept to MSA.

When MSA has received the CM Service Accept, or security procedures have been successfully initiated, MSA sends a Set-up message containing the B subscriber address via BSSA to VMSCA. MSA also uses the Set-up message to indicate the bearer capability required for the call; VMSCA translates this bearer capability into a basic service, and determines whether an interworking function is required. VMSCA sends to VLRA a request for information to handle the outgoing call, using a Send Info For Outgoing Call (SIFOC) message containing the B subscriber address.

If VLRA determines that the call should be connected, it sends a Complete Call message to VMSCA. VMSCA sends a Call Proceeding message via BSSA to MSA, to indicate that the call request has been accepted, and sends an Allocate channel message to BSSA, to trigger BSSA and MSA to set up a traffic channel over the radio interface. The Call Proceeding message includes bearer capability information if any of the negotiable parameters of the bearer capability has to be changed. When the traffic channel

assignment process is complete (indicated by the Allocation complete message from BSSA to VMSCA), VMSCA constructs an ISUP IAM using the B subscriber address, and sends it to the destination exchange.

When the destination exchange returns an ISUP Address Complete Message (ACM), VMSCA sends an Alerting message via BSSA to MSA, to indicate to the calling user that the B subscriber is being alerted.

When the destination exchange returns an ISUP ANswer Message (ANM), VMSCA sends a Connect message via BSSA to MSA, to instruct MSA to connect the speech path.

The network then waits for the call to be cleared.

For an emergency call, a different CM service type (emergency call) is used, and the mobile may identify itself by an IMEI. It is a network operator option whether to allow an emergency call when the mobile identifies itself by an IMEI.

5.2.5 INFORMATION FLOW FOR RETRIEVAL OF ROUTING INFO FOR AN MT CALL

The information flow for retrieval of routing information for an MT call is shown in figure ISUP signalling between the originating exchange and GMSCB, and between GMSCB and VMSCB is shown by solid lines; signalling over the MAP interfaces between GMSCB and HLRB and between HLRB and VLRB, and over the B interface between VLRB and VMSCB is shown by chain lines; signalling over the Iu interface (for UMTS) or the A interface (for GSM) between VMSCB and BSSB is shown by dashed lines; and signalling over the radio interface between BSSB and MSB is shown by dotted lines.

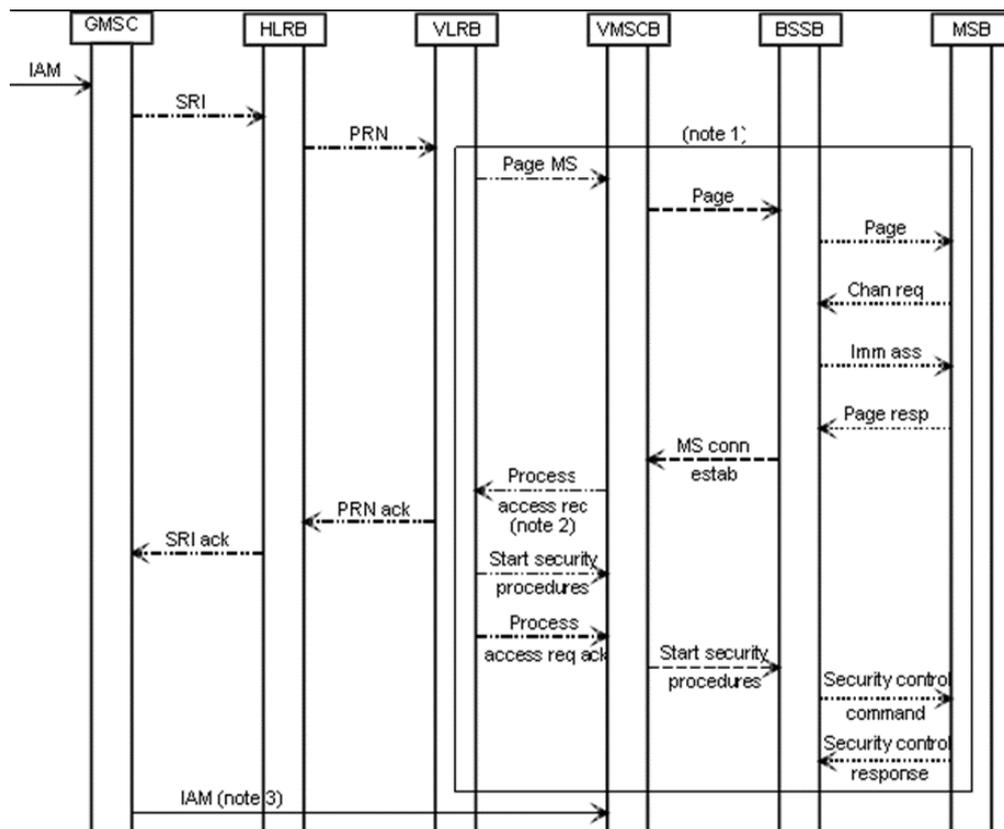


Figure 28: Information flow for retrieval of routing information for a basic mobile terminated call

NOTE 1: If pre-paging is used, paging is initiated after VLRB has accepted the PRN message.

NOTE 2: VMSCB starts the timer for the release of radio resources after it sends the Process Access Request message to VLRB. VMSCB releases the radio resource allocated for the MT call if the timer expires before the IAM is received, and when the MAP RELEASE_RESOURCES message is received from the GMSC.

NOTE 3: If an ISUP REL message is received at the GMSC between sending of SRI and receiving of SRI ack, the GMSC does not send IAM to the VMSC. Instead a MAP Release_Resources message may be sent to the VMSC.

When GMSCB receives an IAM, it analyses the called party address. If GMSCB can derive an HLR address from the B party address, it sends a request for routing information (SRI) to HLRB. If GMSCB supports pre-paging (i.e. it is prepared to wait long enough for the SRI ack to allow pre-paging to be completed), it indicates this by an information element in the SRI message.

HLRB decides whether pre-paging is supported according to the following criteria:

GMSCB has indicated that it supports pre-paging; and

HLRB supports pre-paging (i.e. it is prepared to wait long enough for the PRN ack to allow pre-paging to be completed).

HLRB sends a request for a roaming number (PRN) to VLRB; if pre-paging is supported, it indicates this by an information element in the PRN message. If Paging Area function is supported in HLRB then HLRB sends the paging area if stored in HLR. VLRB returns the roaming number in the PRN ack, and HLRB relays the roaming number to GMSCB in the SRI ack. GMSCB constructs an IAM using the roaming number, and sends it to VMSCB.

If the GMSC performs domain selection through HLR interrogation and the HLR supports domain selection functionality, HLRB executes domain selection functionality. The HLR shall:

send PRN to VLRB as defined in this section, if the result of domain selection is to handle the call in CS domain; or

reply with SRI ack without sending PRN to VLRB, if the result of domain selection is to transfer the call from CS domain to IMS domain.

5.2.6 INFORMATION FLOW FOR AN MT CALL

An example information flow for an MT call is shown in figure ; many variations are possible. ISUP signalling between GMSCB and VMSCB is shown by solid lines; signalling over the B interface between VMSCB and VLRB is shown by chain lines; signalling over the Iu interface (for UMTS) or the A interface (for GSM) between VMSCB and BSSB is shown by dashed lines; and signalling over the radio interface between VMSCB or BSSB and MSB is shown by dotted lines. NOTE 1: Security procedures may be initiated at any stage after the network has accepted the page response; the position in this message flow diagram is an example.

NOTE 2: If Security procedures are not required, the MSC may send a Start security procedures message indicating that no ciphering is required.

NOTE 3: This message flow diagram assumes that the MS has already been authenticated on location registration. If this is not so (for the first MT call after VLR restoration), the network may initiate authentication after the MS responds to paging.

NOTE 4: The network may request the IMEI from the MS, and may check the IMEI, at any stage after the MS responds to paging, either as part of the procedure to start

security procedures or explicitly after security procedures have been started; this is not shown in this message flow diagram.

NOTE 5: If a connection between MSCB and MSB has been established as a result of pre-paging, the paging procedure is not performed.

NOTE 6: If a connection between MSCB and MSB has been established as a result of pre-paging, VLRB sends the Call arrived message to MSCB to stop the guard timer for the release of the radio connection.

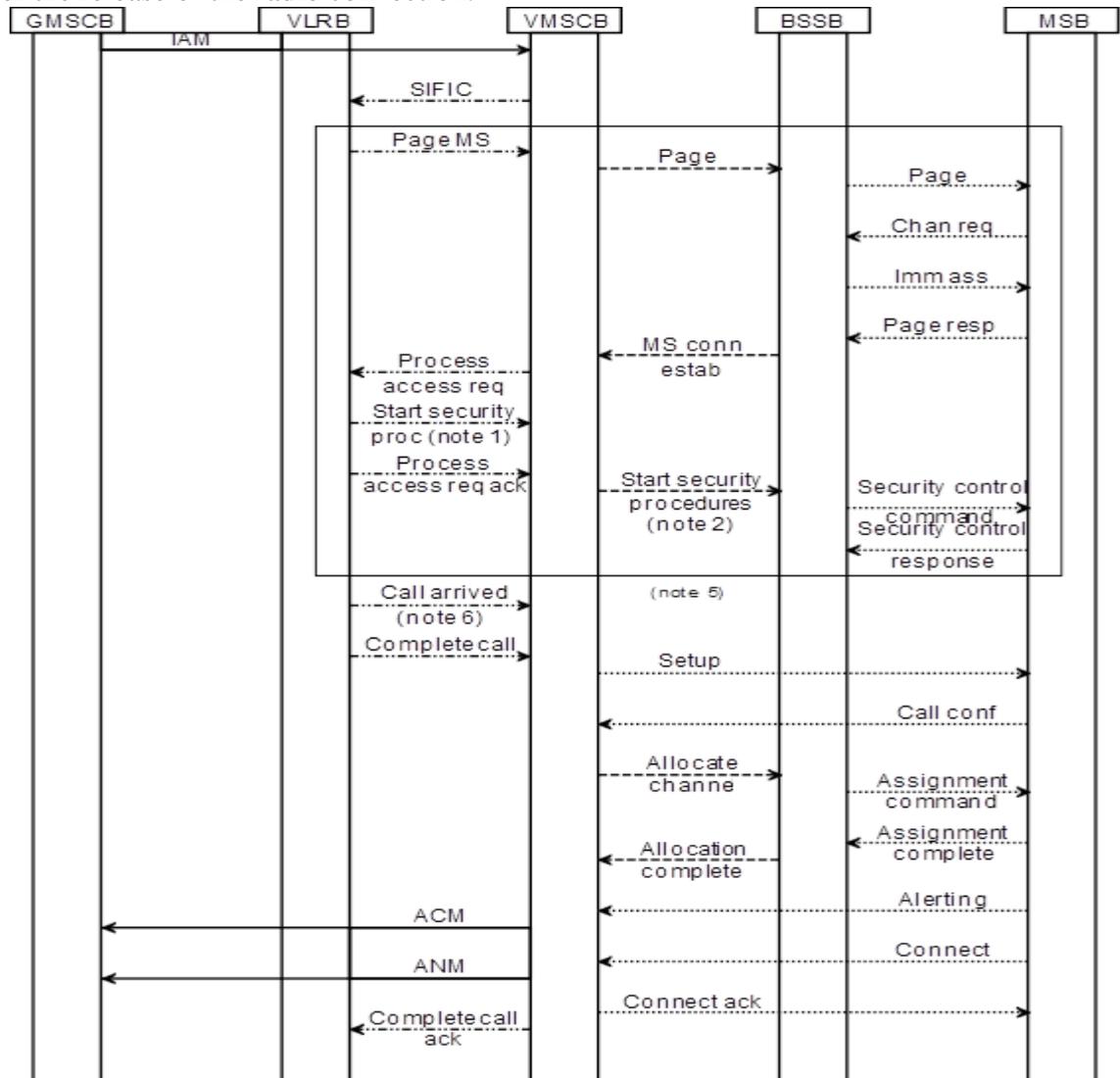


Figure 29: Information flow for a basic mobile terminated call

When VMSCB receives an IAM from GMSCB it sends to VLRB a request for information to handle the incoming call, using a Send Info For Incoming Call (SIFIC) message containing the roaming number received in the IAM.

If VLRB recognizes the roaming number, and MSB is allowed service, it sends a request to VMSCB to page MSB. If a radio connection between the network and MSB is already established, VMSCB responds immediately to the page request. If no radio connection exists, VMSCB sends a page request to BSSB, and BSSB broadcasts the page on the paging channel. If VPLMNB supports GPRS and the Gs interface between VLRB and the SGSN is implemented (see 3GPP TS 23.060 [9]) and there is a valid association between VLRB and the SGSN for the MS, the paging signal towards the MS goes from VMSCB via VLRB and the SGSN to the BSS.

If MSB detects the page, it sends a channel request to BSSB, which responds with an immediate assignment command, to instruct MSB to use the specified signalling channel. MSB then sends a page response on the signalling channel; BSSB relays this to VMSCB. VMSCB sends a Process access request message to VLRB to indicate that MSB has responded to paging. VLRB may then initiate authentication, as described in 3GPP TS 33.102 [32] for UMTS and 3GPP TS 43.020 [1] for GSM. VLRB may also initiate security procedures at this stage, as described in 3GPP TS 33.102 [32] for UMTS and 3GPP TS 43.020 [1] for GSM.

If the MS is paged in a CSG cell, VLRB shall control if the CSG cell is allowed by the CSG subscription data stored in VLRB. If the CSG cell is not allowed, VLRB shall reject the Process Access Request.

If the MS is paged in a hybrid cell, VLRB shall set the CSG membership status in the Process Access Request ack according to the CSG subscription data stored in VLRB.

VLRB may restore CSG data from CSS for a MT call after a VLRB restart.

If VLRB determines that MSB is allowed service, it sends a Process access request ack to VMSCB. The Process access request ack message triggers a Start security procedures message towards BSSB; if VMSCB has not received a Start security procedures message from VLRB, the Start security procedures message indicates no ciphering.

VLRB then sends a Complete call message to VMSCB. VMSCB sends a Set-up message towards MSB. The Set-up message may include bearer capability information for the call.

When MSB receives the Set-up message from BSSB, it responds with a Call confirmed message. The Call Confirmed message includes bearer capability information if any of the negotiable parameters of the bearer capability has to be changed. When VMSCB receives the Call confirmed message via BSSB, it sends an Allocate channel message to BSSB. BSSB instructs MSB to tune to a traffic channel by sending an Assignment command. When MSB has tuned to the specified traffic channel it responds with an Assignment complete, message, which BSSB relays to VMSCB as an Allocation complete, and sends an Alerting message to indicate that the called user is being alerted. VMSCB sends an ACM to GMSCB, which relays it to the originating exchange.

When the called user answers, MSB sends a Connect message, which BSSB relays to VMSCB. VMSCB:

- responds with a Connect ack message towards MSB.
- sends an ANM to GMSCB, which relays it to the originating exchange.
- sends a Complete call ack to VLRB.
- the network then waits for the call to be cleared.

5.3 DETAILS CALL FLOW DIAGRAM

5.3.1 BASIC MOBILE ORIGINATING CIRCUIT SWITCHED CALL DIAGRAM

A 3G UMTS originating voice call setup involves complex signalling to setup and release the call.

In this Procedure the UE is attached to the Network in Idle mode. The following steps need to be executed in order for a MO call to complete:

- RRC Connection Setup
- Service Request
- Security Procedures (Identity / Authentication / Security mode)

- Call Setup Request
- Radio Link and RAB Configuration
- Call Connection

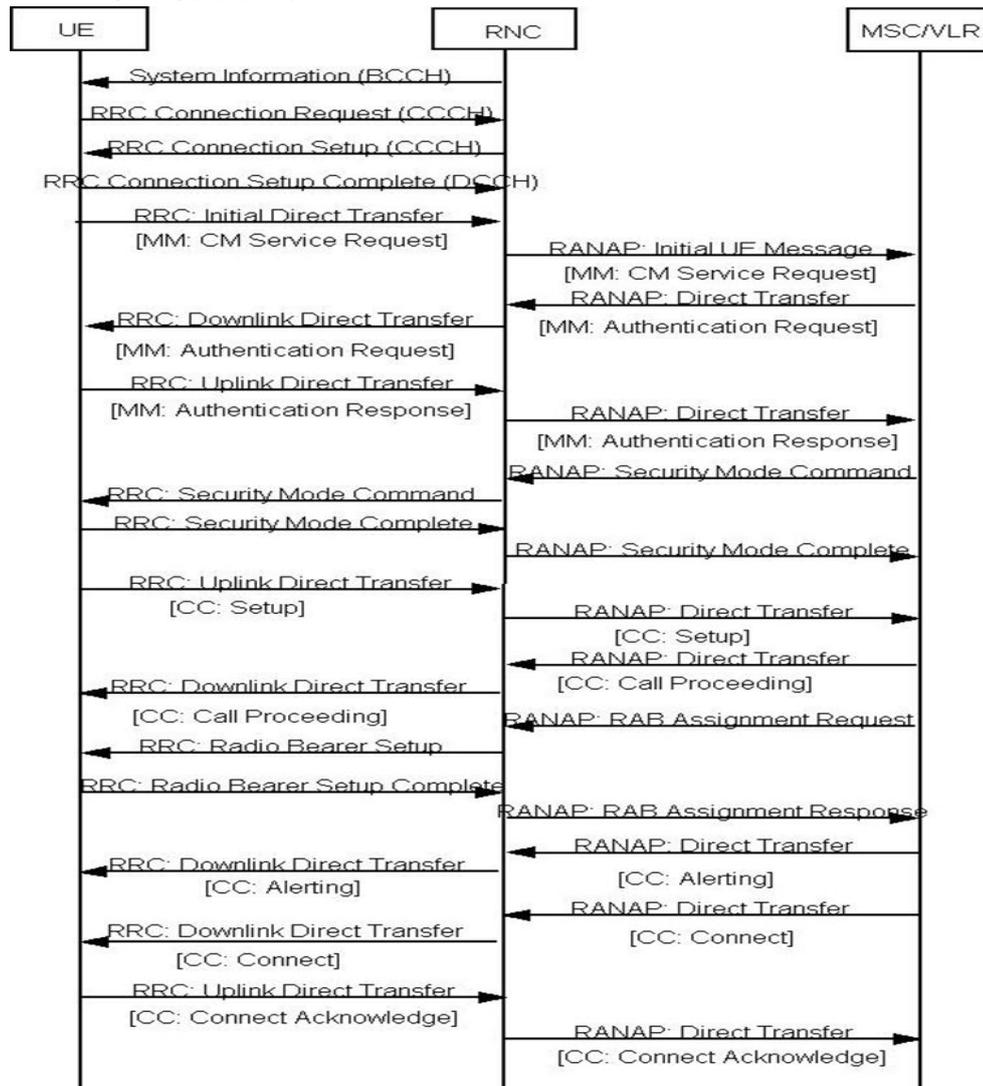


Figure 30: Mobile Originated Circuit Switched Call flow

Call Control (CC) Messages exchanged between CC entity of UE and CC entity of network are summarized below for MO call establishment:

- (UE) SETUP >>>(NETWORK)
- (UE)<<< CALL PROCESSING (NETWORK)
- (UE)<<< ALERTING (NETWORK)
- (UE)<<< CONNECT (NETWORK)
- (UE) CONNECT ACK >>>(NETWORK)

5.3.2 BASIC MOBILE TERMINATING CIRCUIT SWITCHED CALL FLOW

The following steps need to be executed in order for a MT call to complete:

- RRC Paging
- RRC Connection setup
- Security Procedures (Identity / Authentication / Security mode)
- Call confirmed
- Radio bearer setup

- Alerting
- Connect

Call Control (CC) Messages exchanged between CC entity of UE and CC entity of network are summarized below for MT call establishment:

(UE)<<< SETUP (NETWORK)
 (UE) CALL CONFIRMED >>> (NETWORK)
 (UE) ALERTING >>> (NETWORK)
 (UE) CONNECT >>> (NETWORK)
 (UE)<<< CONNECT ACK (NETWORK)

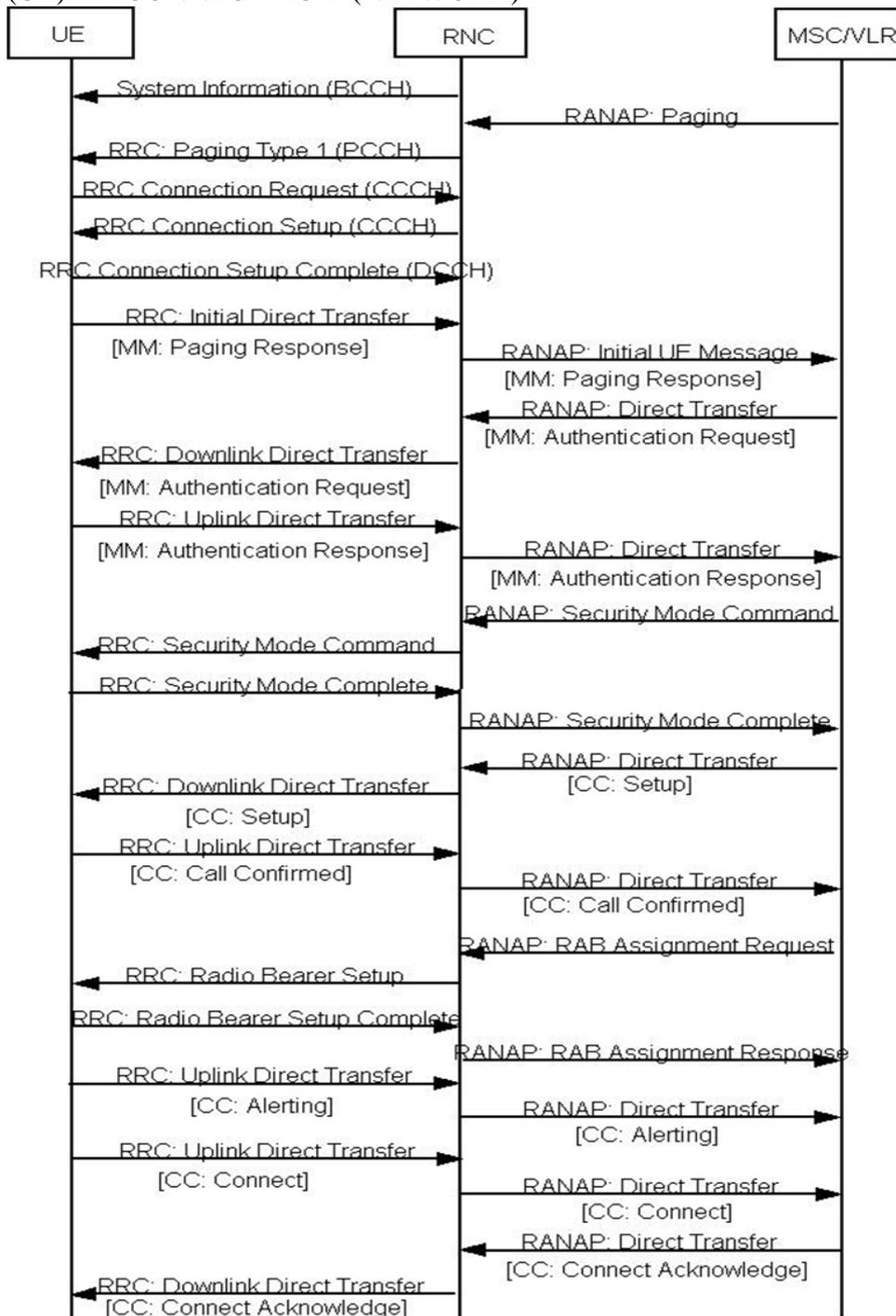


Figure 31: Mobile Terminated Circuit Switched Call flow

5.3.3 MOBILE ORIGINATED PACKET SWITCHED CALL FLOW

General packet switched call flow(PS call/Data call) between Mobile(UE) and network compatible with WCDMA covers messages exchanged between Layer 3 entities at both side. It includes channels used at layer 1 to carry these messages over the air.

At the start of this Procedure the UE is RRC Idle, PMM Detached and SM Inactive.

The following steps need to be executed in order for a mo call to complete;

Establish an RRC connection to the UTRAN

Establish an Iu connection to the CN

Make an Attach Request

Carry out Security Procedures

Complete the Attach

Request PDP context activation

Set-up RAB's for the connection

Create GTP connections and activate PDP Context at the GGSN

Data Transfer

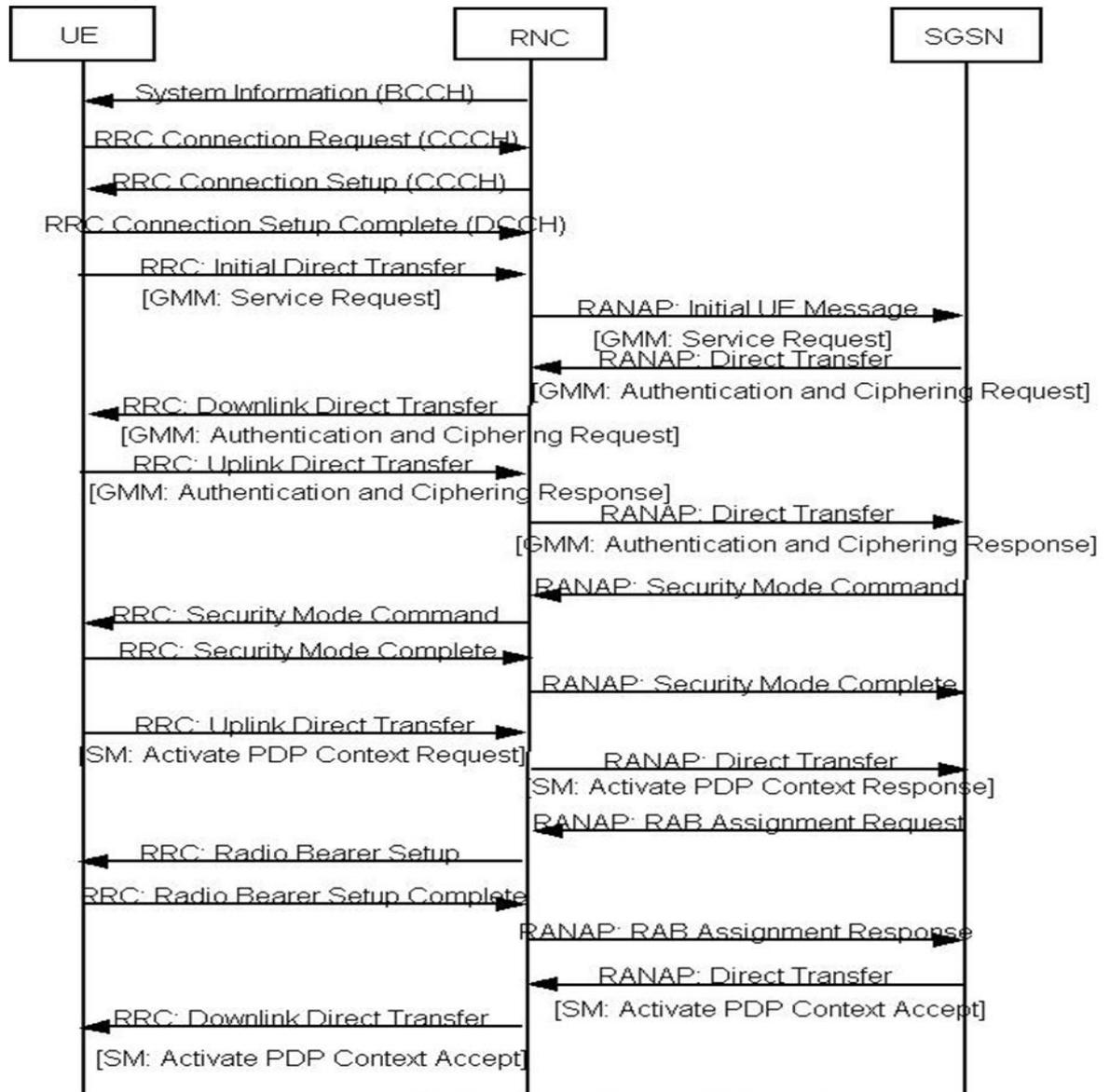


Figure 32: Mobile Originated Packet Switched Call flow

5.3.4 MOBILE TERMINATED PACKET SWITCHED CALL FLOW

The following steps need to be executed in order for a MT Packet switched call to complete:

- RRC Paging
- RRC Connection setup
- Service Request
- Security Procedures (Identity / Authentication / Security mode)
- PDP Context activation
- Radio bearer setup
- Data Transfer

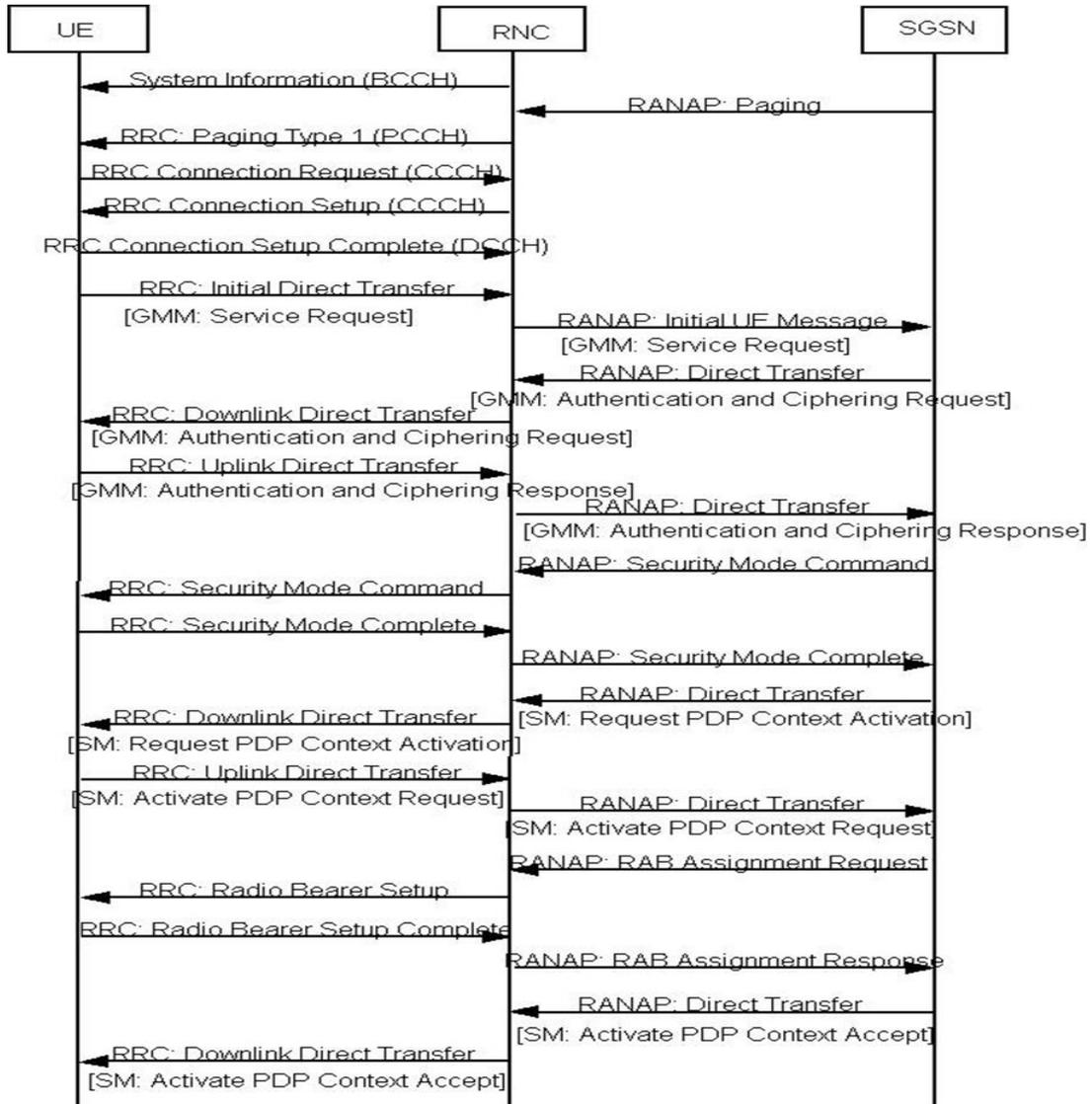


Figure 33: Mobile Terminated Packet Switched Call flow

5.4 CONCLUSION

In this chapter we have understood regarding various types of 3G calls i.e. circuit switched and packet switched in detail.

6 3G RADIO NETWORK OPTIMIZATION

6.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- WCDMA Radio Network Optimization
- WCDMA Optimization and monitoring
- Challenges in WCDMA Optimization
- WCDMA Drive Test
- WCDMA Parameters

6.2 INTRODUCTION

The overall planning goal in any wireless system is to maximize coverage and capacity while meeting the KPIs (key performance indicators) and QoS (quality of service). The UMTS radio system planning process is similar to the GSM planning process. The phases of the planning process are:

- Dimensioning
- Configuration planning
- Coverage and capacity planning
- Code and frequency planning
- Parameter planning
- Optimization and monitoring

Figure shows the UMTS planning process. In particular, the figure shows the one key issue in UMTS coverage and capacity planning, namely that the traffic level has to be considered continuously in UMTS radio planning.

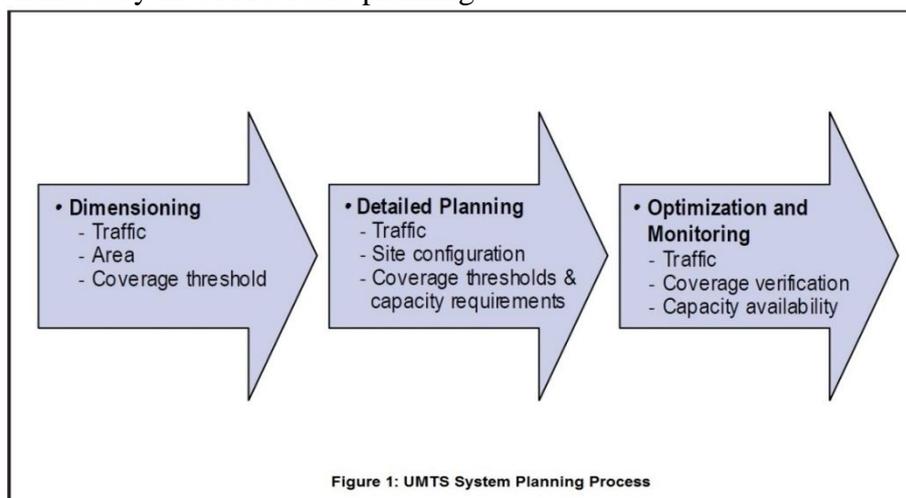


Figure 34: The UMTS Planning and Optimization process

6.3 WCDMA OPTIMIZATION AND MONITORING

Network optimization can initially be seen as a very involving task as a large number of variables are available for tuning, impacting different aspect of the network performance. To simplify this process a step by step approach is proposed in Figure. This approach divides the optimization in simpler steps, each step focusing on a limited set of parameters:

- RF optimization will focus mainly on RF configuration and in a lesser extent on reselection parameters.

- Voice optimization will focus on improving the call setup (Mobile Originated and Mobile Terminated) and call reliability thus focusing mainly on access and handover parameters.
- Advance services optimization will rely extensively on the effort conducted for voice. The initial part of the call setup are similar for all type of services and vendor have not at this point defined different set of handover parameters for different services. Consequently, optimizing these services will focus on a limited set of parameters, typically power assignment, quality target, and Radio Link Control (RLC) parameters.
- Inter-system (also known as inter-RAT) change (both reselection and handover) optimization is considered once the WCDMA layer is fully optimized. This approach will ensure that inter-system parameters are set corresponding to finalize boundaries rather than set to alleviate temporary issues due to sub-optimal optimization.

Even after careful RF planning, the first step of optimization should concentrate on RF. This is necessary as RF propagation is affected by so many factors (e.g., buildings, terrain, vegetation...) that propagation models are never fully accurate. RF optimization thus takes into account any difference between predicted and actual coverage, both in terms of received signal (RSCP) and quality of the received signal (Energy per chip / Noise spectral density(E_c/N_o)). In addition, the same qualitative metrics defined for planning should be considered: cell overlap, cell transition, and coverage containment of each cell. At the same time, assuming that a UE (User Equipment) is used to measure the RF condition in parallel with a pilot scanner, reselection parameters can be estimated considering the dynamics introduced by the mobility testing: during network planning dynamics cannot be considered, as network planning tools are static by nature, only simulating at one given location at a time, irrespectively of the surrounding. In addition, once the RF conditions are known, dynamic simulation can be used to estimate the handover parameters, even before placing any calls on the network.

Service optimization is needed to refine the parameter settings (reselection, access, and handover). Because the same basic processes are used for all types of services, it is best to set the parameters while performing the simpler and best understood of all services: voice. Either for access or for handover, the main difference between voice and other service is the resource availability. Testing with voice service greatly simplifies the testing procedure and during analysis limits the number of parameters, or variable, to tune. During this effort, parameter setting will be the main effort.

Different set of parameters are likely to be tried to achieve the best possible trade-offs: coverage vs. capacity, call access (Mobile Originated and Mobile Terminated) reliability vs. call setup latency, call retention vs. Active Set size to name only a few. The selection of the set of parameter to leave on the network will directly depend on the achieved performance and the operator priority (coverage, capacity, access performance, call retention performance...).

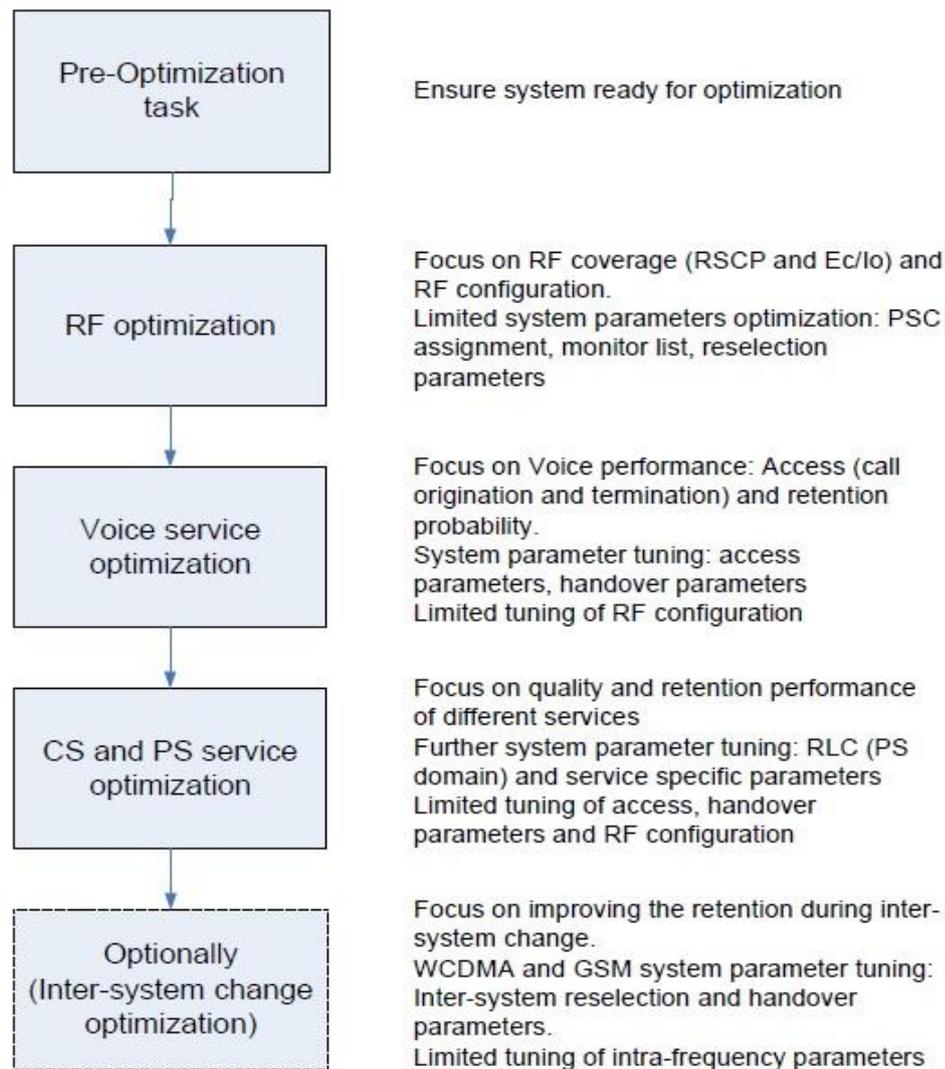


Figure 35: step by step approach

Once the performance targets are reached for voice, optimizing advanced services such as video-telephony and packet switched (PS) data service will concentrate on a limited set of parameters: power assignment, quality target (BLER target), and any bearer specific parameters (RLC -Radio Link Control or channel switching parameters for example). During the optimization of PS data service the importance of good RF optimization will be apparent when channel switching is considered. Channel switching is a generic term referring to the capability of the network to change the PS data bearer to a different data rate (rate switching) or a different state (type switching). Channel switching is intended to adapt the bearer to the user needs and to limit the resource utilization. Saving resource will be achieved by reducing the data rate when the RF conditions degrade. By reducing the data rate, the spreading gain increases, resulting in lower required power to sustain the link.

Once the basic services are optimized, i.e., the call delivery and call retention performance targets are met, the optimization can focus on service continuity, through inter-system changes, and application specific optimization. Inter-system changes, either reselection or handover, should be optimized only once the basic WCDMA optimization is completed to ensure that the WCDMA coverage boundary is stable.

Application optimization can be seen as a final touch of service optimization and is typically limited to the PS domain. In this last effort, the system parameters are optimized not to get the highest throughput or the lowest delay, but to increase the subscriber experience while using a given application. A typical example would be the image quality for video-streaming. The main issue for this application based optimization might be that different applications may have conflicting requirements. In such case, the different applications and their impacts on the network should be prioritized. Irrespective of the application considered, the main controls available to the optimization engineer are the RLC parameters, target quality and channel switching parameters. The art in this process is to improve the end user perceived quality, while improving the cell or system capacity

6.4 OPTIMIZATION CHALLENGES FOR WCDMA

Three particularly important optimization challenges for WCDMA cell sites are examined: traffic load balancing, handoff overhead management, and interference control. The fundamental problem of traffic loading is that cellular traffic is distributed unevenly among different geographical areas of the network. In fact, even within cells traffic tends to be distributed unevenly among the sectors. Such imbalance has the effect of locking up network capacity in under-utilized sectors while causing blocking problems in the most heavily used sectors. Balancing the traffic load among the sectors of a cell alleviates the blocking and creates headroom for traffic growth. And by creating headroom at network hot spots, a targeted traffic load-balancing strategy allows more traffic growth and more efficient use of infrastructure and spectrum across the entire network. One way of achieving load balancing is to modify the antenna orientation and angular beam width of each sector to unify the traffic. This is possible using smart array antennas, as shown in Figure. Another aspect of WCDMA optimization that directly affects cell site capacity is the management of handoff overhead. The soft/softer handoff feature of the CDMA air interface improves the quality and reliability of CDMA calls. However, because a given mobile may be in contact with two or more cells or sectors at any given time, as in areas A and B in Figure , soft/softer handoff implies a significant cost in capacity. After measuring the pilot strength in the area, the size of handoff zones within the cell footprint should be decreased. Handoff zones should be shifted from high-traffic areas to low-traffic areas. Interference directly limits capacity of CDMA cell sites. One of the biggest interference problems in WCDMA networks is pilot pollution. Pilot pollution is often caused due to high-elevation sites with RF coverage footprints much larger than normal. The solution is to reduce the size of the coverage footprint. This can be accomplished by reducing the elevation of offending antennas, introducing down tilt, or reducing the transmitted power.

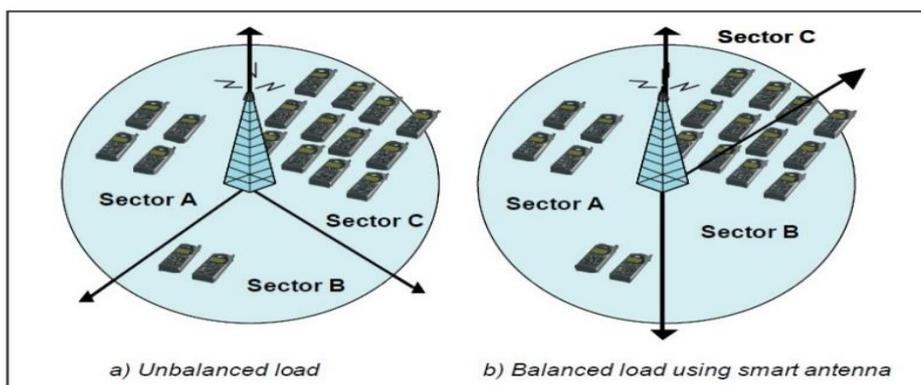


Figure 36: Balancing Traffic Load

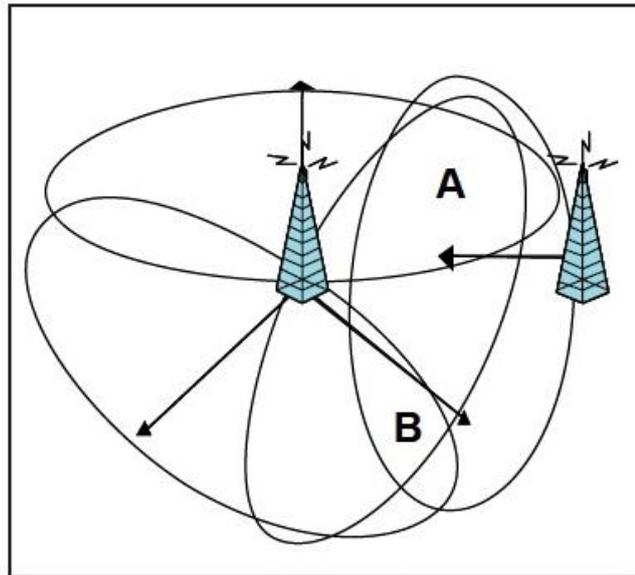


Figure 37: Inefficient Design

6.5 INTER-RAT HANDOVER (INTER RADIO ACCESS TECHNOLOGY HANDOVER)

The 2G/3G inter-RAT handover involves the handover from GSM to UMTS and the handover from UMTS to GSM. The handover is controlled mainly by the network. For MSs in dedicated mode, inter-RAT handovers can be performed, including the emergency handover, better cell handover, inter-RAT load handover, and inter-RAT service handover.

6.5.1 INTER-RAT HANDOVER FROM UMTS TO GSM

MSs in dedicated mode can be handed over from a UMTS cell to a GSM cell. The handover decision and handover procedure are controlled by the RNC. The BSS considers the incoming handover from UMTS to GSM as a common inter-BSC handover. The parameter **Inter-RAT In BSC Handover Enable** determines whether inter-RAT handover from UMTS to GSM is enabled. If **Inter-RAT In BSC Handover Enable** is set to **No**, the BSS rejects all the requests for the handover from UMTS to GSM.

6.5.2 INTER-RAT HANDOVER FROM GSM TO UMTS

The parameter **Inter-RAT In BSC Handover Enable** determines whether the inter-RAT handover from GSM to UMTS is enabled. If **Inter-RAT In BSC Handover Enable** is set to **NO (No)**, the BSS rejects all the requests for the handover from GSM to UMTS and does not select a UMTS cell as the target cell.

In dedicated mode, an MS obtains the list of neighbouring UMTS cells and other information from the Measurement Information. Then, the MS reports the measurement result to the BSS through the measurement report. After receiving the measurement result, the BSS determines whether to initiate the inter-RAT handover from GSM to UMTS based on the measurement result and the handover algorithm.

6.6 BASIC WCDMA DRIVE TEST PARAMETERS

6.6.1 CPICH EC/NO:

Chip Energy by Noise- Common Pilot channel Ec/No (CPICH Ec/No) is the ratio of the energy of the chip and the combined power of all the signals including the specific pilot channel. It also shows the level of Noise disrupting the specific CPICH.

Ranges for Ec/No:(Unit is dB)

- 0 to -7 Good
- to -10 Acceptable
- -10 to -36 Bad

6.6.2 CPICH RSCP:

Received signal Code Power is the level of the signal received by the U.E. or in simple RSCP is the total power of the entire cell or a specific Common Pilot Channel received by the user Equipment.

Ranges of RSCP: (Unit is dbm)

- -30 to -75 Good
- -75 to -85 Acceptable
- -85 to -140 Bad

6.6.3 TX POWER:

Tx Power is the transmitting power of the mobile station. Its value can vary from 50 to -50. The minimum the Tx Power of the mobile station the better it is for call quality. Tx Power is the power of mobile station measured in the dedicated mode. If you are in a low coverage area the mobile will increase its Tx power to avoid your call from being dropped.

6.6.4 RSSI:

Received Signal Strength Indicator is the total power of the entire common pilot channel received by the Mobile station Including Neighbors interference and noise as well of neighbors and itself also.

$RSSI = RSCP + Ec/No$

RSSI Ranges:

- 0 to -75 Good
- -75 to -85 Acceptable
- -85 to -140 Bad

6.6.5 SIR:

Signal to Interference ratio is the ratio of energy in the DPCC (Dedicated Physical control channel) to that of the interference and noise received by the User Equipment.

6.6.6 SQI:

It is the speech quality index which is a parameter to rate the voice quality on that particular call. It ranges from 0 to 30. While 30 being the Best Value. Adaptive Multi Rate (AMR) is also used to enhance the speech or the voice quality of the specific call.

WCDMA use AMR source Coding. AMR vary with different Ranges Highest AMR Value is 12.20 and lowest AMR value is 4.75.

6.6.7 RRC STATE:

It tells the current state and channel as in idle or dedicated.

6.6.8 CELL NAME:

Specific Name of the Node B allotted by the Operator according to its location and Serial value.

6.6.9 SCRAMBLING CODES:

Scrambling Codes are usually used to identify different cells of a node B. They are of two types.

1- Secondary Scrambling Code

2- Primary Scrambling Code

Secondary Scrambling Code are used in Beam forming cases.

Primary Scrambling codes (0 to 511) are actually the Scrambling codes usually used to identify different sectors. They totally lies from 0 to 8191. More over 512 PSC are divided into a group of 64.Each contains 8PSC.

Total Down link Scrambling Codes $16*8=512$.

6.6.10 AS (ACTIVE SET):

Set of scrambling codes on which the user equipment is currently latched on. Generally,there can be maximum three scrambling codes in an Active Set.

6.6.11 MN (MONITORED NEIGHBOR):

Neighbor cell that is detected by user equipment as a neighbor.

6.6.12 DN (DETECTED NEIGHBOR):

Detected Neighbor are cells detected by UE, which are neither in the Active set nor in the Monitored set. (Missing Neighbor Definitions). Hence the U.E does not handover onto these cells. It can be because of Overshooting, incomplete neighbor list or in case of a new site. It is very important to optimize a network and have no DN's as they are one of the major reasons of call drops in 3G.

6.7 CONCLUSION

3G Radio Network is very important and its parameter and planning plays a vital role in network performance.

7 BACKHAUL MEDIA FOR MOBILE RADIO NETWORK (OFC/ OFC SYSTEMS/ MINI LINK) AND RRH

7.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- Importance of backhaul media in 3G
- Various type of Backhaul media
- Choice of backhauling
- Concept of Cloud RAN

7.2 INTRODUCTION

The physical part of a communications network between the central backbone and the individual local networks is known as backhaul. Mobile backhaul refers to the transport network that connects the core network and the RAN (Radio Access Network) of the mobile network. Recently, the introduction of small cells has given rise to the concept of front haul, which is a transport network that connects the macro cell to the small cells. Whilst mobile backhaul and front haul are different concept, the term mobile backhaul is generally used to encompass both concepts.

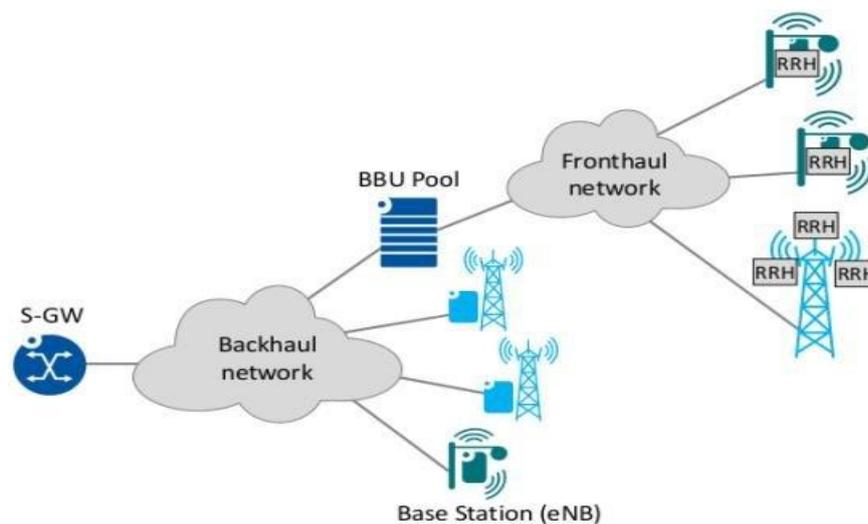


Figure 38: Backhaul Concept

Cell phones communicating with a single cell tower constitute a local subnetwork; the connection between the cell tower and the rest of the world begins with a backhaul link to the core of the internet service provider's network (via a point of presence). A backhaul may include wired, fiber optic and wireless components. Wireless sections may include using microwave bands and mesh and edge network topologies that may use a high-capacity wireless channel to get packets to the microwave or fiber links.

7.3 MOBILE BACKHAUL N/W

- Mobile backhaul is the transport network that connects the core network and the RAN/Cell Site.

- The connection between the cell tower and the rest of the world begins with a backhaul link to the core N/w.
- A backhaul may include wired, fiber optic and wireless components.
- Wireless sections may include using microwave bands and mesh and edge network topologies
- Interconnection b/n core network elements is done through backbone N/w.

7.3.1 FRONT HAUL VS BACKHAUL

- Split RAN architecture has reshaped the traditional definitions of front haul and backhaul.
- In its earliest incarnation, backhaul was simply described as the connection between Cell Site to BSC/RNC (In 2G/3G)
- Front haul became a necessary addition when a new link connected centralized BBU to individual RRH.
- Front haul is connection in RAN infrastructure between the Baseband Unit (BBU) and Remote Radio Head (RRH).
- Front haul originated with LTE networks when operators first moved their radios closer to the antennas.
- This new link was established to supplement to the backhaul connection between the BBU and central network core.

7.4 IMPORTANCE OF MOBILE BACKHAUL

Wireless and fixed-line backhaul infrastructure is an essential component of the mobile telecommunications network. Mobile networks are ubiquitous and support a mix of voice, video, text and data traffic originating from and terminating to mobile devices. All of this traffic must be conveyed between the mobile cellular base stations and the core network. The 3G and 4G Long-Term Evolution (LTE) strive for more network capacity, latency reduction, and the need to deliver an enhanced user experience. In the era of 5G, where a network will be densified and more stringent requirement will be imposed, mobile backhaul will become even more important.

7.5 MOBILE BACKBONE NETWORK

Mobile backbone network refers to the interconnection of core elements situated at separate geographic locations. As the requirement of bandwidth is large, typically, OFC is used in the backbone network. However, MW is also sometimes used in the backbone network, particularly in those areas where laying fibre is not a feasible option due to difficult terrain, time constraints or economic viability.

7.6 TECHNOLOGY CHOICES FOR MOBILE BACKHAUL

The most common network type in which backhaul is implemented is a mobile network. A backhaul of a mobile network, also referred to as mobile-backhaul connects a cell site towards the core network. The two main methods of mobile backhaul implementations are fiber-based backhaul and wireless point-to-point backhaul. Other methods, such as copper-based wire line, satellite communications and point-to-multipoint wireless technologies are being phased out as capacity and latency requirements become higher in 4G and 5G networks.

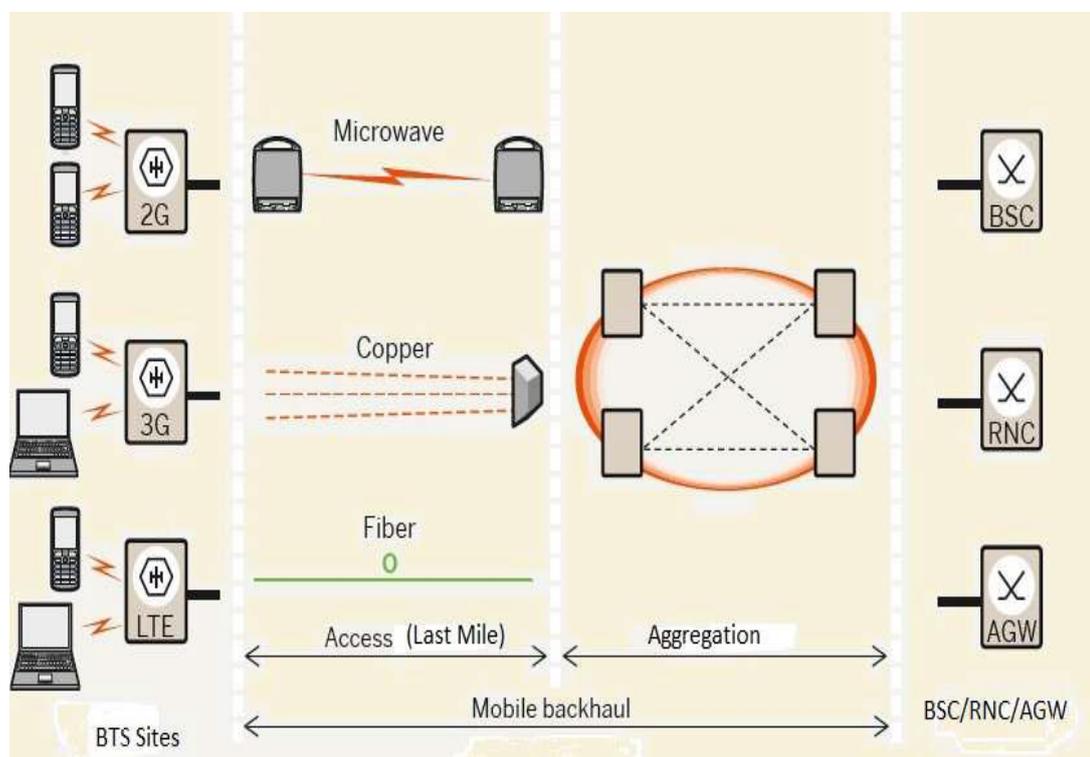


Figure 39: Mobile Backhaul Network Choices

The technological solutions used for backhaul, including both wireline and wireless solutions are given below:

7.6.1 COPPER-LINE

Copper-based backhaul was the primary backhaul technology for 2G/3G. At the heart of copper-based backhaul is the T1/E1 protocol, which supported 1.5 Mbps to 2 Mbps. This bandwidth can be boosted by using DSL over the copper pair and DSL is still an option for mobile backhaul for indoor small cells, in-building and public venue small cell networks.

7.6.2 FIBRE-OPTIC IN BACKHAUL MEDIA FOR MOBILE RADIO NETWORK (OFC/OFC SYSTEMS)

This technology is the mainstay wired backhaul in MNO networks and second overall only to microwave backhaul. Even though fibre has significant inherent bandwidth carrying capability, several additional techniques can be used to offset any bandwidth constraints and essentially rendering the fibre assets future-proof.

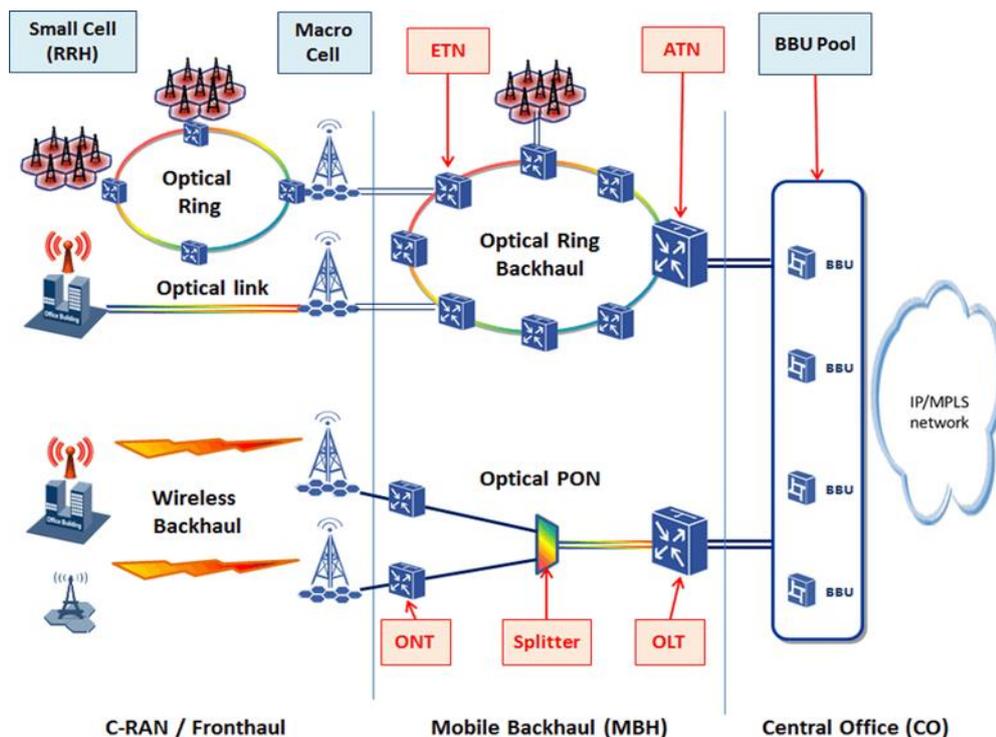


Figure 40: OFC Media and System Mobile Network Backhaul

These techniques include Wavelength Division Multiplexing (WDM) technology which enables multiple optical signals to be conveyed in parallel by carrying each signal on a different wavelength or colour of light. WDM can be divided into Coarse WDM (CWDM) or Dense WDM (DWDM). CWDM provides 8 channels using 8 wavelengths, while DWDM uses close channel spacing to deliver even more throughput per fibre. Modern systems can handle up to 160 signals, each with a bandwidth of 10 Gbps for a total theoretical capacity of 1.6 Tbps per fibre.

The traffic generated by LTE has accelerated the demand for Fiber to the Tower (FTTT) and has required Mobile Network Operators (MNOs) to upgrade many aspects of their backhaul networks to fibre-based Carrier Ethernet. The main limitations of fibre are the cost and logistics of deploying fibre (ducts etc.). Also it can take several months to provision a cell site with fibre optic backhaul. Fibre optic will remain as the main choice for backhaul.

7.6.3 WIRELESS BACKHAUL (MICROWAVE MINI-LINK)

Despite fibre being the preferred choice for 3G/4G/5G backhaul, microwave backhaul is the most used technology due to a combination of its capability and relative ease of deployment (i.e. no need for trenches/ducting) making it a low-cost option that can be deployed in a matter of days. Microwave backhaul solutions in the 7 GHz to 40 GHz bands, in addition to higher microwave bands such as V-band (60 GHz) and the E-band (70/80 GHz) can be relied. Backhaul links using the V-band or the E-band are well suited to supporting 5G due to their 10 Gbps to 25 Gbps data throughput capabilities.



Figure 41: Microwave Mini-Links for Mobile Communications

Microwave can be used in LOS or NLOS mode which makes it ideal to be used in a chain, mesh or ring topologies to enable resilience and/or reach.

7.6.4 LOS VS. NLOS

LOS backhaul has the advantage of using a highly directed beam with little fading or multi-path dispersion and enables efficient use of spectrum as multiple transceivers can be located within a few feet of each other and use the same frequency to transmit different data streams.

NLOS backhaul is much more “plug and play” and so take less time with less skilled labour to set up. NLOS backhaul OFDM technology (Orthogonal Frequency Division Multiplexing) to relay information back to a central base station. NLOS backhaul needs only to be within a range of the receiver unit with OFDM providing a level of tolerance to multi-path fading not possible with LOS

7.6.5 SATELLITE BACKHAUL

Satellite Backhaul is a niche solution and used in fringe areas (e.g. remote rural areas) and sometimes as an emergency/temporary measure (e.g. a disaster area. This backhaul is used in developing markets and as a complementary role in developed markets. The technology can deliver 150Mbps/10Mbps (downlink/.uplink). However, latency is a challenge as there a round trip delay of circa 500-600ms for a geostationary satellite. LEO (Low Earth Orbit) satellites have tried to address the latency issue (i.e. using a much lower orbit of 1500km versus 36000km and resulting in a one way trip of circa 50ms). However, LEO satellites are not geostationary and thus there is sometimes a need to route traffic via multiple satellites.

7.6.6 FREE SPACE OPTICS (FSO)

Free Space Optics (FSO) is a newer low-latency technology that offers speeds comparable to fibre optics that transmit voice, video and data with up to 1.5Gbps, and can be deployed as backhaul to expand mobile network footprint with building-to-building connectivity. The high bandwidth can be provided with a reception of light by deploying free space optics technology.

BSNL is likely to use free space optics, a new line-of-sight outdoor wireless technology, to overcome backhaul constraints in large arid areas of Rajasthan and Gujarat plains.

7.6.7 WIFI BACKHAUL

There is marginal use of this technology for macrocell backhaul. The unlicensed nature of the technology combined with the growing interference from increasing public and private WLANs plus poor transmission ranges severely limits its deployment.

7.7 CHALLENGES IN MOBILE BACKHAUL

There are a number of market trends that result in new challenges and requirements that must be met by the backhaul.

7.7.1 EVOLUTION OF LTE

Technical innovations occurring on LTE, which is known as LTE-Advanced Pro or 4.5G which enable enhancements such as improved peak bandwidth and greater energy efficiency for IoT connections. The peak bandwidth of 4.5G is around 1Gbps which is 8-10x higher than standard LTE, and will enable (inter alia) support of video traffic at 4K resolution to mobile devices.

7.7.2 EMERGENCE OF 5G

The 5G network will comprise both NR (New Radio) as well as a new 5G Core Network (5GC). The advent of NR offers a leap in bandwidth speeds in comparison to 3G and 4G via the utilisation of higher frequency spectrum. The higher frequencies enable wider channel bandwidths at the access but also result in smaller cell sizes. Both have implications for backhaul.

7.7.3 NETWORK SLICING

In 5G Network, one concept of “network slicing” is introduced whereby the physical network infrastructure can be partitioned into bespoke logical networks (“slices”) in the RAN and 5G core which are targeted to the needs of a specific application or use case. Slicing will impact on the backhaul network.

7.7.4 SUBSCRIBER GROWTH

Backhaul strategy/evolution must cope with both an increase in subscriptions as well as a large number of those subscriptions being “high bandwidth” users.

7.7.5 MOBILE DATA TRAFFIC GROWTH

The increasing subscriber total plus increased access bandwidth usage of those subscribers results in mobile data traffic increasing at a rate.

7.7.6 STRINGENT LATENCY REQUIREMENTS

Both 5G mission-critical applications and increased video streaming will result in more stringent end-end latency requirements and impact on the backhaul latency budget.

If higher latency backhaul links are deployed (e.g. satellite links), then such backhaul would only carry 2G/3G and non-latency sensitive LTE services.

7.7.7 NETWORK DENSIFICATION:

The increased demand for mobile broadband results in the number of macrocell. The new macrocells include both 4G and 5G technologies. This results in extra traffic to backhaul as well as additional challenges due to the smaller cell size for 5G NR.

7.8 ALTERNATIVE ARCHITECTURES FOR MOBILE BACKHAUL OPTIMISATION

7.8.1 MULTI ACCESS EDGE COMPUTING

MEC (Multi-access edge computing) is where computing and intelligence capabilities that were mostly centralized in the core network are provided at the edge of the access network. MEC enables high bandwidth and ultra-low latency access to cloud computing/IT services at the edge to be accessed by applications developers and content providers.

MEC, while incurring a cost to implement core functions at the edge, can provide opportunities to optimise backhaul demand via caching and/or local breakout. Caching reduces the load on mobile backhaul and enhances the customer experience by storing frequently accessed contents in the edge network. Customers can access the contents at a lower latency (with less distance for signal to travel) and backhaul demand is reduced as there is no need to reach further to the external network to obtain the contents. Local breakout also enables the mobile backhaul to be optimised as the contents do not need to travel to the core network and then to the internet. The caveat with local breakout is that the transport network to connect the edge to the internet needs to be in place and therefore won't optimise cost in certain scenarios.

7.8.2 CLOUD RAN

Cloud RAN is where some layers of radio access network are centralized to an edge site rather than at the cell site, which allows some (or all) of the processing capabilities to be focused at the edge site reducing the complexities at the cell site. This architecture is suitable in the small cell era, where only a little space and cost constraint is affordable at the cell site. While the architecture may not be suitable for traditional macro cell base stations as they would need to process significant load of signal transmitted from/received by various radio elements, heterogeneous networks with many small cells would benefit from this architecture.

As shown in the figure below, Cloud RAN in its two forms (low-level and high-level splits) significantly reduces complexities and capabilities at the cell site to be concentrated in the edge site. The low-level split is where only the physical layer is processed at the edge site while all the electronics are concentrated in the edge site. This architecture allows easy installation and very low complexity at the cell site but comes at a higher front haul cost as baseband signals would need to be transferred. On the other hand, high-level split brings relatively less front haul cost but comes with more complexity at the cell site than low-level split.

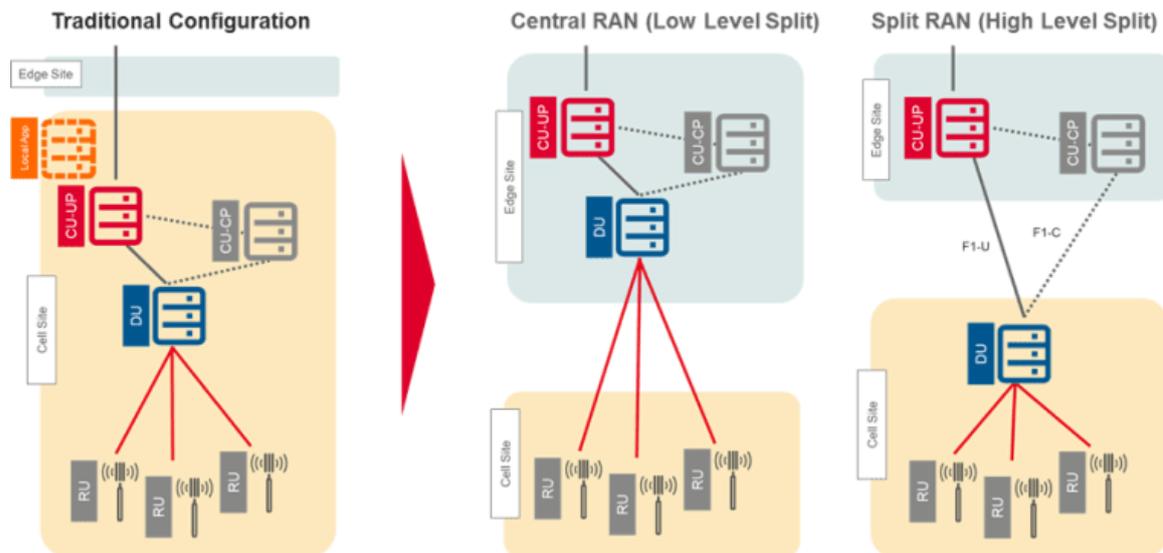


Figure 42: Cloud RAN Architecture

7.8.3 RRH

A remote radio head (RRH), also called a remote radio unit (RRU) in wireless networks, is a remote radio transceiver that connects to radio base station unit via electrical or wireless interface.

The RRH is termed “Remote” as it is usually installed on a mast-top, or tower-top location that is physically some distance away from the base station hardware which is often mounted in an indoor rack-mounted location. In wireless system technologies such as GSM, CDMA, UMTS, LTE this Radio equipment is remote to the BTS/NodeB/eNodeB, and is also called Remote Radio Head.

This equipment will be used to extend the coverage of a BTS/NodeB/eNodeB like rural areas or tunnels. They are generally connected to the BTS/NodeB/eNodeB via a fibre optic cable using Common Public Radio Interface protocols.

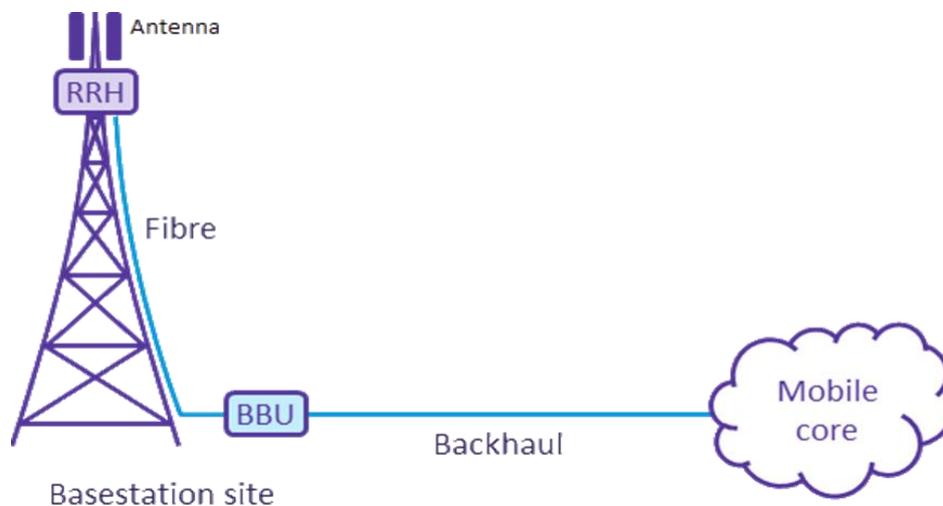


Figure 43: RRH

Using Wireless (Microwave, Millimetre Wave, MMW, Free Space Optics, and FSO) links instead of fibre allows the Remote Radio Head (RRH) to be connected without need for fibre optics. By avoiding the needs for digging, trenches, leased circuits

from telcos, dark fibre or way-leaves for disrupting busy city streets, 4G/LTE networks can be realised very quickly with installation taking hours rather than days, weeks or months.

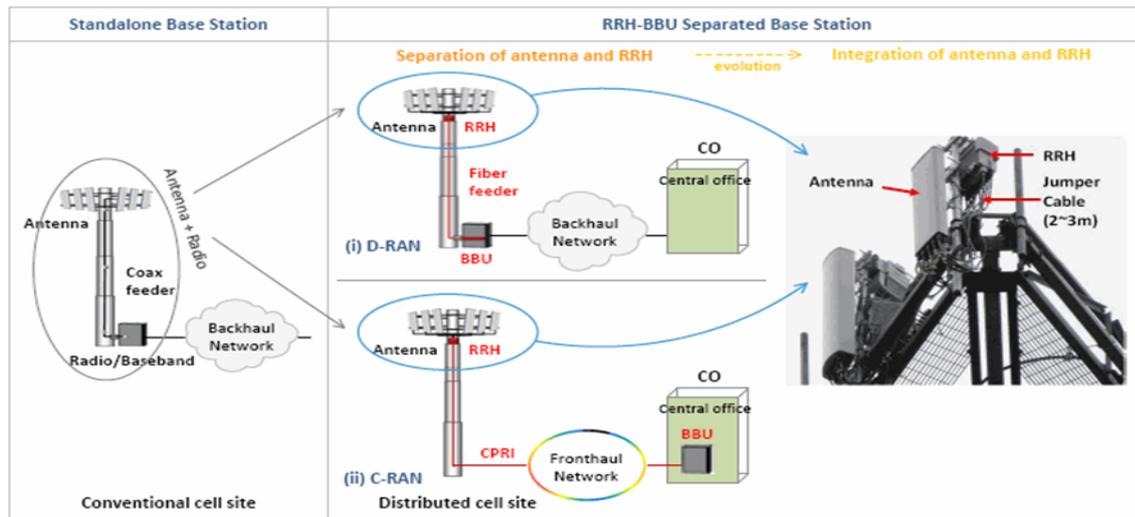


Figure 44: Backhaul for RRH

7.8.4 IMPORTANCE OF RRH

RRHs have become one of the most important subsystems of today's new distributed base stations. The RRH contains the base station's RF circuitry plus analog-to-digital/digital-to-analog converters and up/down converters. RRHs also have operation and management processing capabilities and a standardized optical interface to connect to the rest of the base station. This will be increasingly true as LTE and WiMAX are deployed. Remote radio heads make MIMO operation easier; they increase a base station's efficiency and facilitate easier physical location for gap coverage problems. RRHs will use the latest RF component technology including Gallium nitride (GaN) RF power devices and envelope tracking technology within the RRH RF power amplifier (RFPA).

7.8.5 RRH PROTECTION IN FIBER TO THE ANTENNA SYSTEMS

Fourth generation (4G) and beyond infrastructure deployments will include the implementation of Fiber to the Antenna (FTTA) architecture. FTFA architecture has enabled lower power requirements, distributed antenna sites, and a reduced base station footprint than conventional tower sites. The use of FTFA will promote the separation of power and signal components from the base station and their relocation to the top of the tower mast in a Remote Radio Head (RRH).

According to the Telcordia industry standard that establishes generic requirements for Fiber to the Antenna (FTFA) protection GR-3177, the RRH shifts the entire high-frequency and power electronic segments from the base station to a location adjacent to the antenna. The RRH will be served by optical fiber and DC power for the optical-to-electronic conversion at the RRH.

RRHs located on cell towers will require Surge Protective Devices (SPDs) to protect the system from lightning strikes and induced power surges. There is also a

change in electrical overstress exposure due to the relocation of the equipment from the base station to the top of the mast.

7.8.6 PROTECTION FROM LIGHTNING DAMAGE

RRHs can be installed in a low-profile arrangement along a rooftop, or can involve a much higher tower arrangement. When installed at the highest point on a structure (whether a building or a dedicated cell tower), they will be more vulnerable to receiving a direct lightning strike and higher induced lightning levels, compared with those installed in a lower profile manner below the upper edges of the building.

As noted in GR-3177, while surges can be induced into the RRH wiring for lightning striking the nearby rooftop or even the base station closure, the worst case will occur when a direct strike occurs to the antenna or its supporting structure. Designing the electrical protection to handle this situation will provide protection for less damaging scenarios... it can also be use in optical fiber communication but different type.

7.9 CONCLUSION

In order to have best of Network and throughput from it backhaul is of at most importance. Introduction of cloud RAN has open the path for low latency network and path for future radio technologies.

8 HSPA,HSPA⁺ AND MIGRATION TO 4G (REL5 TO REL8)

8.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- HSAP and HSPA+ Standards
- Various releases
- HSPA and HSPA+ technology
- Migration to 4G

8.2 UMTS HSPA AND 3GPP STANDARDS

3G HSPA provides a major improvement in performance to the 3G UMTS mobile telecommunications system. It provides additional facilities that are added on to the basic 3GPP UMTS standard. The top data rates for HSPA compete well with the 4G LTE technology. As such the 3G infrastructure usage was prolonged and enabled many operators to maximise the use of their investment before having to add the capability for 4G.

The evolution of UMTS-HSPA happens in stages referred to as 3GPP Releases. The upgrades and additional facilities were introduced at successive releases of the 3GPP standard.

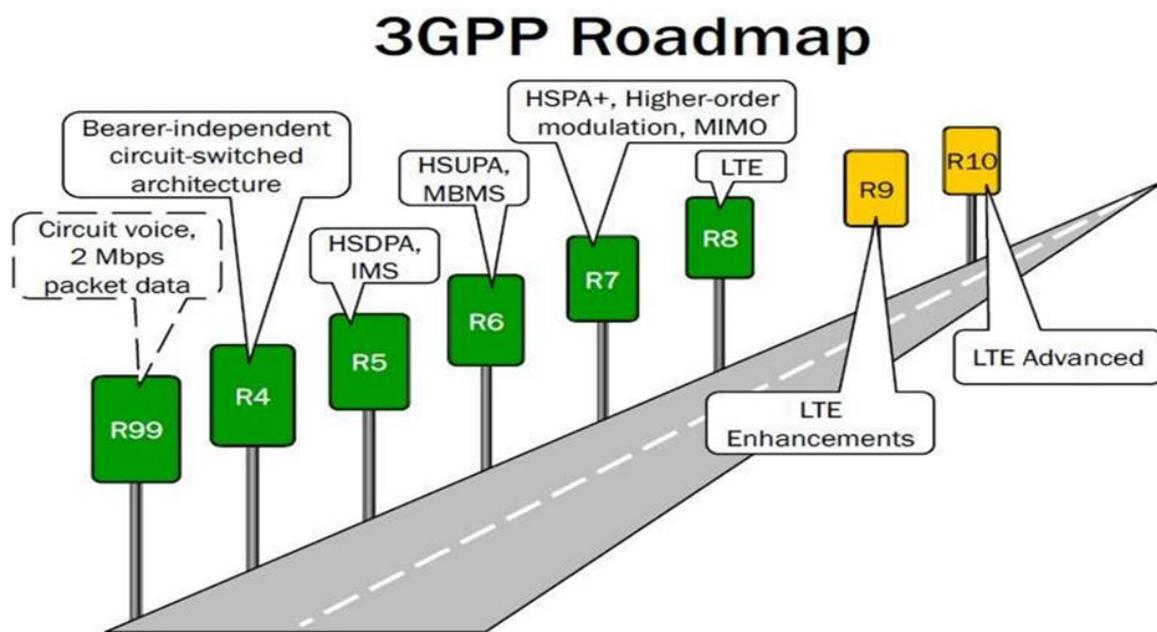


Figure 45: 3GPP UMTS Evolution

- **Release 4:** This release of the 3GPP standard provided for the efficient use of IP, a facility that was required because the original Release 99 focussed on circuit switched technology. Accordingly this was a key enabler for 3G HSDPA.
- **Release 5:** This release included the core of HSDPA itself. It provided for downlink packet support, reduced delays, a raw data rate (i.e. including payload, protocols, error correction, etc) of 14 Mbps and gave an overall increase of around three over the 3GPP UMTS Release 99 standard.

- **Release 6:** This included the core of HSUPA with an enhanced uplink with improved packet data support. This provided reduced delays, an uplink raw data rate of 5.74 Mbps and it gave an increase capacity of around twice that offered by the original Release 99 UMTS standard. Also included within this release was the MBMS, Multimedia Broadcast Multicast Services providing improved broadcast services, i.e. Mobile TV.
- **Release 7:** This release of the 3GPP standard included downlink MIMO operation as well as support for higher order modulation up to 64-QAM in the downlink and 16-QAM in the uplink. However it only allows for either MIMO or the higher order modulation. It also introduced protocol enhancements to allow the support for Continuous Packet Connectivity (CPC).
- **Release 8:** This release of the standard occurred during the course of 2008 and it defines dual carrier operation as well as allowing simultaneous operation of the high order modulation schemes and MIMO. Further to this, latency is improved to keep it in line with the requirements for many new applications being used.
- **Release 9:** 3GPP Release 9 occurred during 2009 and included facilities for HSPA including 2x2MIMO in the uplink and a 10MHz bandwidth in the downlink. The uplink carriers may be from different bands.
- **Release 10:** HSPA Release 10 utilises up to 4-carriers, i.e. 20 MHz bandwidth which may be from two separate bands. In addition to this 2x2 MIMO in the downlink provides data rates up to 168 Mbps. This figure equates to that obtained for LTE Release 8 when using comparable bandwidth and antennas configurations.
- **Release 11:** Release 11 occurred during 2011 / 2012. It provided the facility for 40MHz bandwidth in the uplink along with up to 4x4 MIMO. The downlink was upgraded to accommodate 64-QAM modulation and MIMO.

8.3 HSPA: HIGH SPEED PACKET ACCESS

High speed packet access, HSPA is an upgrade to 3G UMTS to provide very high higher data rates in both uplink and downlink. 3G UMTS enabled mobile communications to move from voice-centric systems to data centric ones. However the speeds that could be supported were nowhere near sufficient to enable Internet surfing and video downloads. To overcome this 3G UMTS was upgraded with high speed packet access, HSPA to provide a major leap in performance and make it suitable to cover its requirements.

Initially the downlink was addressed using high speed downlink packet access, HSDPA and then upgrades were added to the uplink with high speed uplink packet access.

Further upgrades were added later with dual carrier and MIMO capabilities to raise the data speeds hugely above those first envisaged for 3G.

8.3.1 HSPA BENEFITS

The system provides an enhancement on the basic 3G WCDMA / UMTS cellular system, providing data transfer rates that are considerably in excess of those originally envisaged for 3G as well as much greater levels of spectral efficiency.

The system provides many advantages for users over the original UMTS system.

3G HSPA SPEED & HIGHLIGHT FEATURES			
3GPP RELEASE	TECHNOLOGY	DOWNLINK SPEED (MBPS)	UPLINK SPEED (MBPS)
Rel 5	HSDPA	14.4	0.384
Rel 6	HSUPA	14.4	5.7
Rel 7	2xdata capacity 2x voice capacity	28	11
Rel 8	Multi-carrier	42	11
Rel 9	Multicarrier, 10 MHz, 2x2 MIMO UL, 10 MHz & 16-QAM D/L	84	23
Rel 10	20 MHz 2x2 MIMO in UL, 10	168	23
Rel 11	40 MHz 2x2 / 4x4 MIMO UL, 10 MHz 64-QAM MIMO DL	336 - 672	70

Table 1. 3G HSPA SPEED & HIGHLIGHT FEATURES

8.3.2 3G HSPA FEATURES

The UMTS cellular system as defined under the 3GPP Release 99 standard was orientated more towards switched circuit operation and was not well suited to packet operation. Additionally greater speeds were required by users than could be provided with the original UMTS networks. Accordingly the changes required for HSPA were incorporated into many UMTS networks to enable them to operate more in the manner required for current applications.

HSPA provides a number of significant features that enable the new service to provide a far better performance for the user. While 3G UMTS HSPA offers higher data transfer rates, this is not the only feature, as the system offers many other improvements as well:

1. **Use of higher order modulation:** 16QAM is used in the downlink instead of QPSK to enable data to be transmitted at a higher rate. This provides for maximum data rates of 14 Mbps in the downlink. QPSK is still used in the uplink where data rates of up to 5.8 Mbps are achieved. The data rates quoted are for raw data rates and do not include reductions in actual payload data resulting from the protocol overheads.

2. **Shorter Transmission Time Interval (TTI):** The use of a shorter TTI reduces the round trip time and enables improvements in adapting to fast channel variations and provides for reductions in latency.
3. **Use of shared channel transmission:** Sharing the resources enables greater levels of efficiency to be achieved and integrates with IP and packet data concepts.
4. **Use of link adaptation:** By adapting the link it is possible to maximize the channel usage.
5. **Fast Node B scheduling:** The use of fast scheduling with adaptive coding and modulation (only downlink) enables the system to respond to the varying radio channel and interference conditions and to accommodate data traffic which tends to be "bursty" in nature.
6. **Node B based Hybrid ARQ:** This enables 3G HSPA to provide reduced retransmission round trip times and it adds robustness to the system by allowing soft combining of retransmissions.

For the network operator, the introduction of 3G HSPA technology brings a cost reduction per bit carried as well as an increase in system capacity. With the increase in data traffic, and operators looking to bring in increased revenue from data transmission, this is a particularly attractive proposition. A further advantage of the introduction of 3G HSPA is that it can often be rolled out by incorporating a software update into the system. This means its use brings significant benefits to user and operator alike.

8.3.3 3G UMTS HSPA CONSTITUENTS

There are two main components to 3G UMTS HSPA, each addressing one of the links between the base station and the user equipment, i.e. one for the uplink, and one for the downlink.

The two technologies were released at different times through 3GPP. They also have different properties resulting from the different modes of operation that are required. In view of these facts they were often treated as almost separate entities. The two technologies are summarised below:

- **HSDPA - High Speed Downlink Packet Access:** HSDPA provides packet data support, reduced delays, and a peak raw data rate (i.e. over the air) of 14 Mbps. It also provides around three times the capacity of the 3G UMTS technology defined in Release 99 of the 3GPP UMTS standard.
- **HSUPA - High Speed Uplink Packet Access:** HSUPA provides improved uplink packet support, reduced delays and a peak raw data rate of 5.74 Mbps. This results in a capacity increase of around twice that provided by the Release 99 services.

8.3.4 HSDPA : HIGH SPEED DOWNLINK PACKET ACCESS

High Speed Downlink Packet Access enables high speed packet data up to 14.4 Mbps to be carried in the downlink of 3G UMTS. 3G HSDPA High Speed Downlink Packet Access provides additional capability to the basic 3G UMTS cellular telecommunications system.

HSDPA was the first upgrade along the path to HSPA which enabled high speed data to be carried in both directions. However as much more data was carried in the

downlink direction, HSDPA was standardised and implemented first to provide the maximum benefit as soon as possible.

8.4 HSDPA TECHNOLOGIES

The 3G HSDPA upgrade includes several changes that are built onto the basic 3GPP UMTS standard. While some are common to the companion HSUPA technologies added to the uplink, others are specific to HSDPA High Speed Downlink Packet Access, because the requirements for the each direction differ.

- **Additional channels:** In order to be able to transport the data in the required fashion, and to provide the additional responsiveness of the system, additional channels have been added.

To achieve the high speed data HSDPA uses new channels including: High Speed Downlink Shared Channel (HS-DSCH), High Speed Signalling Control Channel(HS-SCCH), High Speed Dedicated Physical Control Channel (HS-DPCCH).

- **Modulation:** One of the keys to the operation of HSDPA is the use of an additional form of modulation. Originally W-CDMA had used only QPSK as the modulation scheme, however under the new system 16-QAM which can carry a higher data rate, but is less resilient to noise is also used when the link is sufficiently robust. The robustness of the channel and its suitability to use 16-QAM instead of QPSK is determined by analyzing information fed back about a variety of parameters. These include details of the channel physical layer conditions, power control, Quality of Service (QoS), and information specific to HSDPA.
- **Improved scheduling:** Further advances have been made in the area of scheduling. By moving more intelligence into the base station, data traffic scheduling can be achieved in a more dynamic fashion. This enables variations arising from fast fading can be accommodated and the cell is even able to allocate much of the cell capacity for a short period of time to a particular user. In this way the user is able to receive the data as fast as conditions allow.
- **Fast HARQ:** Fast HARQ (hybrid automatic repeat request), has also been implemented along with multi-code operation and this eliminates the need for a variable spreading factor. By using these approaches all users, whether near or far from the base station are able to receive the optimum available data rate.

HSDPA provided a significant improvement in performance for 3G. With peak user data rates of around 10 Mbps and peak raw data rates of 14.4 Mbps, the system gave a marked improvement over what was available with basic 3G UMTS. When combined with HSUPA and other HSPA upgrades, the system was able to provide performance that rivalled that of the next generation networks.

8.5 HSUPA : HIGH SPEED UPLINK PACKET ACCESS

HSUPA, High Speed Uplink Packet Access, provided a considerable improvement in performance in the uplink for 3G UMTS networks. High Speed Uplink

Packet Access, HSUPA provides a major increase in data rate and overall performance for 3G UMTS networks. As the name indicates, HSUPA applies to the uplink, and as such it is the companion to HSDPA which is applied to the downlink.

With both HSDPA and HSUPA active, the overall scheme is referred to as HSPA - high speed packet access. Although when using HSUPA, there is a considerable increase in performance, the overall data rate in the uplink is not as fast as that available in the downlink. This is because the majority of data is passed in the downlink rather than the uplink.

In addition to this there are additional difficulties providing the same performance from the UE in view of some of the restrictions imposed by the fact that a large number of UEs are communicating with the NodeB.

8.5.1 HSUPA TECHNOLOGIES

HSUPA brings enhanced performance through the addition of new features that sit on top of the existing UMTS technology.

The key specification parameters that are introduced by the use of HSUPA are:

- **Increased data rate:** The use of HSUPA is able to provide a significant increase in the data rate available. It allows peak raw data rates of 5.74 Mbps.
- **Lower latency:** The use of HSUPA introduces a TTI of 2 ms, although a 10ms TTI was originally used and is still supported.
- **Improved system capacity:** In order to enable the large number of high data rate users, it has been necessary to ensure that the overall capacity when using HSUPA is higher.
- **Modulation order:** Originally only BPSK modulation, that adopted for UMTS, was used. Accordingly it did not support adaptive modulation schemes. Higher order modulation was introduced in Release 7 of the 3GPP standards when 64QAM was allowed.
- **Hybrid ARQ:** In order to facilitate the improved performance the Hybrid ARQ (Automatic Repeat request) used for HSDPA is also employed for the uplink, HSUPA.
- **Fast Packet Scheduling:** In order to reduce latency, fast packet scheduling has been adopted again for the uplink as for the downlink, although the implementation is slightly different.

With these specification parameters enable HSUPA to complement the performance of HSDPA, providing an overall performance improvement for systems incorporating HSPA.

The addition of HSUPA to the 3G UMTS network enabled the uplink as well as the downlink to provide much improved performance. With both HSDPA (downlink) and HSUPA (uplink) active the complete package was called HSPA - high speed packet access. Although most of the data is passed into the downlink, many users found the uplink

without HSUPA very slow and it degraded the overall user experience. With HSUPA active the overall experience was much improved.

8.6 EVOLVED HSPA / HSPA+

Once the basic HSPA was running, further evolutions were implemented in the form of Evolved HSPA / HSPA+ / HSPA Evolution. As data usage increased still further, HSPA was improved in a series of revisions to provide what was termed Evolved HSPA, HSPA+ or even HSPA Evolution.

The overall Evolved HSPA / HSPA+ involved a series of enhancements that improved not only the data speed, but also reduced latency and gave an overall improvement in performance.

To achieve these enhancements were made to the radio access network as well as backhaul along with an on-going improvement to the network itself.

8.6.1 HSPA+ IN 3GPP RELEASES

The definition of HSPA+ / Evolved HSPA have been included in Releases 7 and 8 of the 3GPP standards.

- **3GPP Release 7:** This release of the 3GPP standard included downlink MIMO operation as well as support for higher order modulation up to 64 QAM in the uplink and 16 QAM in the downlink. However it only allows for either MIMO or the higher order modulation. It also introduced protocol enhancements to allow the support of more users that are in a "continuously on" state.
- **3GPP Release 8:** This release of the standard defines dual carrier operation as well as allowing simultaneous operation of the high order modulation schemes and MIMO. Further to this, latency is improved to keep it in line with the requirements for many new applications being used.

8.6.2 EVOLVED HSPA / HSPA+ HIGHLIGHT FEATURES

There are a number of major new features as well as some enhancements to existing capabilities that enable HSPA+ or Evolved HSPA to provide a significant improvement in performance over that provided by the standard HSPA systems.

Some of the major features include:

- **Higher Order Modulation:** Although MIMO provides some significant improvements in throughput, where the multiple antennas needed for MIMO are not available, and where signal strength is relatively high, it is possible to increase the order of the modulation to enable higher throughput rates. However this can only be achieved when signal levels are sufficiently high otherwise data errors increase.
- **MIMO:** Many other systems have utilised MIMO and so too, HSPA+ is able to gain significant advantages from its use.

- **Layer 2 protocol enhancements:** In order to benefit from the higher data rates over the HS-DSCH enhancements to the RLC and MAC-hs protocols have been introduced.
- **Continuous packet connectivity:** With much of the data traffic being in the form of IP data, continuous connectivity is an increasing requirement. To achieve the HS-DSCH and EODCH channels have been reconfigured to enable them to be rapidly able to transmit user data.
- **Enhanced CELL_FACH operation:** This enhanced operation is required to assist in maintaining the always-on packet connectivity during periods when there have been little or no activity.

8.6.3 HSPA+ DATA RATE COMPARISON WITH LTE

The next migration of the cellular services beyond HSPA+ is known as LTE. Using a completely new air interface based around the use of OFDM rather than W-CDMA which is used for UMTS, HSPA and HSPA+, it offers even higher data traffic rates. It is then anticipated that it will be used as the basis for the next generation, i.e. 4G systems.

It is however worth comparing the maximum data rates offered by both HSPA+ and LTE.

CHANNEL BANDWIDTH (MHZ)	HSPA+ DATA RATE (MBPS)	LTE DATA RATE (MBPS)
5	42	37
10	84	73
20	--	150

Table 2. HSPA+ data rate comparison

Although the basic comparisons appear to show that LTE will offer few advantages, there are several other features of LTE that mean that it is a preferable option for the long term. LTE enables wider bandwidths and the OFDM modulation enables data transmissions to be made more resilient to multipath and other propagation effects.

8.7 LTE: LONG TERM EVOLUTION

LTE Long Term Evolution was the 4G successor to 3G UMTS that provided improved speeds and performance. Providing much higher data speeds and greatly improved performance as well as lower operating costs, the scheme started to be deployed in its basic form around 2008.

Initial deployments gave little improvement over 3G HSPA and were sometimes dubbed 3.5G or 3.99G, but soon the full capability of LTE was realised it provided a full 4G level of performance.

The first deployments were simply known as LTE, but later deployments were designated 4G LTE Advanced and later still 4G LTE Pro.

Not only was the radio access network improved for 4G LTE, but the network architecture was overhauled enabling lower latency and much better interconnectivity between elements of the radio access network, RAN.

8.7.1 LTE EVOLUTION

It was 3GPP release 8 when LTE was introduced for the very first time. All the releases following only enhanced the technology.

Although there are major step changes between LTE and its 3G predecessors, it is nevertheless looked upon as an evolution of the UMTS / 3GPP 3G standards. Although it uses a different form of radio interface, using OFDMA / SC-FDMA instead of CDMA, there are many similarities with the earlier forms of 3G architecture and there is scope for much re-use.

In determining what is LTE and how does it differ from other cellular systems, a quick look at the specifications for the system can provide many answers. LTE can be seen for provide a further evolution of functionality, increased speeds and general improved performance.

COMPARISON WITH OTHER MOBILE COMMUNICATIONS TECHNOLOGIES				
	WCDMA (UMTS)	HSPA HSDPA / HSUPA	HSPA+	LTE
Max downlink speed bps	384 k	14 M	28 M	100M
Max uplink speed bps	128 k	5.7 M	11 M	50 M
Latency round trip time approx	150 ms	100 ms	50ms (max)	~10 ms
3GPP releases	Rel 99/4	Rel 5 / 6	Rel 7	Rel 8
Approx years of initial roll out	2003 / 4	2005 / 6 HSDPA 2007 / 8 HSUPA	2008 / 9	2009 / 10
Access methodology	CDMA	CDMA	CDMA	OFDMA / SC-FDMA

Table 3. Comparison With Other Mobile Communications Technologies

In addition to this, LTE is an all IP based network, supporting both IPv4 and IPv6.

8.7.2 LTE SPECIFICATION OVERVIEW

It is worth summarizing the key parameters of the 3G LTE specification. In view of the fact that there are a number of differences between the operation of the uplink and downlink, these naturally differ in the performance they can offer.

These highlight specifications give an overall view of the performance that LTE will offer. It meets the requirements of industry for high data download speeds as well as reduced latency - a factor important for many applications from VoIP to gaming and interactive use of data. It also provides significant improvements in the use of the available spectrum

LTE BASIC SPECIFICATIONS	
PARAMETER	DETAILS
Peak downlink speed 64QAM (Mbps)	100 (SISO), 172 (2x2 MIMO), 326 (4x4 MIMO)
Peak uplink speeds (Mbps)	50 (QPSK), 57 (16QAM), 86 (64QAM)
Data type	All packet switched data (voice and data). No circuit switched.
Access schemes	OFDMA (Downlink) SC-FDMA (Uplink)
Modulation types supported	QPSK, 16QAM, 64QAM (Uplink and downlink)
Spectral efficiency	Downlink: 3 - 4 times Rel 6 HSDPA Uplink: 2 -3 x Rel 6 HSUPA
Channel bandwidths (MHz)	1.4, 3, 5, 10, 15, 20
Duplex schemes	FDD and TDD
Mobility	0 - 15 km/h (optimised), 15 - 120 km/h (high performance)
Latency	Idle to active less than 100ms Small packets ~10 ms

Table 4. LTE Basic Specifications

8.8 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.

International Telecommunication Union using Radio (ITU-R) defined 4G mobile technology as IMT-Advanced (International Mobile telecommunication Advanced). LTE-Advanced specifications in release 10 includes significant features and improvements to fulfil ITU IMT-Advanced requirements which sets higher speeds than what UE can achieve from 3GPP release 8 specifications.

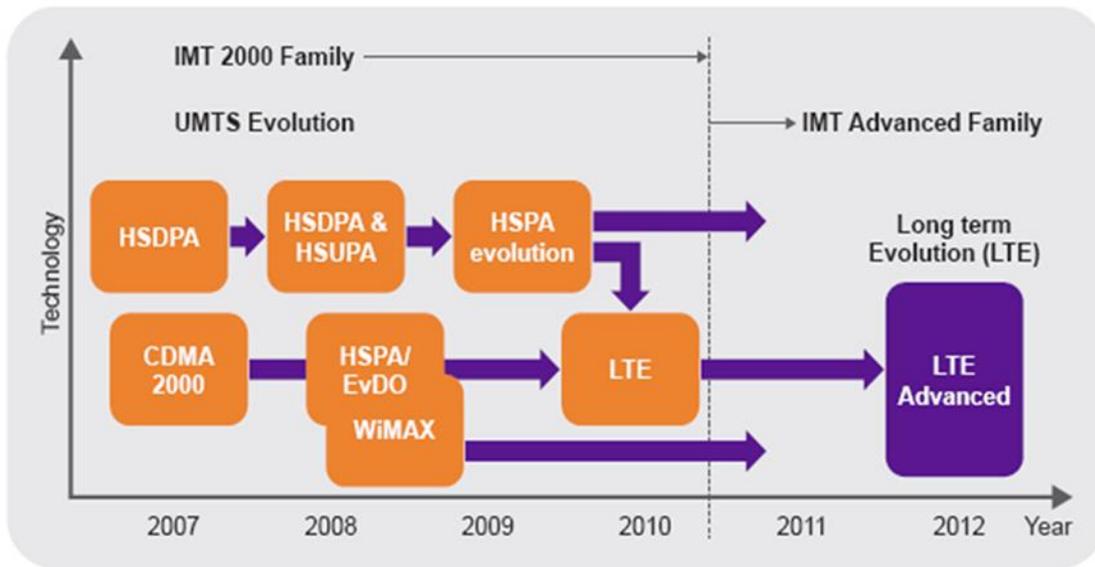


Figure 46: IMT 2000 & IMT Advanced

Some key requirements laid down by IMT-Advanced are as below

Requirements of IMT-Advanced

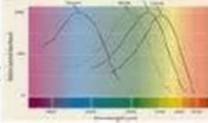
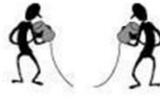
 <p>Very high data rates: 1 Gbps for low mobility, 100 Mbps for high mobility</p>	<p>Interworking and global roaming</p> 
 <p>Enhanced capacity: 40 VoIP users per sector/Mhz</p>	<p>Wider spectrum: Up to 40 or 100 MHz</p> 
 <p>High peak spectral efficiency: 15 bps/Hz (downlink), 6.75 bps/Hz (uplink)</p>	<p>Low latency: U-plane < 10 ms C-plane < 100 ms</p> 
 <p>Support for high mobility: Up to 350 km/hr</p>	<p>Handover interruption: < 27.5 ms (intra-frequency) < 40 ms (inter-frequency)</p> 

Figure 47: Key Requirement of IMT-Advanced

8.8.1 RADIO TECHNOLOGY EVOLUTION TO 4G

OFDM forms the basis of the radio access technology. Along with it there is OFDMA (Orthogonal Frequency Division Multiple Access) along with SC-FDMA (Single Channel Orthogonal Frequency Division Multiple Access). These will be used in a hybrid format. However the basis for all of these access schemes is OFDM.

LTE uses separate multiple-access technologies for the downlink (base station to mobile) and the uplink (mobile to base station). It employs Orthogonal FDMA (OFDMA) for the downlink and Single-Carrier FDMA (SC-FDMA) for the uplink.

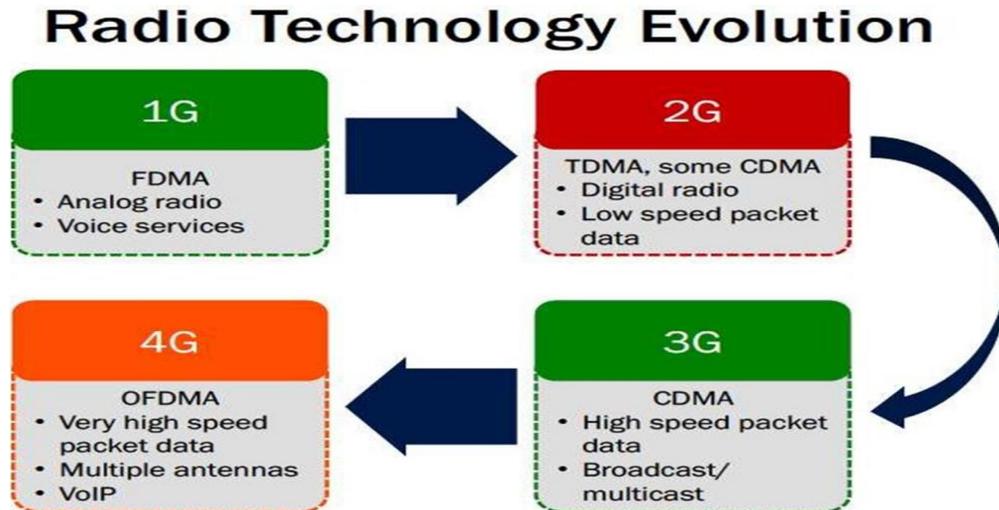


Figure 48: Radio Technology Evolution

8.8.2 NETWORK ARCHITECTURE EVOLUTION

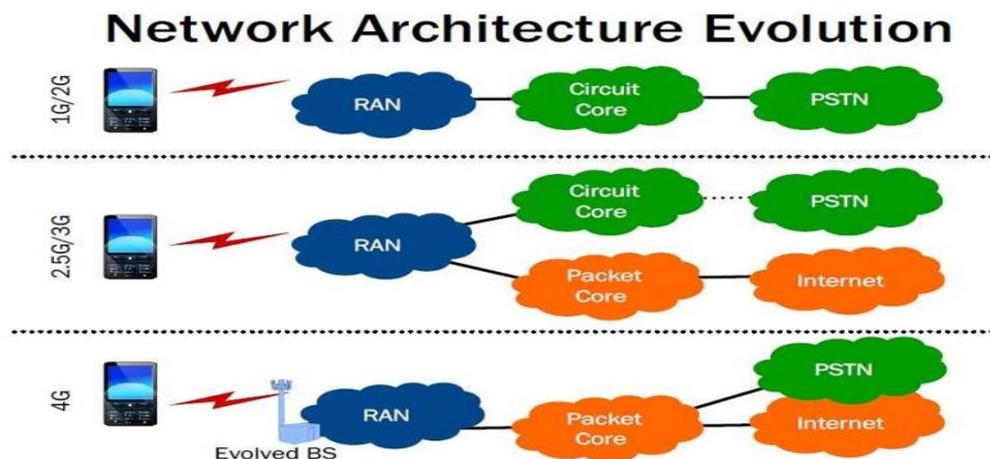


Figure 49: Network Architecture Evolution

8.9 CONCLUSION

In this chapter we have studied about HSPA and HSPA+, along with LTE Technologies. Carrier aggregation is the way for future radio technologies. HSPA+ plays a important role in delivering high speed data over 3G Network.

9 4G AND 5G NETWORK ARCHITECTURE

9.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- 4G Network Architecture
- LTE Architecture goals
- LTE Radio Network E UTRAN
- LTE Network Elements
- 5G Network Architecture

9.2 4G NETWORK ARCHITECTURE

9.2.1 4G LTE SYSTEM ARCHITECTURE

LTE has a flat architecture which minimizes the number of network elements. LTE is optimized for Packet Switched (PS) services but includes functionality to handle Circuit Switched (CS) services, e.g. CS fallback to UMTS/ LTE also supports the speech service using Voice over IP.

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.

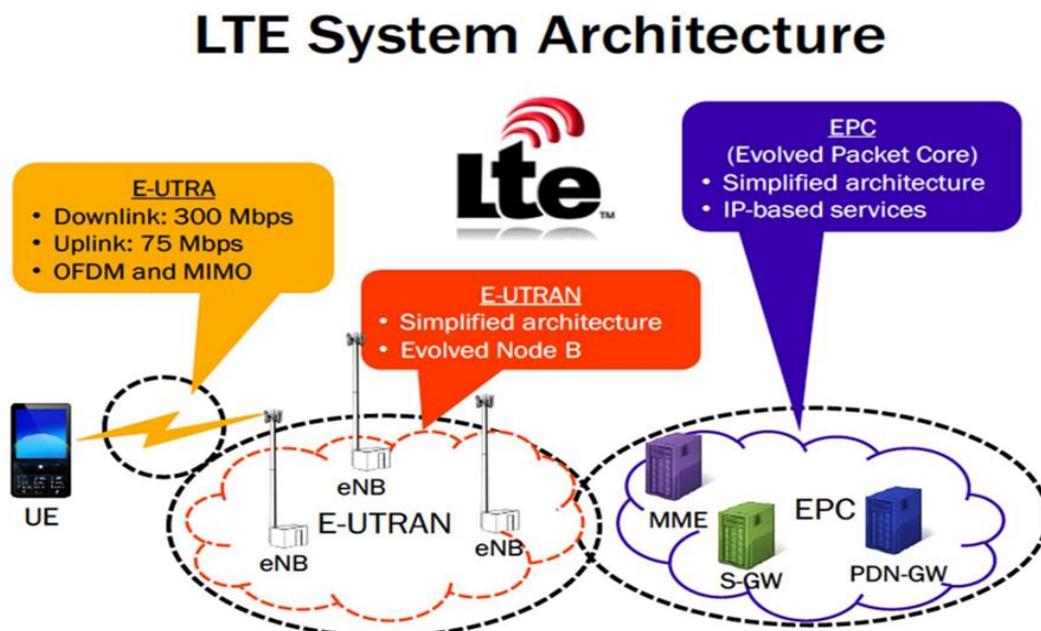


Figure 50: LTE System Architecture

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 signaling and a Serving Gateway for user plane data.

9.2.2 LTE ARCHITECTURE GOAL

LTE Architecture Goals

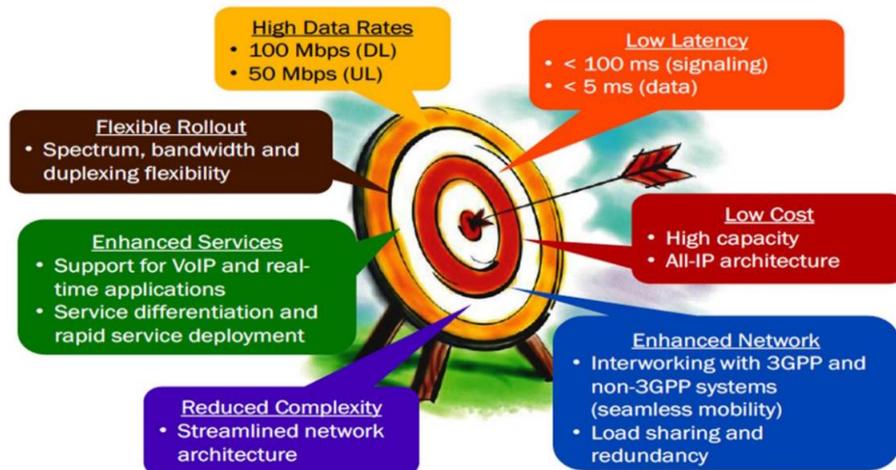


Figure 51: LTE Architecture Goal

9.2.3 LTE RADIO NETWORK : THE E-UTRAN

The radio access network of LTE is known as Evolved UMTS Terrestrial Radio Access Network which is evolved version of UMTS access network. 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.

LTE Radio Network (E-UTRAN)

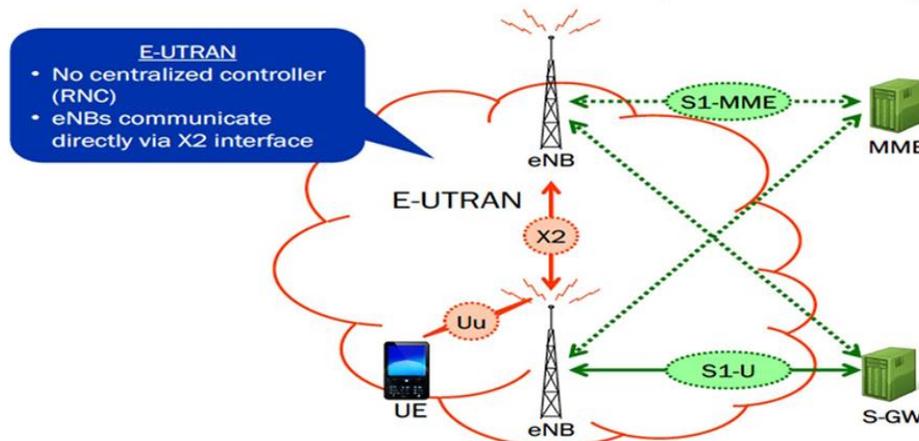


Figure 52: LTE Radio Network

9.2.4 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-FDMA is also a frequency division multiple access scheme and usually represents an alternative to OFDM. Its main advantage is a lower peak-to-average power ratio, 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.

9.2.5 ENODEB

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

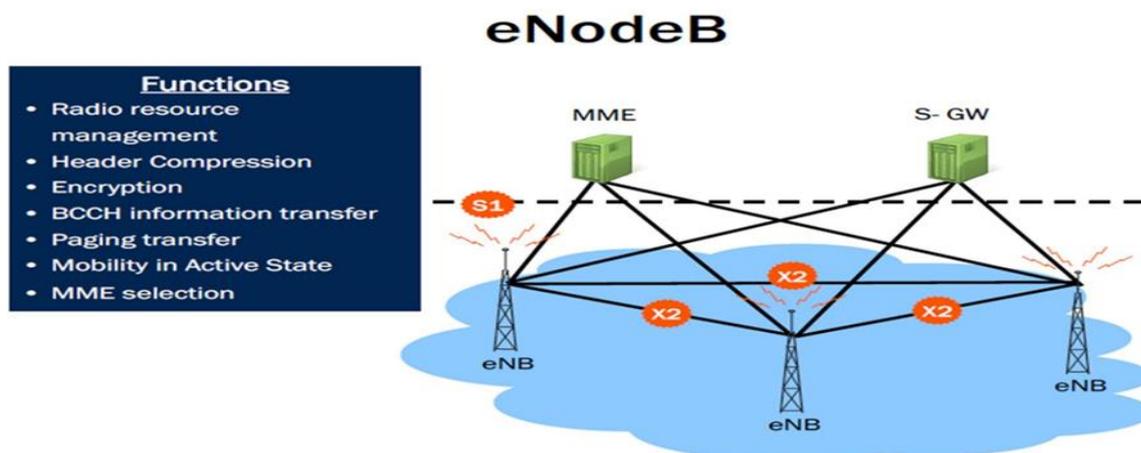


Figure 53: eNodeB

The eNodeB 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.

9.2.6 INTERFACES OF THE ENODEB

LTE-Uu Interface

The LTE-Uu is the radio interface that connects the UEs to the eNodeBs, eNodeB with the UE. It handles all the signalling messages between the eNodeB 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.

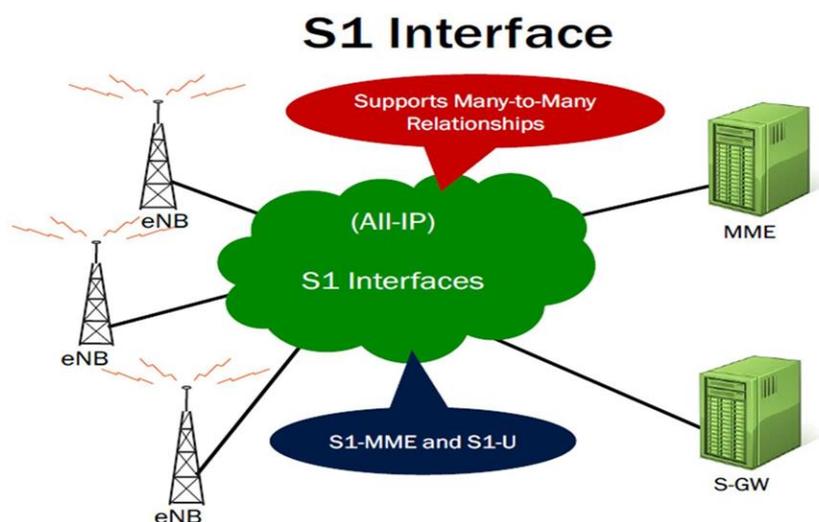


Figure 54: S1 Interface

Therefore, when the eNodeB 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 eNodeB and one MME can set up a single Stream Control Transmission Protocol (SCTP) connection. Once the TNL has been established, the eNodeB 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 eNodeB 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-eNodeB handover, and allows intra-3GPP mobility.

X2 Interface

The X2 interface provides connectivity between two or more eNodeBs. There are two parts of the X2 interface, the X2-C, the interface between the control planes of eNodeBs, and the X2-U, the interface between the user planes of eNodeBs. 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 eNodeBs exchange information related to load, interference or handover.

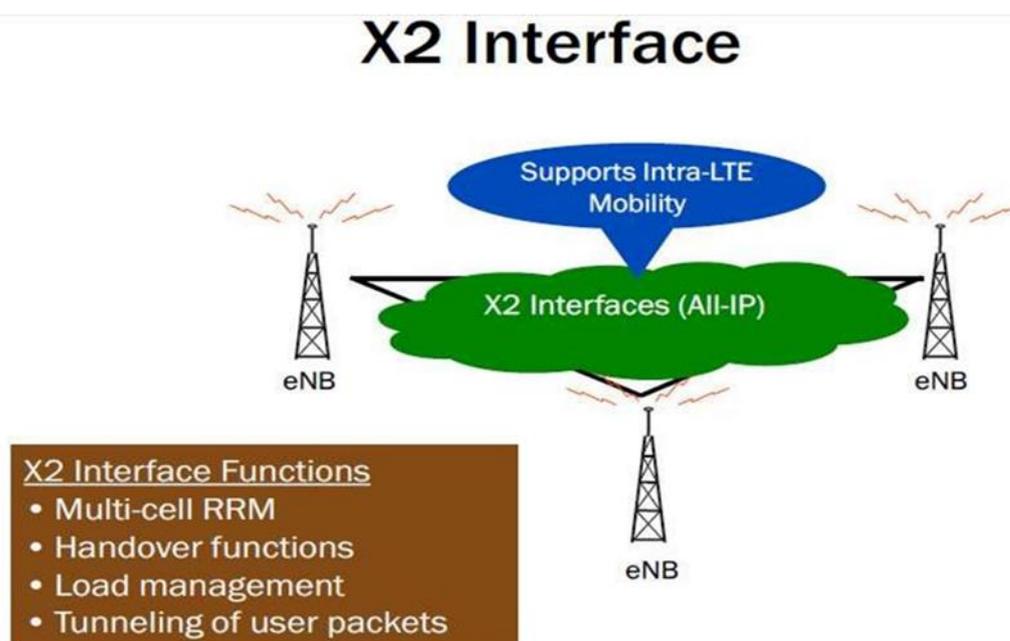


Figure 55: X2 Interface

Two or more eNodeBs 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-eNodeB handover
- Tracing function
- X2 interface management and error handling

9.2.7 4G LTE EPC ARCHITECTURE

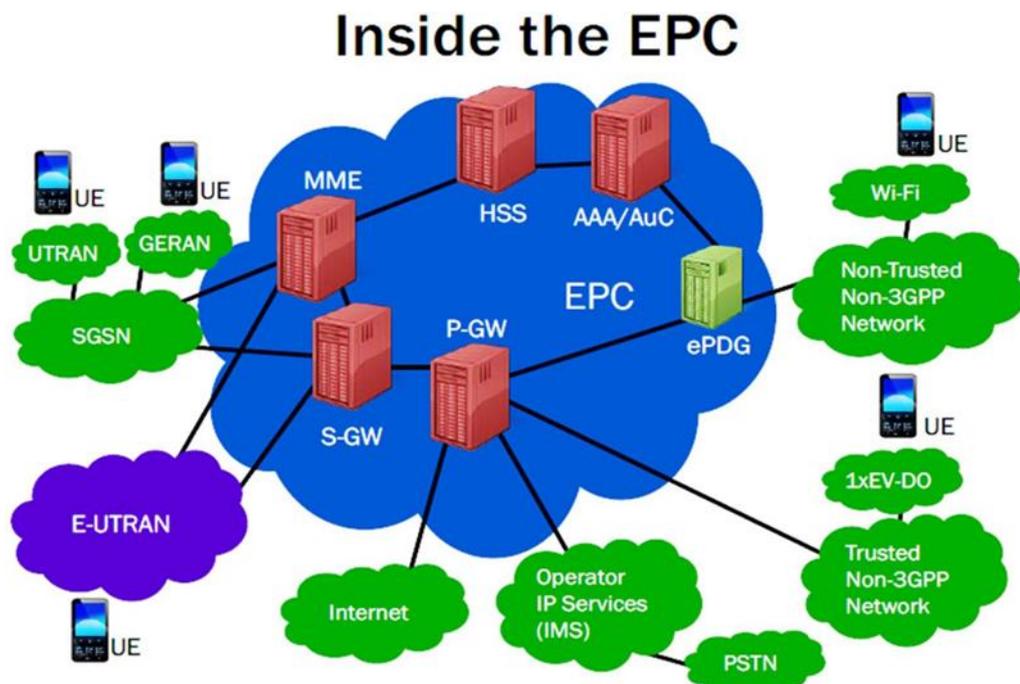


Figure 56: Mobile Core (Evolved Packet Core).

The 4G Mobile Core, which 3GPP officially refers to as the Evolved Packet Core (EPC), consists of five main components.

- MME (Mobility Management Entity)
- HSS (Home Subscriber Server)
- PCRF (Policy & Charging Rules Function)
- SGW (Serving Gateway)
- PGW (Packet Gateway)

Although specified as distinct components, in practice the SGW (RAN-facing) and PGW (Internet-facing) are often combined in a single device, commonly referred to as an S/PGW.

The first three run in the Control Plane (CP) and the second two run in the User Plane (UP).

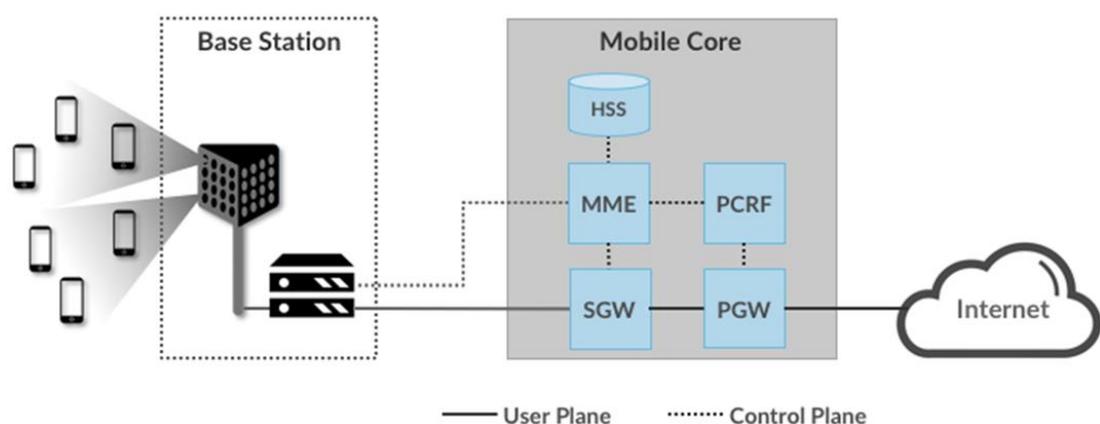


Figure 57: 4G Mobile Core (Evolved Packet Core).

9.2.8 MME (MOBILITY MANAGEMENT ENTITY)

Tracks and manages the movement of UEs throughout the RAN.

Mobility Management Entity (MME)

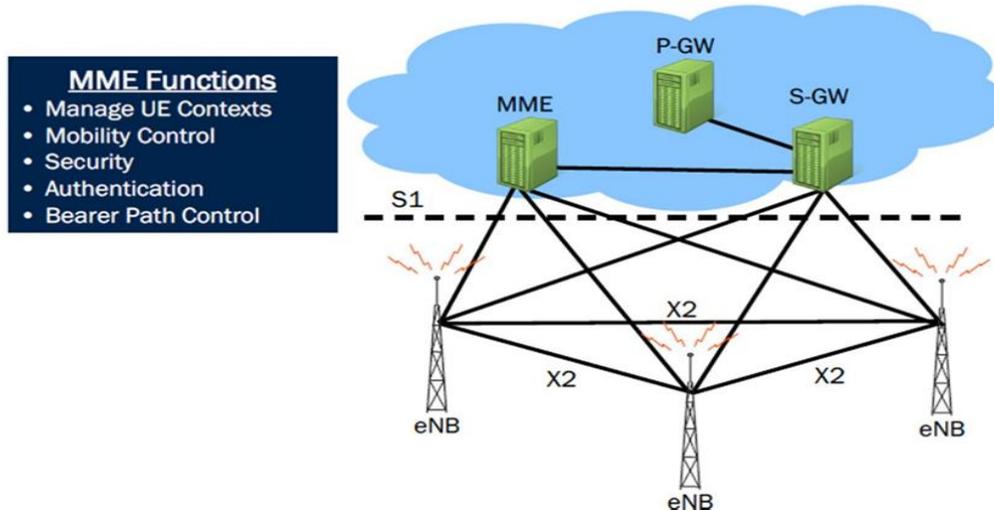


Figure 58: MME

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.

9.2.9 HSS (HOME SUBSCRIBER SERVER)

A database that contains all subscriber-related information.

Home Subscriber Server (HSS)

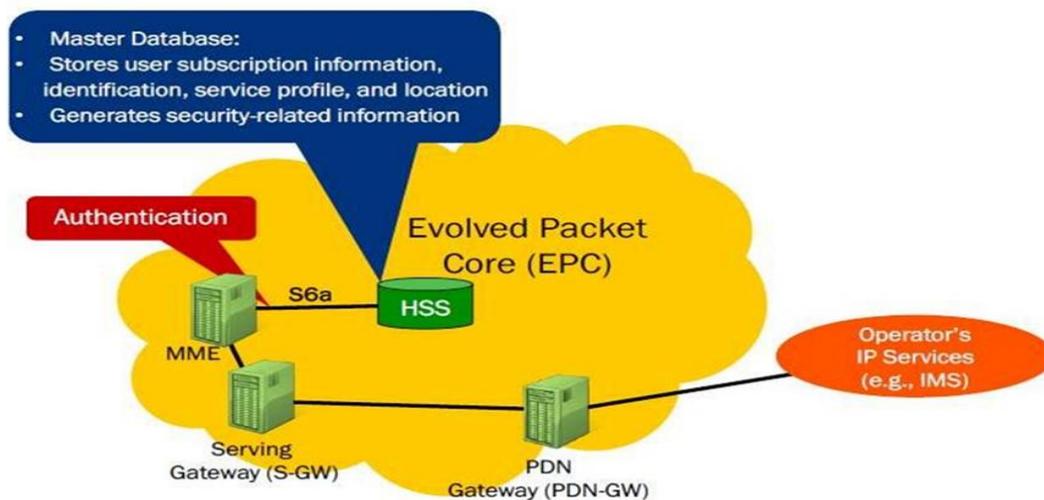


Figure 59: HSS

9.2.10 PCRF (POLICY & CHARGING RULES FUNCTION)

Tracks and manages policy rules and records billing data on subscriber traffic.

9.2.11 SGW (SERVING GATEWAY)

Forwards IP packets to and from the RAN. Anchors the Mobile Core end of the bearer service to a (potentially mobile) UE, and so is involved in handovers from one base station to another.

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.

Serving Gateway (S-GW)

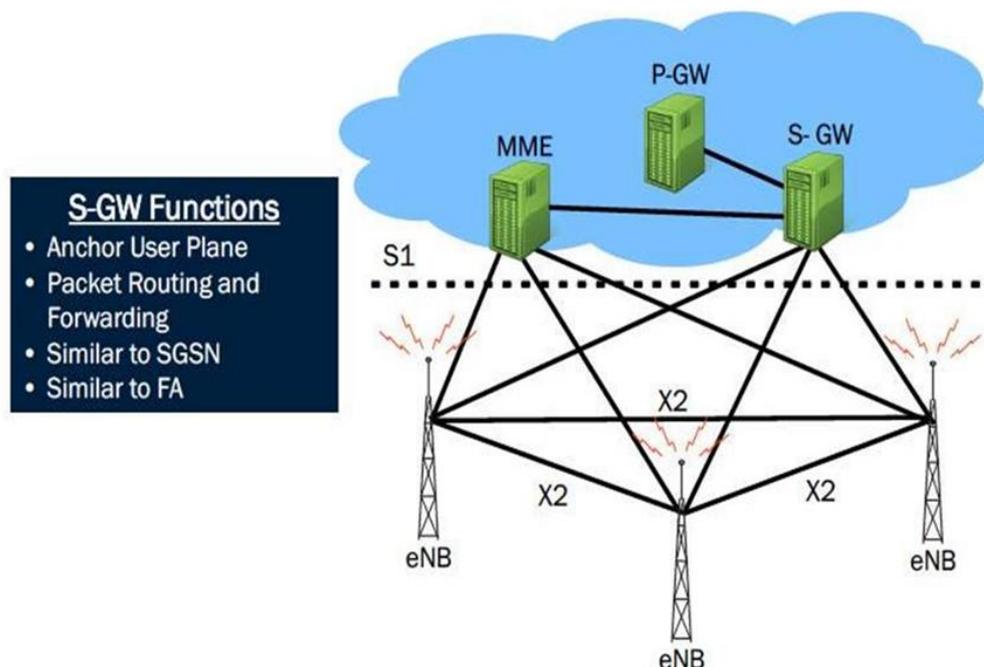


Figure 60: SGW (Serving Gateway)

9.2.12 PGW (PACKET GATEWAY)

Essentially an IP router, connecting the Mobile Core to the external Internet. Supports additional access-related functions, including policy enforcement, traffic shaping, and charging. 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.

Packet Data Network Gateway

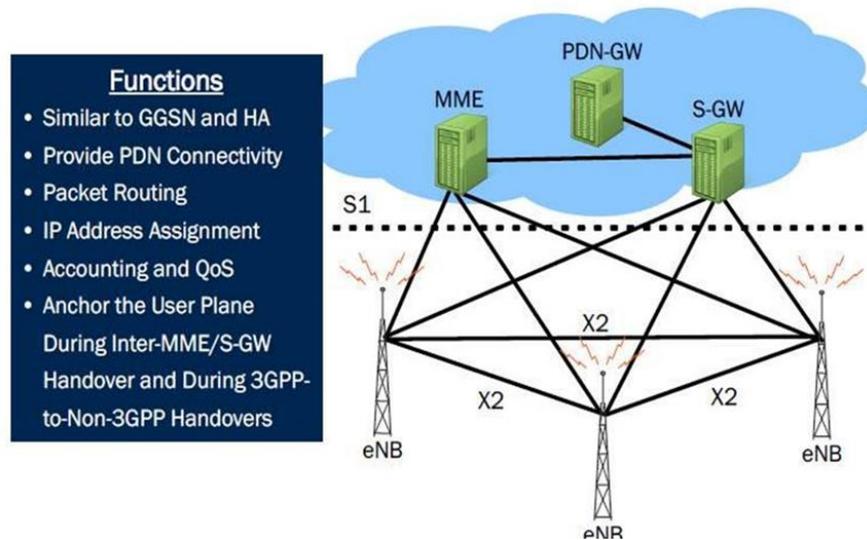


Figure 61: PGW (Packet Gateway)

9.3 5G NETWORK ARCHITECTURE

9.3.1 5G SYSTEM ARCHITECTURE

The 5G System (5GS) includes the 5G Core Network (5GC), the 5G Access Network (5G-AN) and the User Equipment (UE). The 5G Core Network provides connectivity to the internet and to application servers. The 5G Access Network can be a 3GPP Next Generation Radio Access Network (NG-RAN), or a non-3GPP Access Network.



Figure 62: 5G System Architecture

3GPP has specified both 'Reference Point' and 'Service based' architectures for the 5G System (5GS).

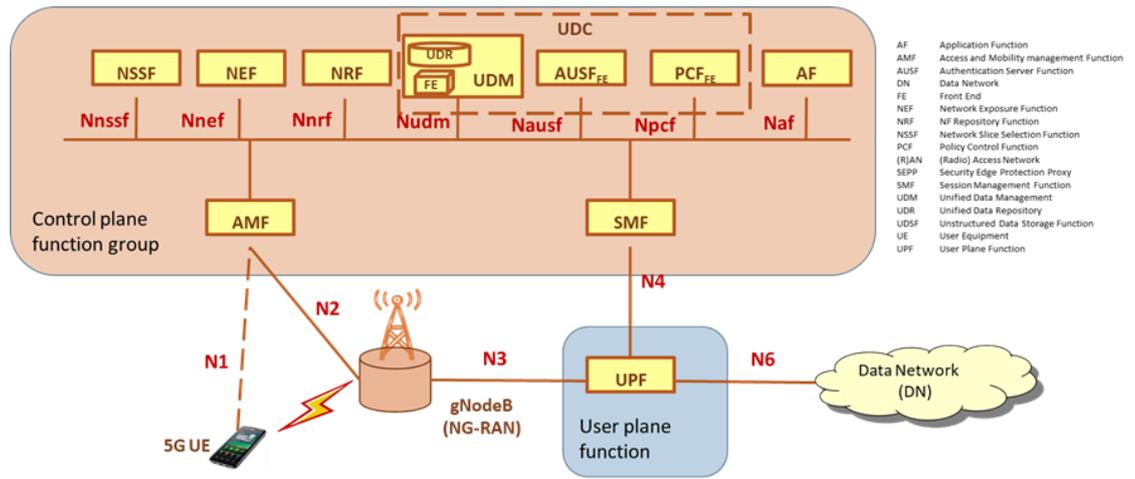


Figure 63: Architectures for the 5G System (Actual).

Concept of Reference Point Architecture

The 'Reference Point' architecture is based upon a set of Network Elements (NE) which uses point-to-point interfaces to inter-connect those Network Elements. Signalling procedures are specified for each point-to-point interface.

The 'Reference Point' architecture can lead to repetition within the specifications if the same signalling procedure is used across multiple interfaces

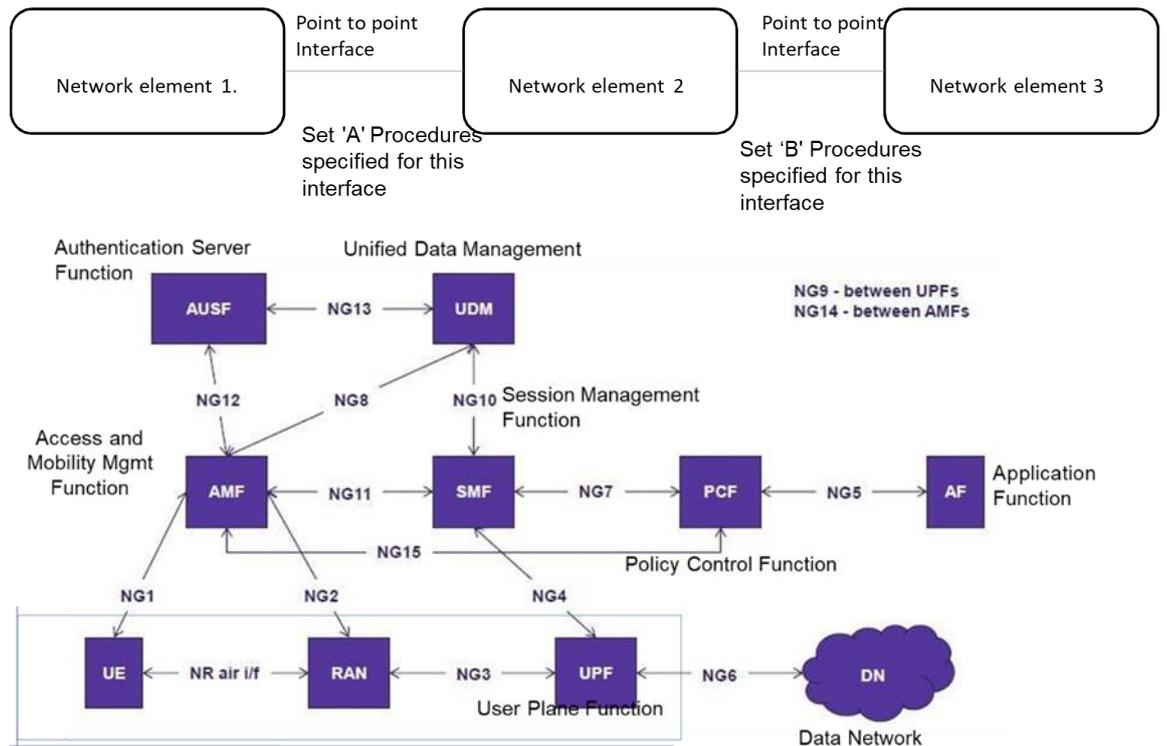


Figure 64: Reference Point architecture

Concept of Service based system architecture

The 'Service based' architecture replaces the set of Network Elements with a set of Network Functions (NF). Each Network Function can provide services to other Network Functions, i.e. each Network Function is a service provider. This type of architecture is service based architecture. The point-to-point interfaces are replaced by a common bus which inter- connects all Network Functions. Services are specified for the Network Function providing them, rather than for each pair of providing and consuming Network Functions.

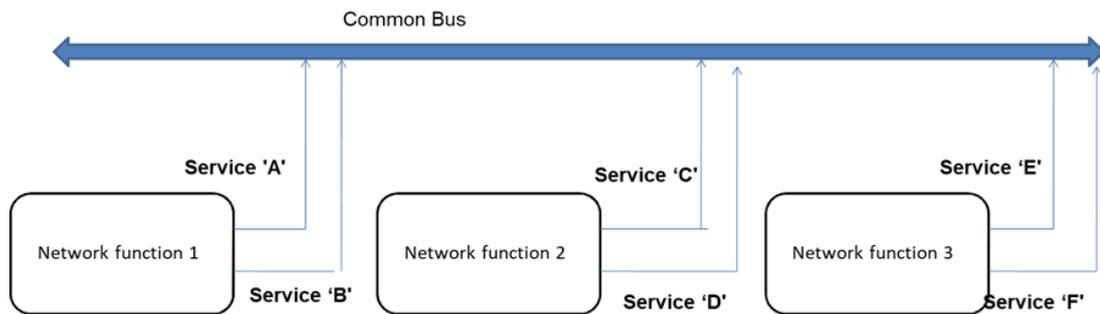


Figure 65: SBA

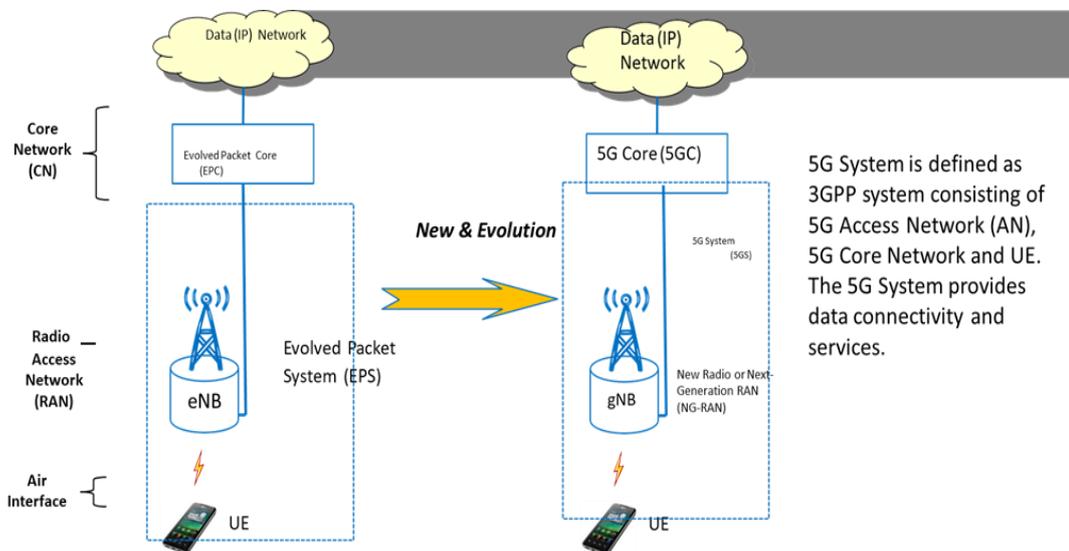


Figure 66: 5G Network Architecture Evolution

9.3.2 5G NEXTGEN NG CORE NETWORK REQUIREMENT

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.

- **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
- **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.
- **Network slicing:** As 5G will require very different types of network for the different applications, a scheme known as network slicing has been devised. 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 another 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.

The performance required for the 5G NextGen network has been defined by the NGMN (Next Generation Mobile Network Alliance). The Next Generation Mobile Networks Alliance is a mobile telecommunications association of mobile operators, vendors, manufacturers and research institutes and by using the experience of all parties, it is able to develop the strategies for the next generation mobile networks, like that for 5G.

As such the 5G NG, NextGen core network will be able to utilise far greater levels of flexibility to enable it to serve the increased and diverse requirements placed upon it by the radio access network and the increased number of connections and traffic.

9.3.3 5G CORE NETWORK ARCHITECTURE

5G core Network is called the Next Generation Core (NG-Core). 5G Mobile Core divided into a Control Plane and a User Plane, an architectural feature known as CUPS: Control and User Plane Separation

The Service Based architecture is applicable to the control plane section of the 5G Core Network.

The Reference Point architecture remains for the user plane section of the 5G Core Network.

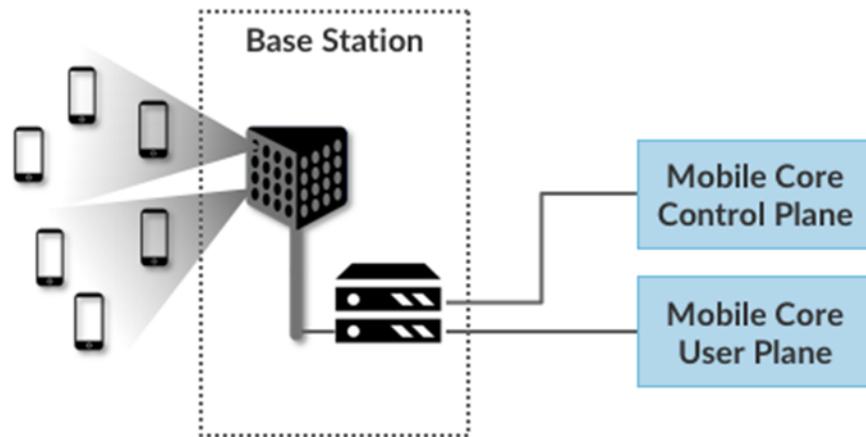


Figure 67: LTE System Architecture

Core Network Architecture Evolution to 5G



- Functional entities
- Single Core
- Dedicated protocols
- Service Based (SBA/SBI/NAPS)
- Virtualization & Slicing
- Softwarization/ Cloudification
- Application Programming Interfaces
- Harmonized protocols (HTTP ...)
- Exposure to 3rd Parties
- Backward & Forward Compatibility

Service Based Core Network

The 5G Mobile Core, which 3GPP calls the NG-Core, adopts Service Based architecture which specifies a set of Network Functions (NF) and a common bus which inter-connects those Network Functions.

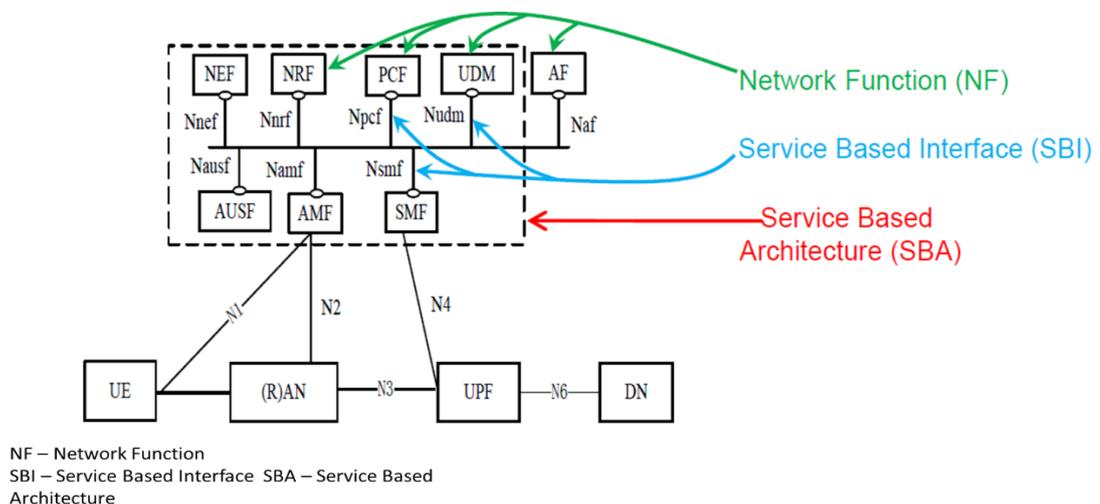


Figure 68: SBA Terminology

The following organizes the set of functional blocks into three groups.

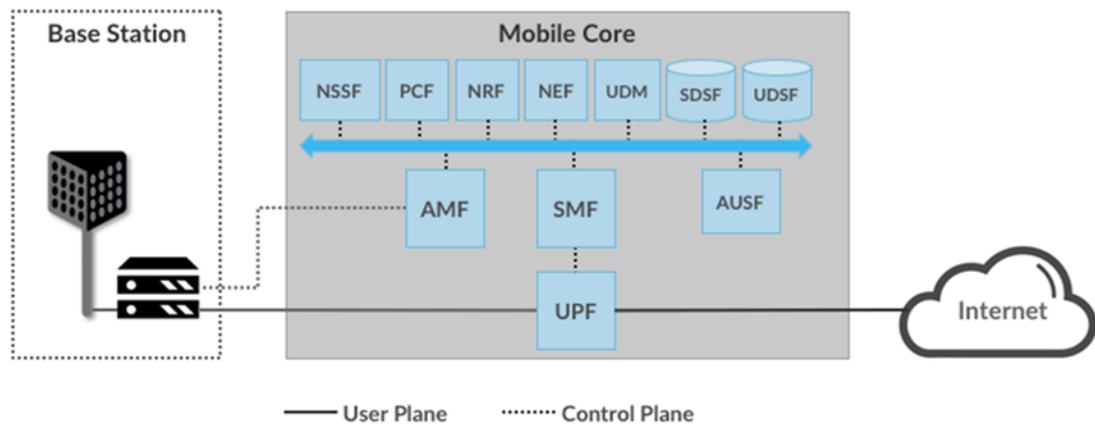


Figure 69: functional blocks

The first group runs in the Control Plane (CP) and has a counterpart in the EPC.

- AMF (Core Access and Mobility Management Function): Responsible for connection and reachability management, mobility management, access authentication and authorization, and location services. Manages the mobility-related aspects of the EPC's MME.
- SMF (Session Management Function): Manages each UE session, including IP address allocation, selection of associated UP function, control aspects of QoS, and control aspects of UP routing. Roughly corresponds to part of the EPC's MME and the control-related aspects of the EPC's PGW.
- PCF (Policy Control Function): Manages the policy rules that other CP functions then enforce. Roughly corresponds to the EPC's PCRF.
- UDM (Unified Data Management): Manages user identity, including the generation of authentication credentials. Includes part of the functionality in the EPC's HSS.
- AUSF (Authentication Server Function): Essentially an authentication server. Includes part of the functionality in the EPC's HSS.

The second group also runs in the Control Plane (CP) but does not have a direct counterpart in the EPC:

- SDSF (Structured Data Storage Network Function): A "helper" service used to store structured data. Could be implemented by an "SQL Database" in a microservices-based system.
- UDSF (Unstructured Data Storage Network Function): A "helper" service used to store unstructured data. Could be implemented by a "Key/Value Store" in a microservices-based system.
- NEF (Network Exposure Function): A means to expose select capabilities to third-party services, including translation between internal and external representations for data. Could be implemented by an "API Server" in a microservices-based system.
- NRF (NF Repository Function): A means to discover available services. Could be implemented by a "Discovery Service" in a microservices-based system.
- NSSF (Network Slicing Selector Function): A means to select a Network Slice to serve a given UE. Network slices are essentially a way to partition

network resources in order to differentiate service given to different users. It is a key feature of 5G that we discuss in depth in a later chapter.

The third group includes the one component that runs in the User Plane (UP):

- UPF (User Plane Function): Forwards traffic between RAN and the Internet, corresponding to the S/PGW combination in EPC. In addition to packet forwarding, it is responsible for policy enforcement, lawful intercept, traffic usage reporting, and QoS policing.

9.3.4 5G NR NEW RADIO

5G NR or 5G New Radio is the new radio air interface being developed for 5G mobile communications. Unlike Previous Generation Core Network of 5G is design to work seamlessly with more than one access technology.

The 5G NR has been defined with no backward compatibility with the existing LTE and LTE- Advanced systems.

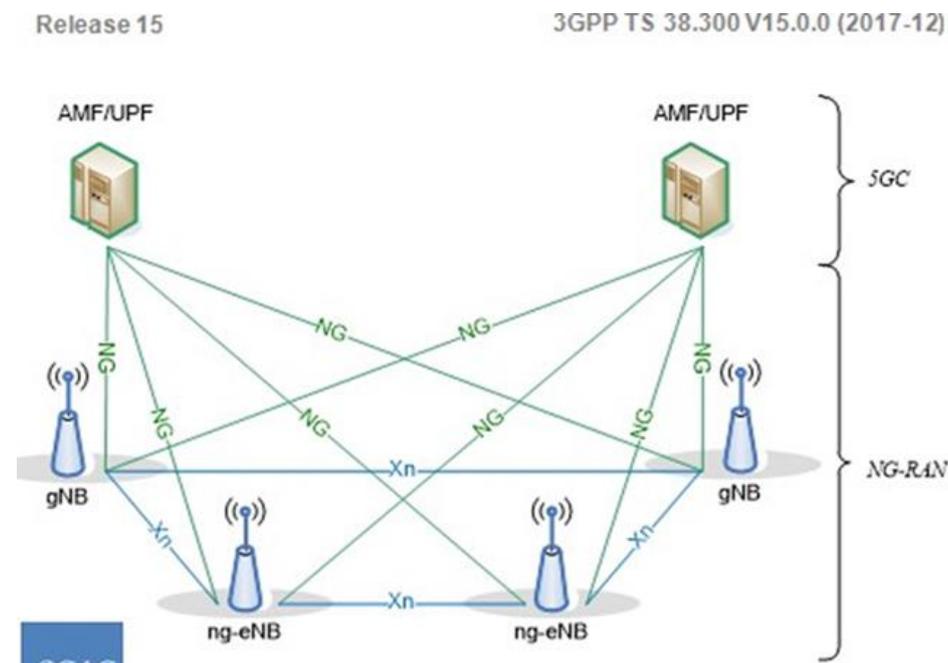


Figure 70: Next Generation Radio Access Network NG-RAN
An NG-RAN node is either:

- A gNB, providing NR user plane and control plane protocol terminations towards the UE; or
- An ng-eNB, providing E-UTRA user plane and control plane protocol terminations towards the UE.
- eNodeB (eNB) :LTE access network from 3GPP Rel-8 up to 3GPP Rel-14
- Next generation eNodeB (ng-eNB) : LTE access network from 3GPP Rel-15 onwards node providing E-UTRA user plane and control plane protocol terminations towards the UE, and connected via the NG interface to the 5GC.
- Next generation NodeB (gNB) : 5G access network from 3GPP Rel-15 onwards.

5G/NR - RAN Architecture

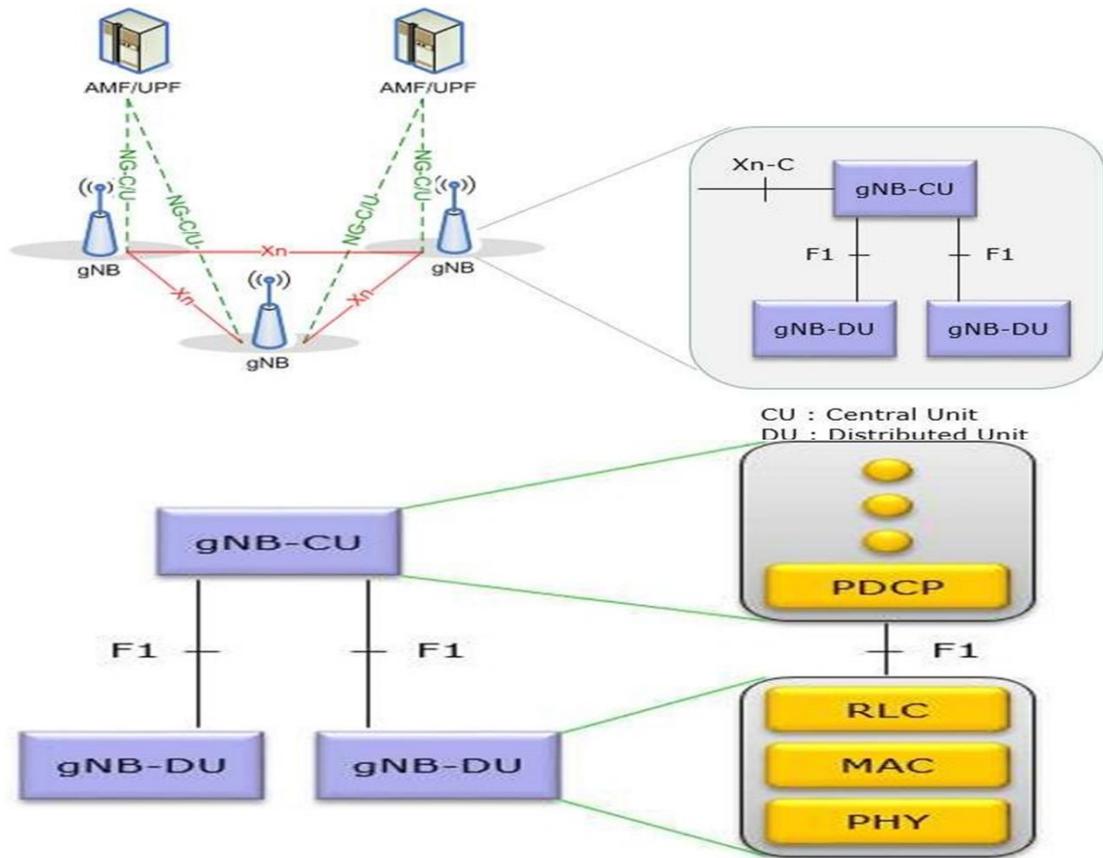


Figure 71: gNodeB Architecture

5G NR gNodeB is split into two part; gNB-Cu 9 central unit and gNB-DU(Distributed unit. Split helps to virtualize the network functionalities. At least as of now, it would be difficult to virtualize the lower layer of gNB(PHY/MAC/RLC), but you would be able to put higher layer protocol stack (PDCP and above) into a open hardware and software-based protocol stack.

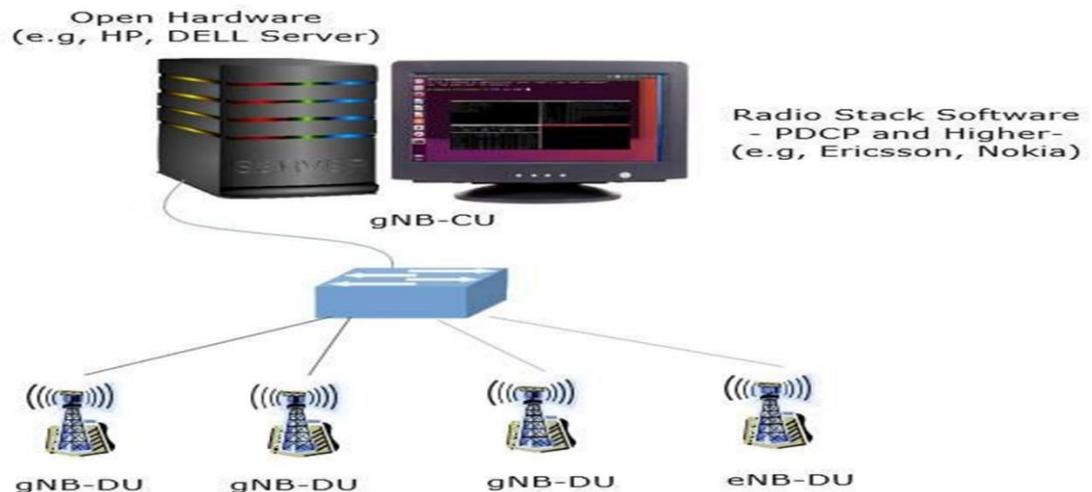


Figure 72: NR Architecture

9.3.5 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

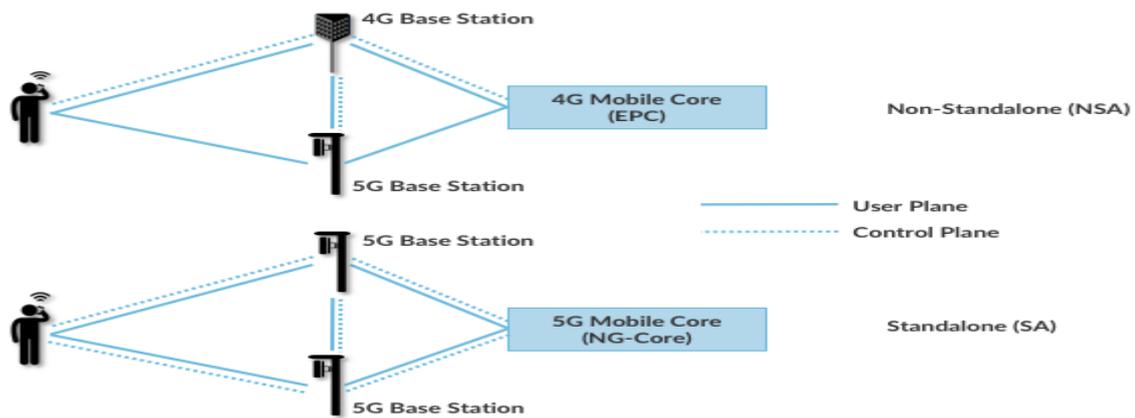


Figure 73: SA and Non SA Deployment

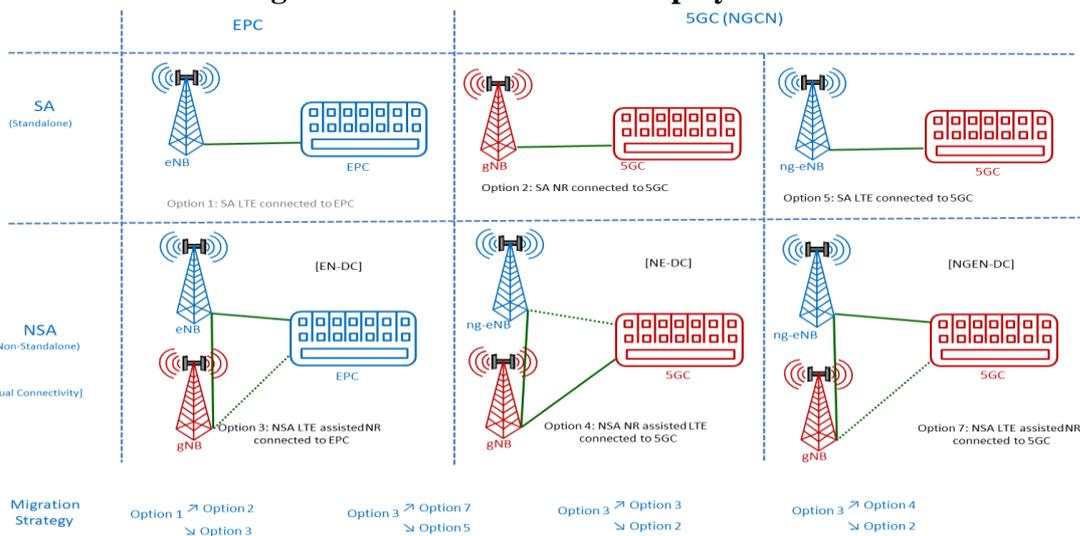


Figure 74: 5G Deployment Options

9.4 CONCLUSION

The 5G Network is the need of hour, as 4G Network has reached to its maximum capabilities and it is difficult to manage latency in it, 5G is required for AI services. The 5G deployment option can be exercised as per availability of existing network. New operator may directly go to 5G Deployment.

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 Retain-ability. This chapter deals with Key Performance Indicators used in GSM, UMTS, HSPA, and LTE networks.

10.2 INTRODUCTION

Key Performance Indicators are a set of quantifiable measures 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)".

10.3 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

10.3.1 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 $\leq 1\%$.

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

10.3.2 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.

10.4 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 $\leq 2\%$.

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 B 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

N/B	Maximum Offered Load Versus B and N											
	B is in %											
	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 5. Erlang B Table

10.4.1 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 $\geq 95\%$

CSSR value depends on

- I. SDCCCH Assignment success Rate
- II. SDCCCH 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.

10.4.2 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 $\leq 2\%$.

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/MS 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.

10.4.3 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.

10.4.4 PAGING SUCCESS RATE

Paging Success rate is the percentage of valid page responses received by the system.

Paging Channel Congestion should be $\leq 1\%$.

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.

10.4.5 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_BLKES_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.

- i) Check for UL-DL imbalance and correct if any problem.

10.5 DATA KPI IMPROVEMENT

10.6 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.

10.6.1 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.

10.6.2 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.

10.6.3 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 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.

10.7 3G UMTS KPI

10.7.1 3G KPIS ARCHITECTURE



Figure 75: 3G KPI Structure

RAN KPI Class :

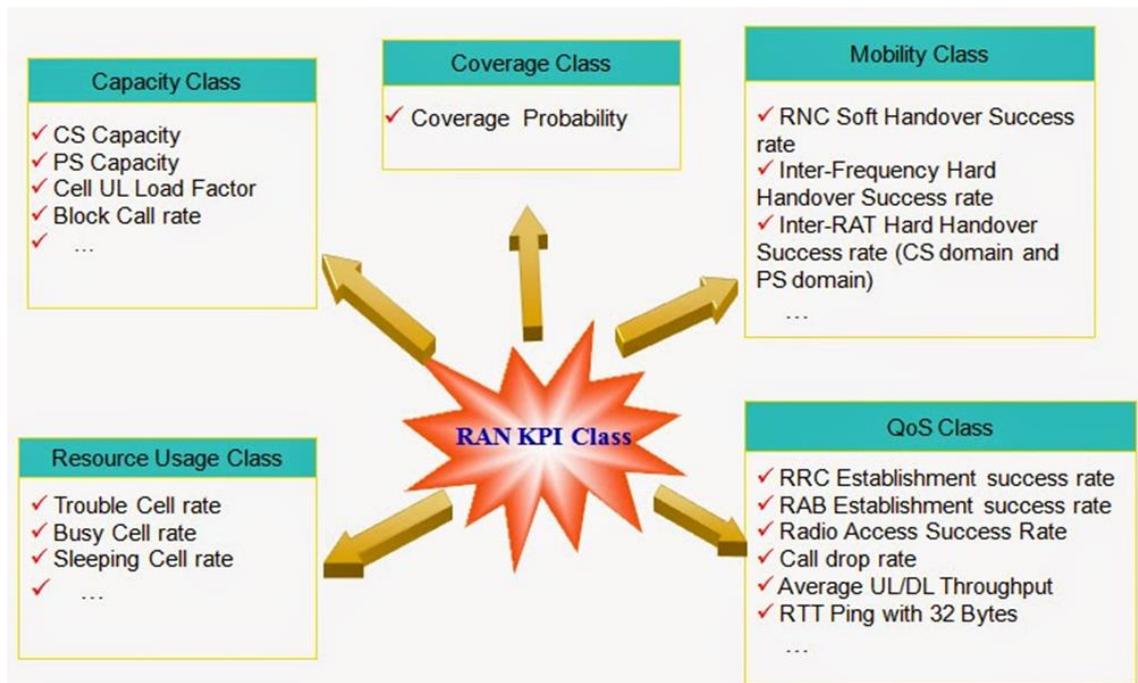


Figure 76: 3G KPI Class

10.7.2 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.

$$\begin{aligned}
 &\text{RAB Establishment Success rate} \\
 &= \frac{(\text{CS RAB Assignment Success Times} + \text{PS RAB Assignment Success Times})}{(\text{CS RAB Assignment Request Times} + \text{PS RAB Assignment Request Times})} \times 100\%
 \end{aligned}$$

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 ASSIGNMENT RESPONSE message.

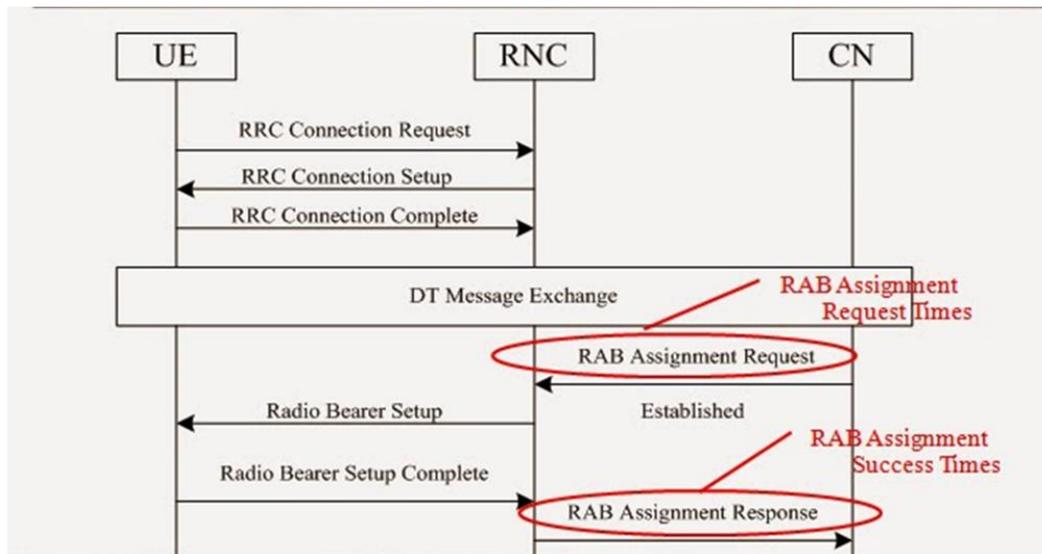


Figure 77: RAB Establishment

10.7.3 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.

$$\text{RRC Establishment Success Rate} = \frac{\text{RRC Connection Setup Complete Times}}{\text{RRC Connection Request Times}} \times 100\%$$

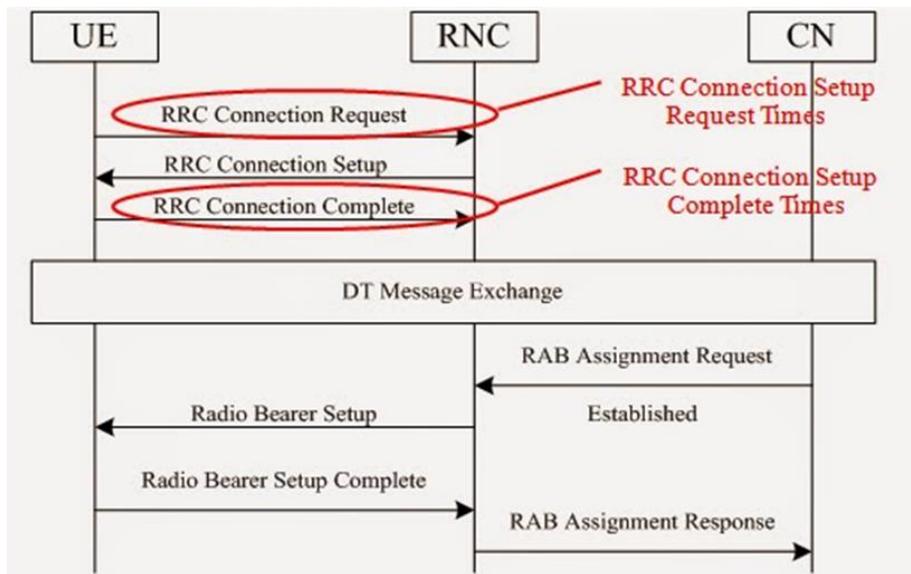


Figure 78: RRC Establishment

RRC setup procedure is the process that establishes the L3 connection 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 of the 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 RRC CONNECTION SETUP COMPLETE

10.7.4 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.

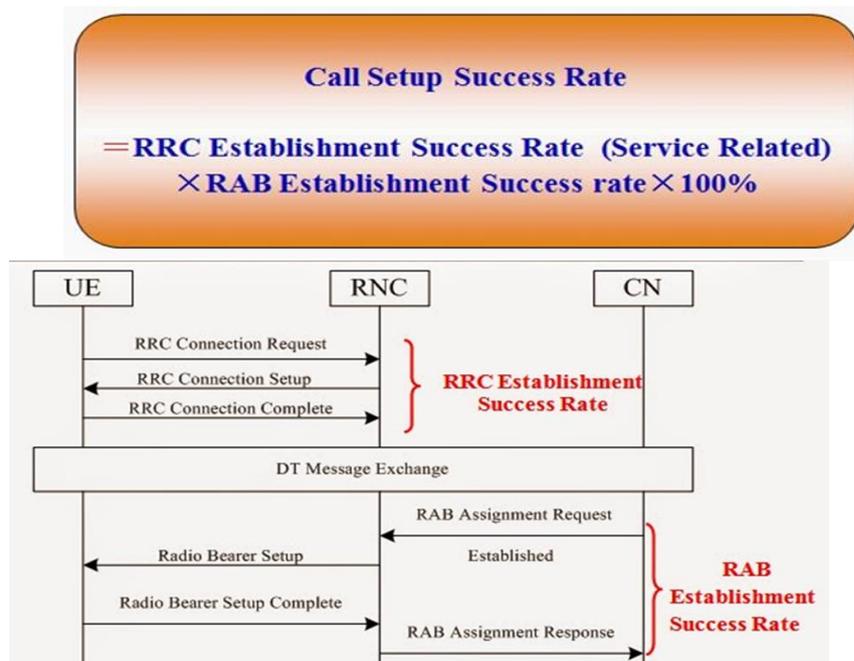


Figure 79: RAB & RRC Establishment

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.

10.7.5 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.

10.7.6 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.

10.7.7 CALL DROP RATE

It is the most important indicators of the customers experience. It reflects the retain ability 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).

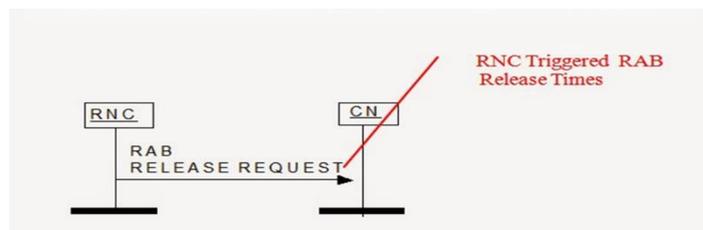


Figure 80: Call Drop

Drops are derived from "IU Release Request" and "RAB Release Request" messages sent from UTRAN to the CN as calculated by the formula:

$$\text{Call Drop Rate} = \frac{(\text{RNC Triggered CS RAB Release Number} + \text{RNC Triggered PS RAB Release Number})}{(\text{Total RAB Release number for CS} + \text{Total RAB Release number for PS})} \times 100\%$$

10.7.8 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.

$$\text{Call Blocking Rate} = \frac{\text{The number of blocked calls}}{\text{The number of call admission requests Times}} \times 100\%$$

10.8 MOBILITY KPI

10.8.1 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.

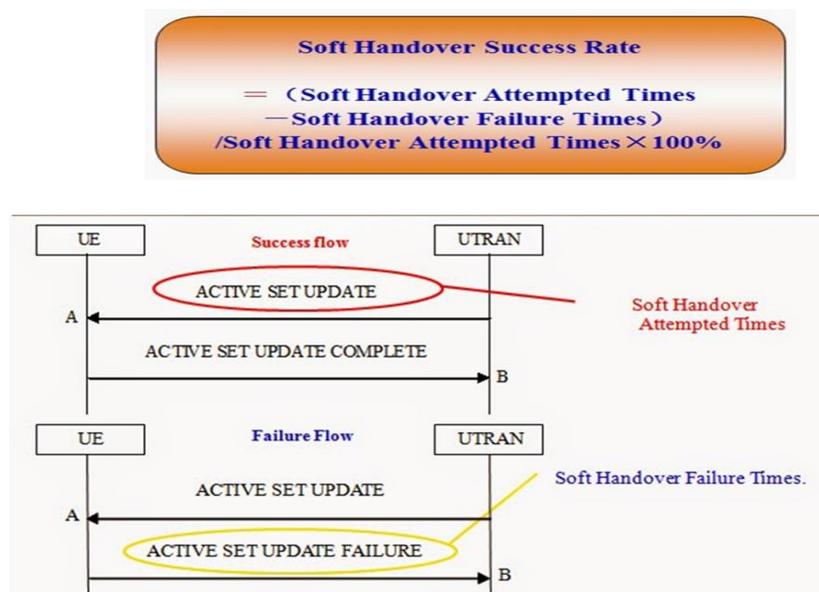


Figure 81: Soft Handover

This indicator reflects the soft handover mobility in the RNC control area.

10.8.2 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.

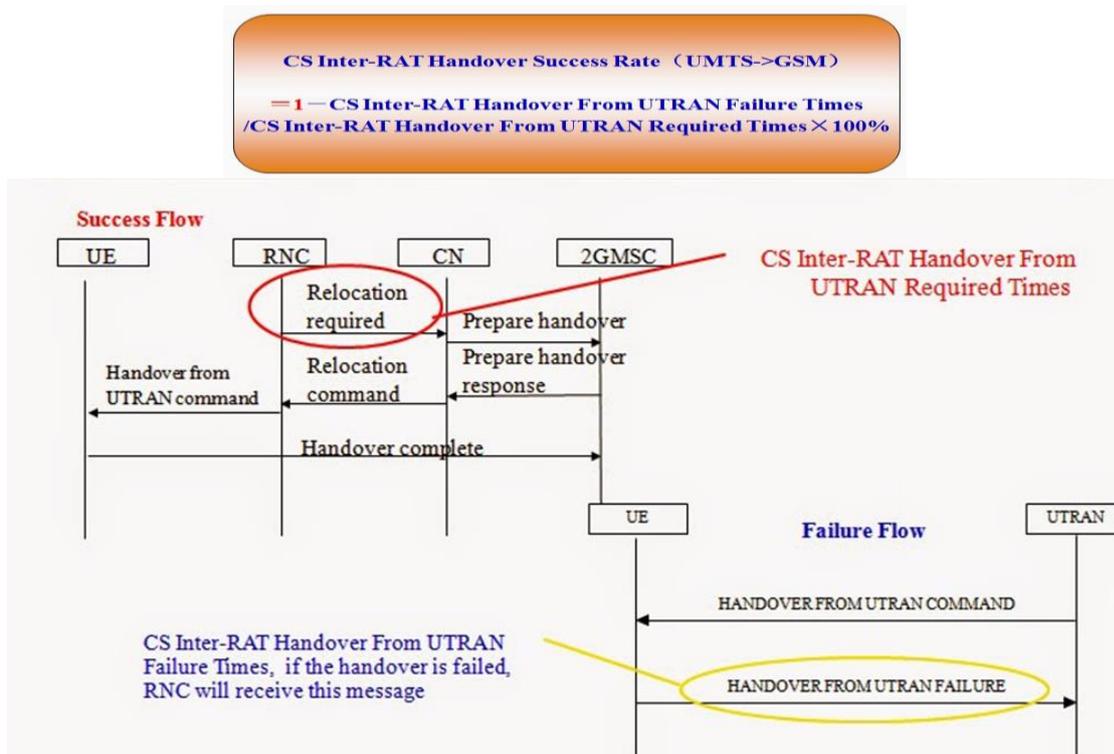
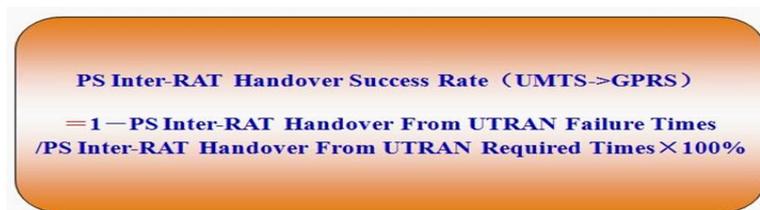


Figure 82: CS Outgoing Inter RAT Handover (UMTS to GSM)

10.8.3 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.



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.

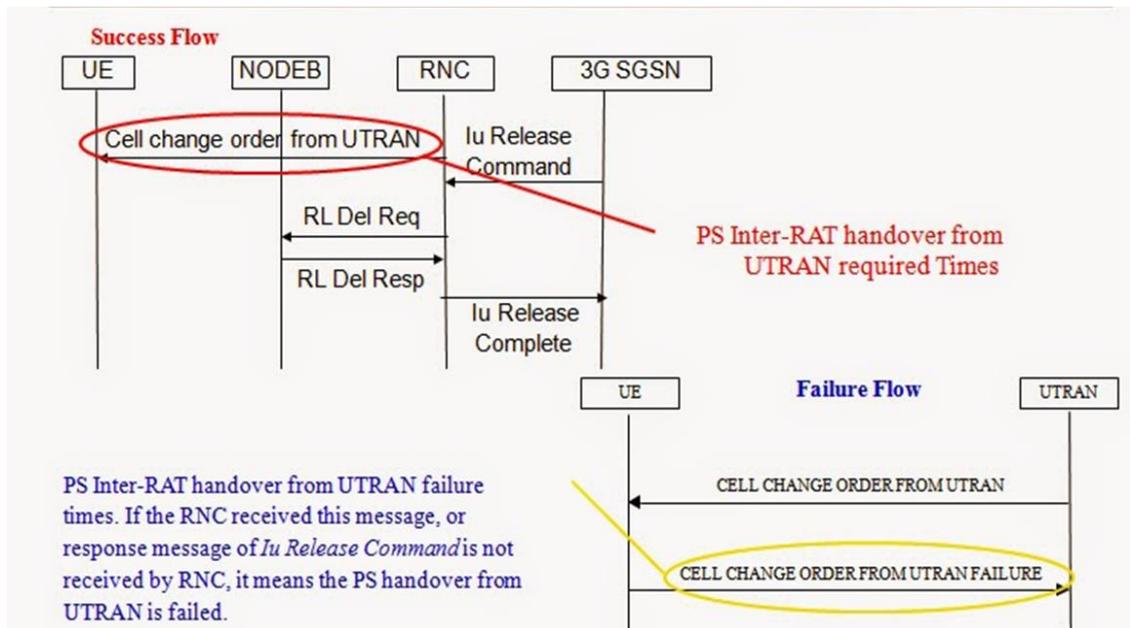


Figure 83: PS Outgoing Inter RAT Handover (UMTS to GSM)

10.8.4 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)

$$= \frac{\text{PS Inter-RAT Handover to UTRAN Success Times}}{\text{PS Inter-RAT Handover to UTRAN Attempted Times}} \times 100\%$$

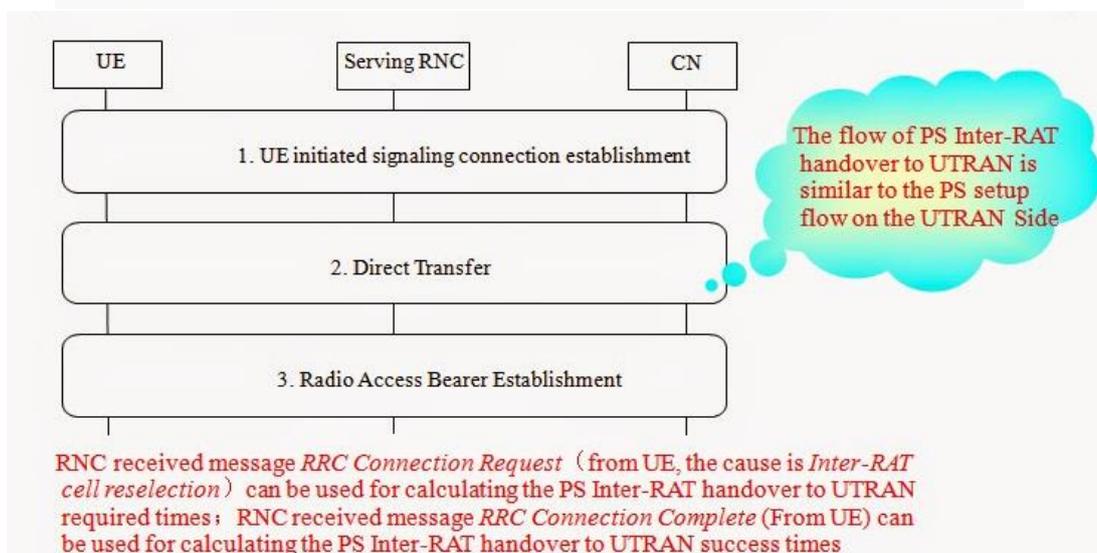


Figure 84: Incoming Inter RAT Handover (GPRS to UMTS)

10.9 UTILISATION KPI

10.9.1 CS SERVICE TRAFFIC ERLANG

This indicator reflects the traffic Erlang of CS conversation service.

CS Call Duration

= \sum [Time (Radio Link Setup Response)
– Time (Radio Link Deletion Response)]

CS Service Traffic ERL = Total CS Call Duration of a Certain Period/3600

10.9.2 PS SERVICE THROUGHPUT

This indicator reflects total throughput of PS service.

UL PS Service Throughput = RNC Received Total RLC PDU Bytes
DL PS Service Throughput = RNC Sent Total RLC PDU Bytes

(Including user data, RLC head data, retransfer data, signaling data, Unit: Kbytes)

10.9.3 UTRAN CELL AVAILABILITY.

A KPI that shows Availability of UTRAN Cell. Percentage of time that the cell is considered available.

10.10 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.

Integrity

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.

Availability

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 one 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	<ul style="list-style-type: none"> RRC setup success rate ERAB setup success rate Call Setup Success Rate <p>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,</p>
Retainability KPI	<ul style="list-style-type: none"> Call drop rate Service Call drop rate <p>Are used to measure how the network keep user's possession or able to hold and provide the services for the users</p>
Mobility KPI	<ul style="list-style-type: none"> Intra-Frequency Handover Out Success Rate Inter-Frequency Handover Out Success Rate Inter-RAT Handover Out Success Rate (LTE to WCDMA) <p>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,...</p>
Integrity KPI	<ul style="list-style-type: none"> E-UTRAN IP Throughput IP Throughput in DL

	<ul style="list-style-type: none"> E-UTRAN IP Latency <p>Are used to measure the character or honesty of network to its user, such as what is the throughput, latency which users were served.</p>
<p>Availability KPI</p>	<ul style="list-style-type: none"> E-UTRAN Cell Availability Partial cell availability (node restarts excluded) <p>Are used to measure how the network keep user's possession or able to hold and provide the services for the users</p>
<p>Utilization KPI</p>	<ul style="list-style-type: none"> Mean Active Dedicated EPS Bearer Utilization <p>Are used to measure the utilization of network, whether the network capacity is reached its resource.</p>

Table 6. LTE KPI

10.10.1 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:

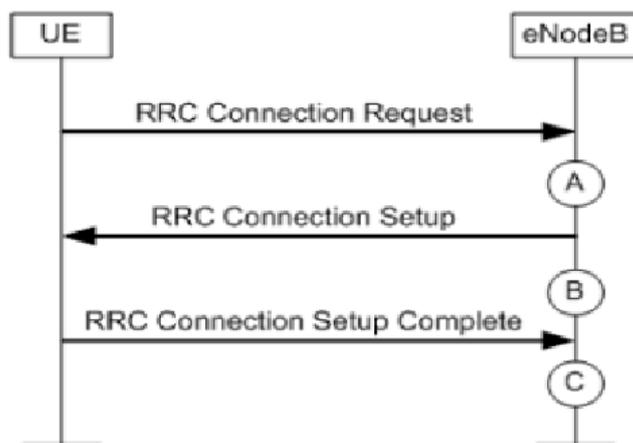


Figure 85: RRC Setup

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 7. RRC Setup Success Rate

10.10.2 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:

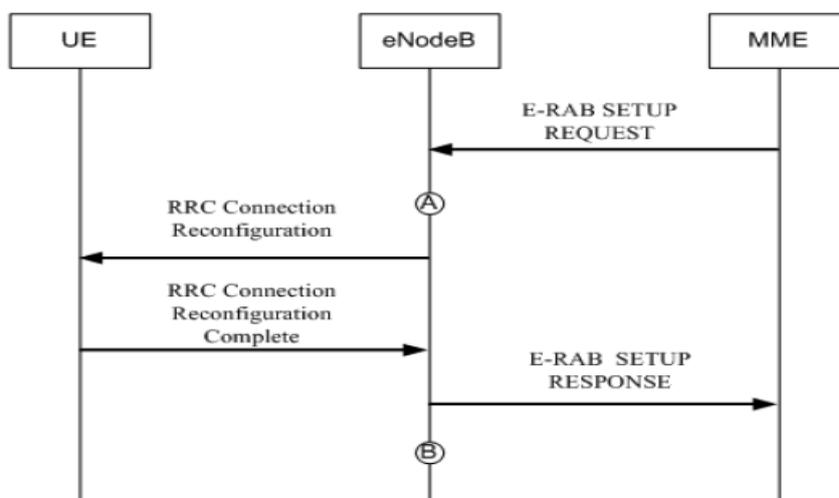


Figure 86: ERAB Setup

KPI Name	E-RAB Setup Success Rate (All)
Measurement Scope	Cell or radio network
Formula	$ERABS_SR = \frac{ERABSetupSuccess}{ERABSetupAttempt} \times 100\%$
Unit	Percentage (%)

Table 8. ERAB Setup Success Rate

10.10.3 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 9. CSSR

10.10.4 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:

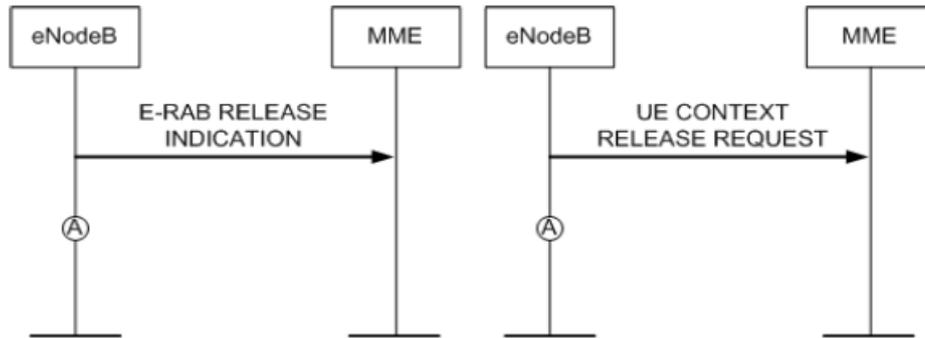


Figure 87: ERAB Release

KPI Name	Service Drop Rate (All)
Measurement Scope	Cell or radio network
Formula	$Service_CDR = \frac{ERABAbnormalRelease}{ERABRelease} \times 100\%$
Unit	Percentage (%)

Table 10. Call Drop

10.10.5 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:

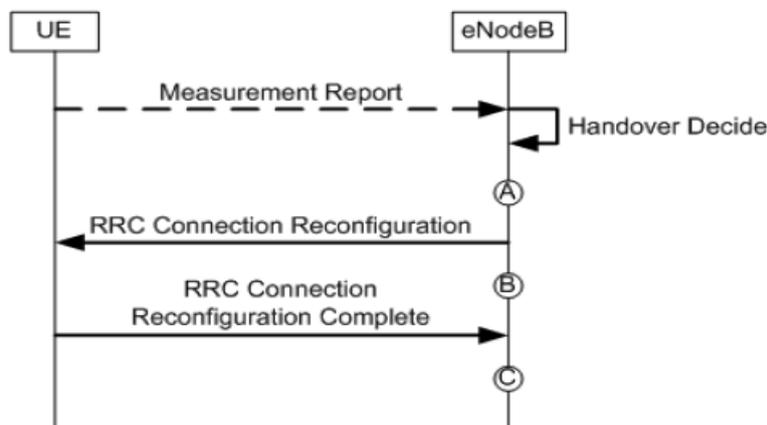


Figure 88: Intra-Frequency Handover Out

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

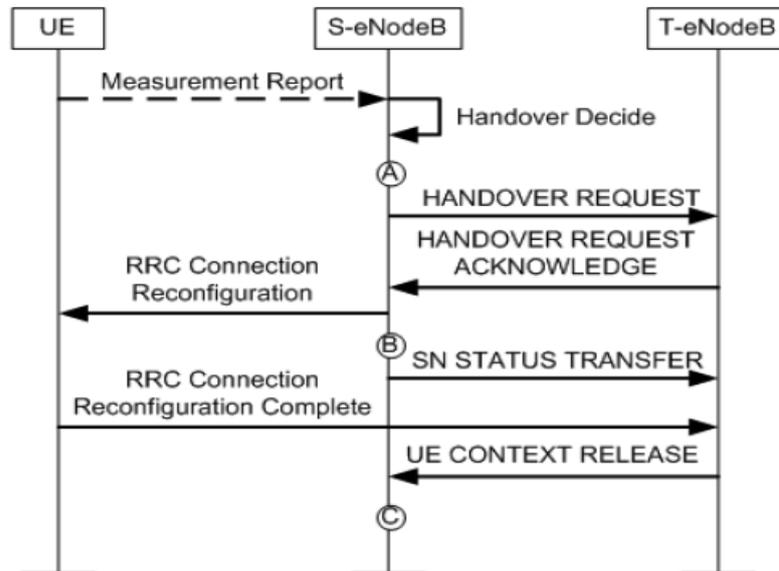


Figure 89: Intra-Frequency Handover inter E-NodeB

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:

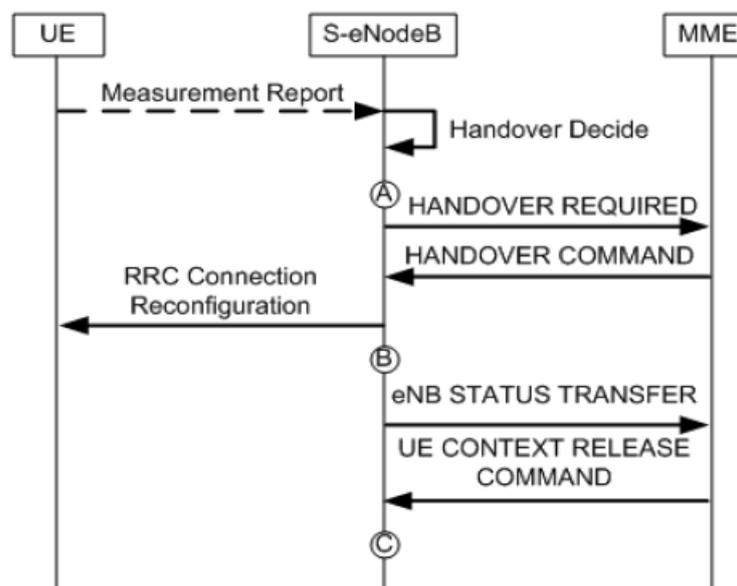


Figure 90: Intra-Frequency Handover inter E-NodeB

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	$IntraFreqHOOOut_SR = \frac{IntraFreqHOOOutSuccess}{IntraFreqHOOOutAttempt} \times 100\%$
Unit	Percentage (%)

Table 11. Intra-Frequency Handover Out Success Rate

10.10.6 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:

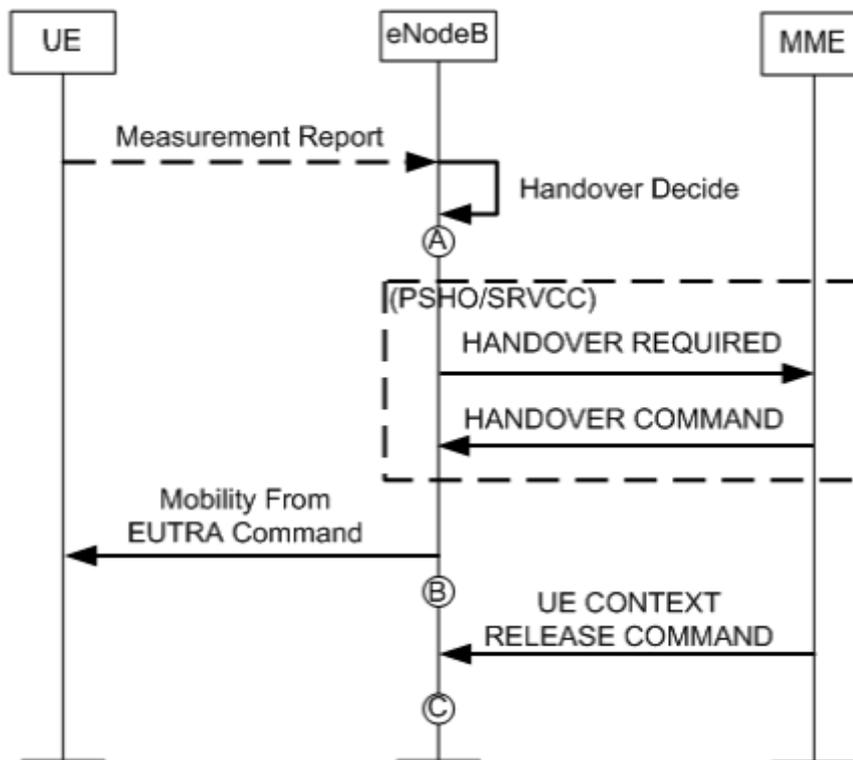


Figure 91: out inter RAT handover

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 (%)

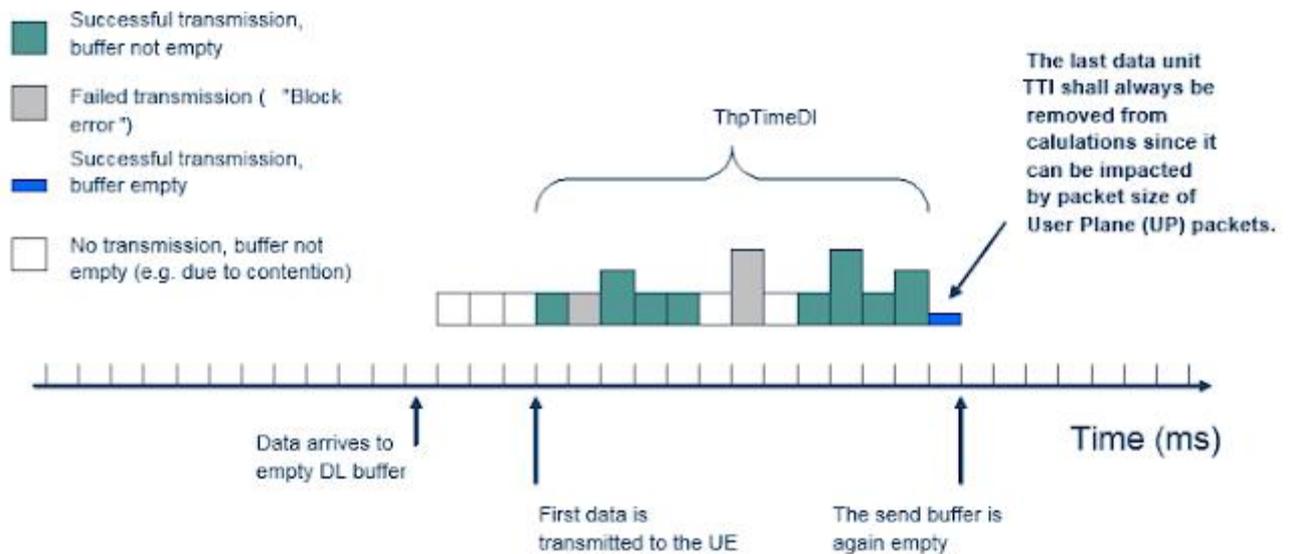
Table 12. Inter-RAT Handover Out Success Rate

10.10.7 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:

$$Downlink \quad Thp_{QCI=x} = DRB.IPThpDl_{QCI=x}$$

$$Uplink \quad Thp_{QCI=x} = DRB.IPThpUl_{QCI=x}$$



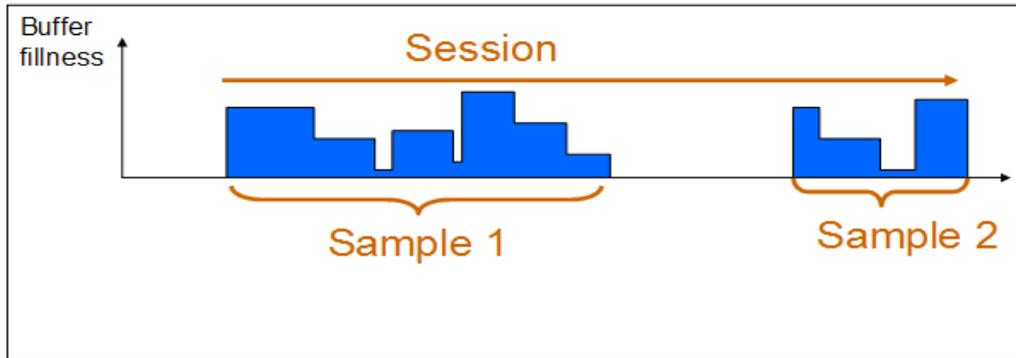
$$ThpVoIDI = \sum \text{Green} \text{ (kbits)}$$

$$Total \ DL \ transferred \ volume = \sum \text{Green} + \text{Blue} \text{ (kbits)}$$

$$IP \ Throughput \ in \ DL = ThpVoIDI / ThpTimeDI \text{ (kbits/s)}$$

Figure 92: 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.



$$IP\ Throughput\ DL = \frac{\sum_{Samples} ThpVolDl}{\sum_{Samples} ThpTimeDl}$$

Figure 93: E-UTRAN IP Throughput

10.10.8 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).

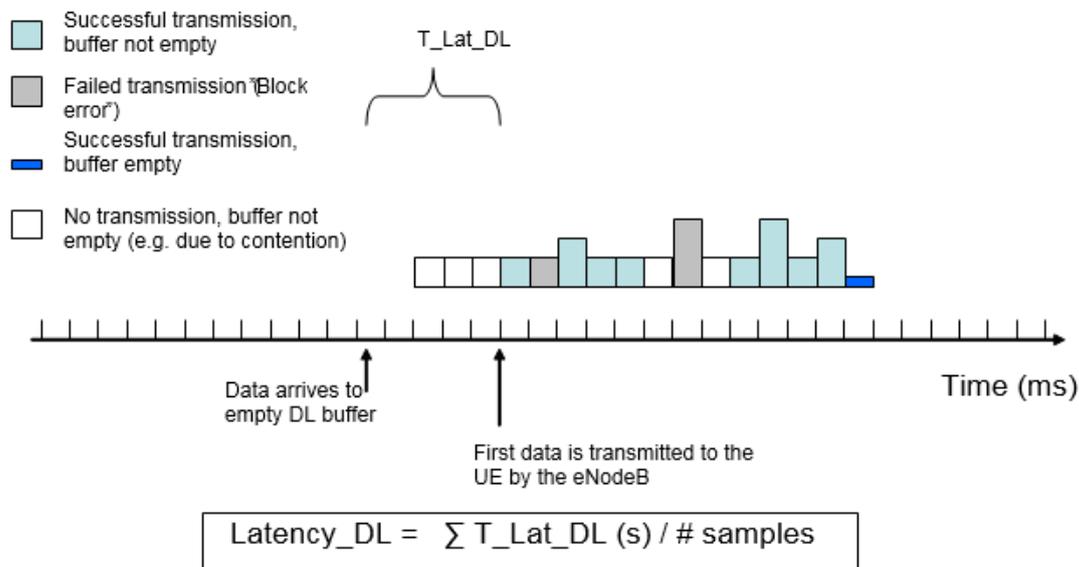


Figure 94: E-UTRAN IP Latency

T_Lat is defined as the time between reception 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:**10.10.9 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.

10.11 CONCLUSION

It is very important to manage KPI of radio network in order to have best of radio network performance.

11 CONCEPT OF SON

11.1 LEARNING OBJECTIVE

After completion of this chapter participant will able to understand about:

- Concept of SON
- SON Implementation
- Issues in SON implementation
- SON Data Creation
- Automatic handover in SON

11.2 INTRODUCTION

Self Organising Network (SON) is a collection of procedures (or functions) for automatic configuration, optimization, diagnostics, and healing of cellular networks. It is considered to be a major necessity in future mobile networks and operations mainly due to possible savings in capital expenditure (CAPEX) and operational expenditure (OPEX) by introducing SON.

The drivers for SON are:

- The number and complexities of networks, nodes, elements and parameters
- Existence of multi-technology, multi-vendor and multi-layer operations within the network
- Traffic growth and capacity management
- Consistent quality and service availability
- The need for knowledge-based and interactive networks

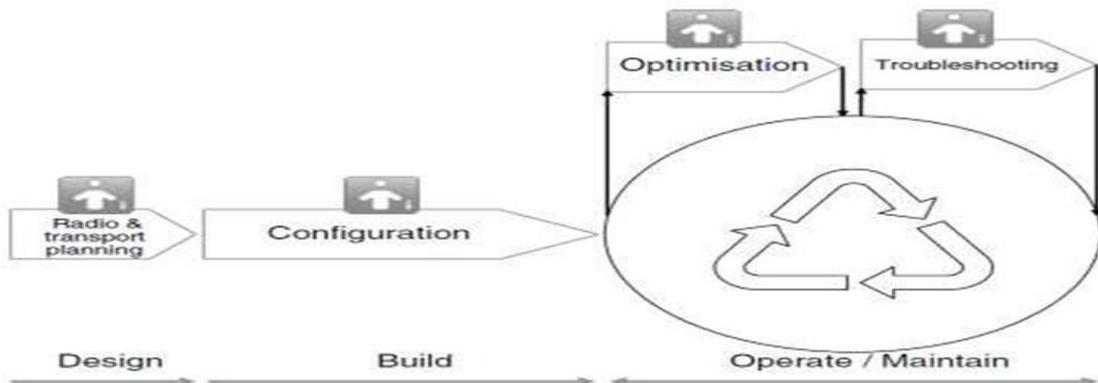


Figure 95: Network without SON Capability

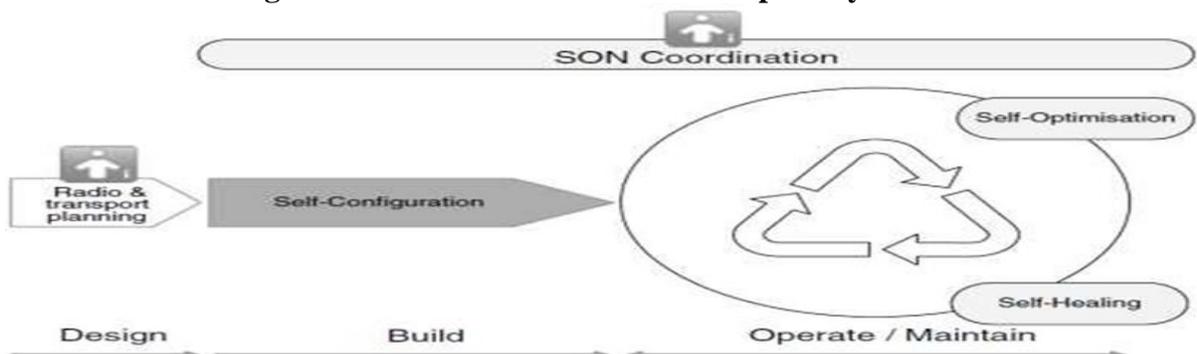


Figure 96: Network with SON Capability

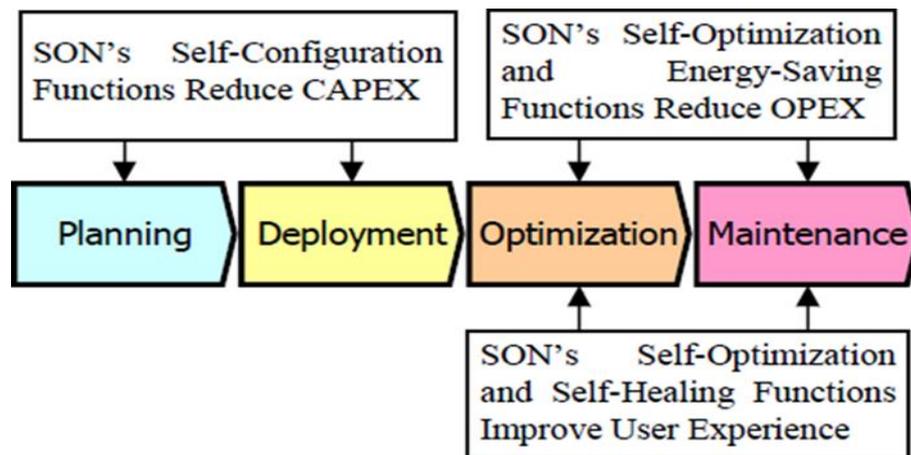


Figure 97: Benefits of SON

The main benefits of introducing SON functions in cellular networks are as follows.

- Reduced installation time and costs.
- Reduced OPEX due to reductions in manual efforts in connection with monitoring, optimizing, diagnosing, and healing of the network.
- Reduced CAPEX due to more optimized use of network elements and spectrum.
- Improved user experience.
- Improved network performance

11.3 SELF ORGANIZING NETWORKS (SON) CONCEPT

The SON functions are usually categorized into three main groups: Self-configuration, self-optimization, and self-healing. It should be noted that a given SON function can belong to more than one of these categories.

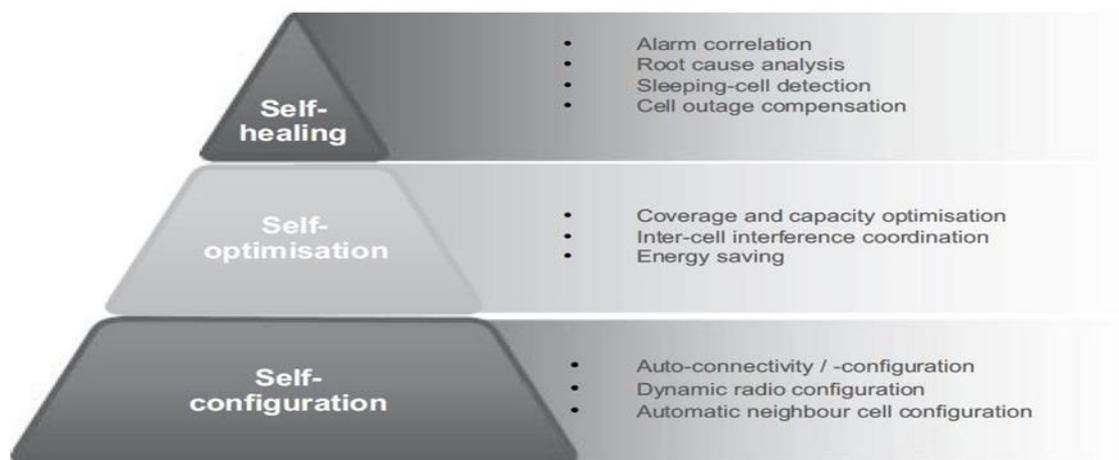


Figure 98: Functions of SON

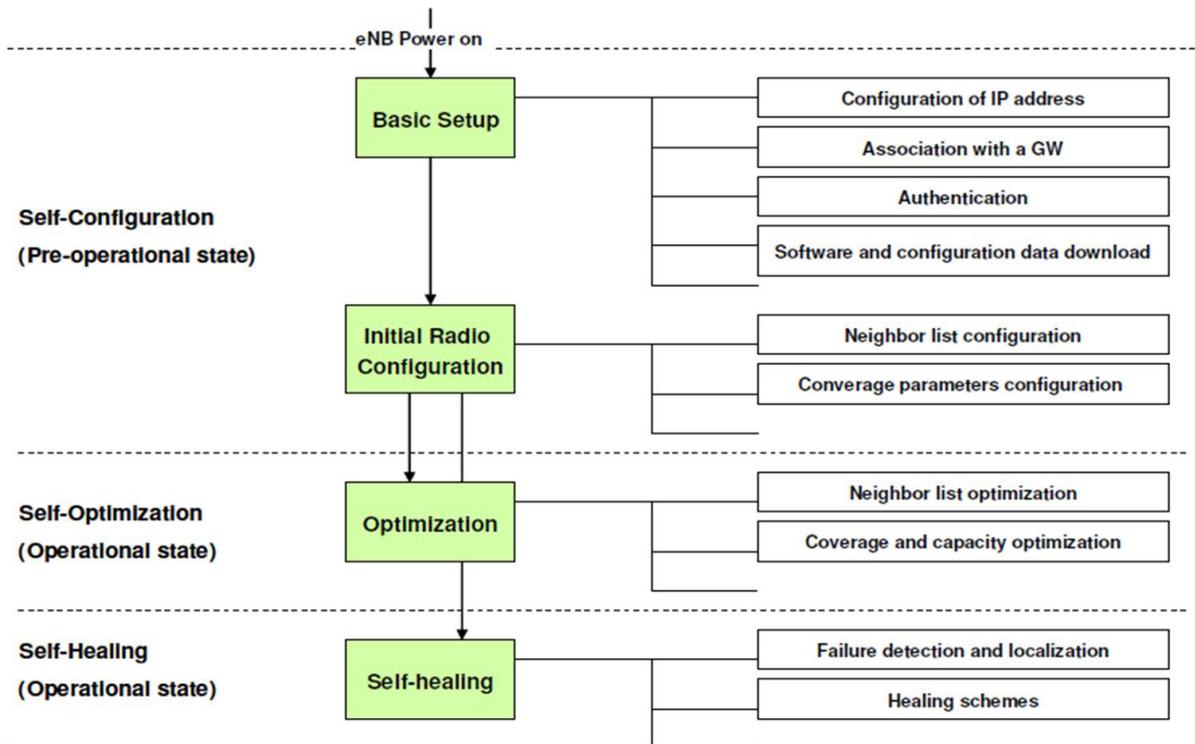


Figure 99: 3GPP SON FRAMEWORK

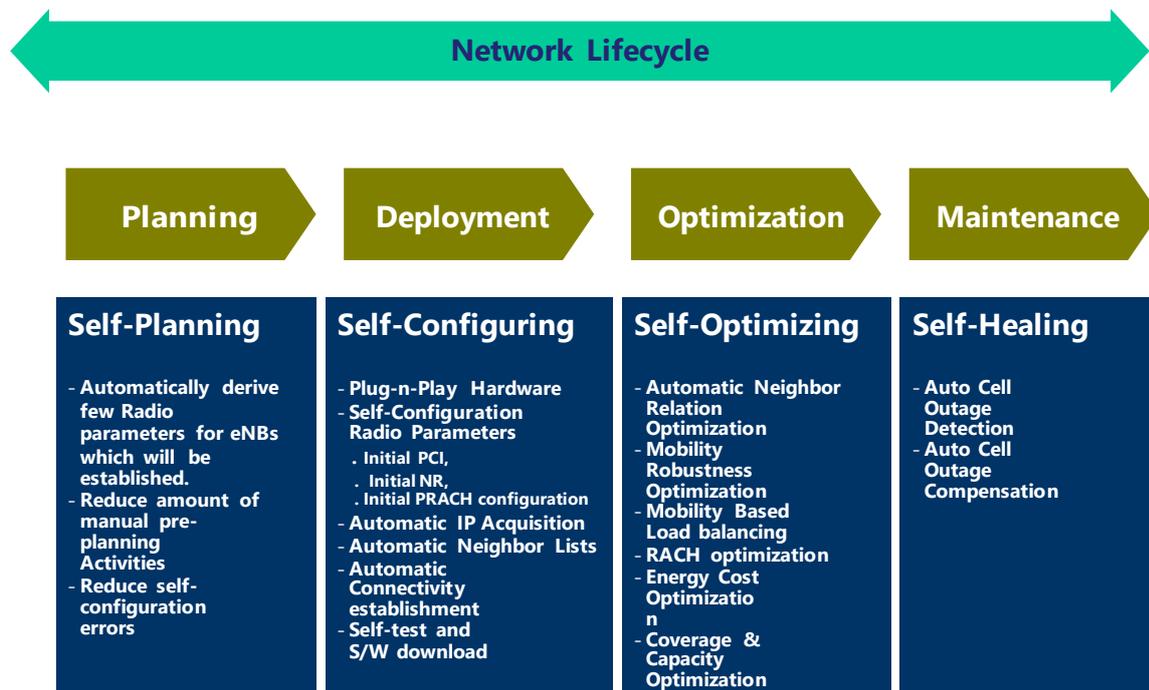


Figure 100: SON Technology

11.3.1 SELF CONFIGURATION

The Self-configuration SON is a collection of algorithms that aims at reducing the amount of human intervention in the overall installation process by providing “plug and play” functionality in network elements such as the E-UTRAN NodeBs (eNBs). This will result in faster network deployment and reduced costs for the operator in addition to a more integral inventory management system that is less prone to human errors. This process involves three key operations: set-up, authentication and radio configuration.

Self-configuration is a broad concept which involves several distinct functions that are covered through specific SON features, such as automatic software management, self test, Physical cell ID configuration (PCI), and automatic neighbor relations (ANR). The latter function is not only used during installation but is also an important part during normal operations.

The self-configuration should take care of all soft-configuration aspects of an eNB once it is commissioned and powered up for the first time. It should detect the transport link and establish a connection with the core network elements, download and upgrade to the latest software version, set up the initial configuration parameters including neighbor relations, perform a self-test, and finally set itself to operational mode. In order to achieve these goals, the eNB should be able to communicate with several different entities.

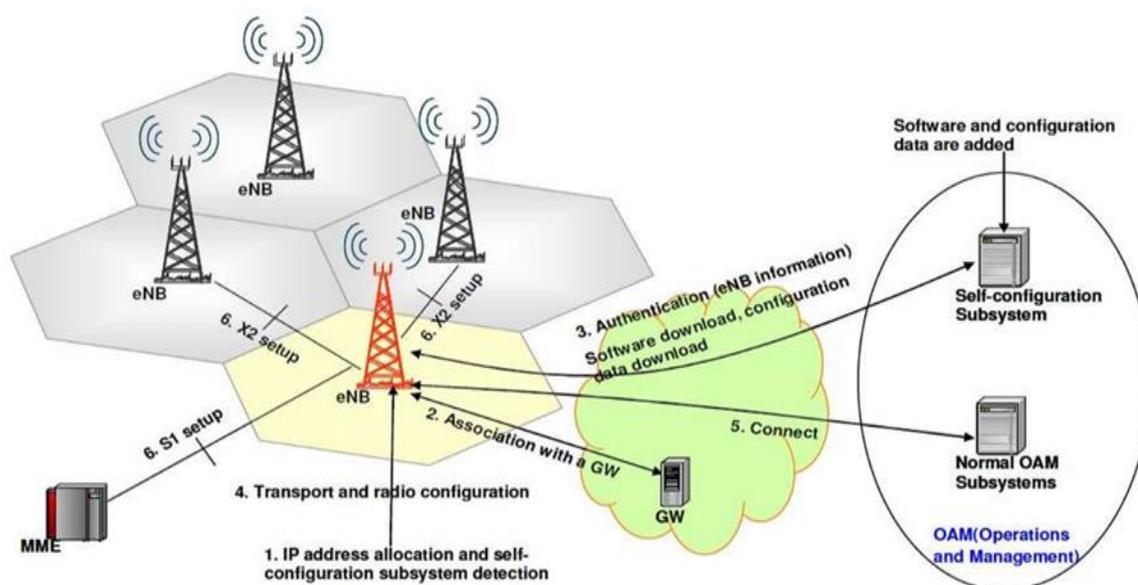


Figure 101: Self Configuration Procedure

The self-configuration actions will take place after the eNBs physically installed, plugged to the power line and to the transport link. When it is powered on, the eNB will boot and perform a self test, followed by a set of self-discovery functions, which include the detection of the transport type, tower-mounted amplifier (TMA), antenna, antenna cable length and auto-adjustment of the receiver-path.

After the self-detection function, the eNB will configure the physical transport link autonomously and establish a connection with the DHCP/DNS (dynamic host configuration protocol/domain name server) servers, which will then provide the IP addresses for the new node and those of the relevant network nodes, including serving gateway, mobility management entity (MME), and configuration server. After this, the eNB will be able to establish secure tunnels for operations administration and maintenance (OAM), S1, and X2 links and will be ready to communicate with the configuration server in order to acquire new configuration parameters.

One of the OAM tunnels created will communicate the eNB with a dedicated management entity, which contains the software package that is required to be installed. The eNB will then download and install the corresponding version of the eNB software, together with the eNB configuration file. Such configuration file contains the

preconfigured radio parameters that were previously planned. A finer parameter optimization will take place after the eNB is in operational state (self-optimization functions).

The self-configuration SON functions were among the first standardized by 3GPP (release 8) and have been more or less stable since then. From the roadmaps of different vendors it can be concluded that self-configuration SON is available and mature. These SON features will be extremely useful in the rollout phase to reduce the installation time compared with ordinary installation procedures, and also later when new eNBs are added to increase the network capacity. The actual decrease in OPEX is not easy to give since the corresponding installation without any (self) automatic features is difficult to foresee.

The self configuration procedures for LTE presents three automated processes: Self configuration of eNB, Automatic Neighbor Relations (ANR) and Automatic Configuration of Physical Cell ID (PCI).

11.3.2 SELF CONFIGURATION OF ENB

This is relevant to a new eNB trying to connect to the network. It is a case where the eNB is not yet in relation to the neighbour cells, but to the network management subsystem and the association of the new eNB with the serving gateway (S-GW). It is the basic set-up and initial radio configuration. The stepwise algorithm for self configuration of the eNB is outlined:

1. The eNB is plugged in/powerd up.
2. It has established transport connectivity until the radio frequency transmission is turned on.
3. An IP address is allocated to it by the DHCP/DNS server.
4. The information about the self configuration subsystem of the Operation and Management (O & M) is given to the eNB.
5. A gateway is configured so that it connects to the network. Since a gateway has been connected on the other side to the internet, therefore, the eNB should be able to exchange IP packets with the other internet nodes.
6. The new eNB provides its own information to that self configuration subsystem so that it can get authenticated and identified.
7. Based on these, the necessary software and information for configuration (radio configuration) are downloaded.
8. After the download, the eNB is configured based on the transport and radio configuration downloaded.
9. It then connects to the Operation Administration Management (OAM) for any other management functions and data-ongoing connection.
10. The S1 and X2 interfaces are established.

11.3.3 AUTOMATIC NEIGHBOUR RELATIONS (ANR)

ANR is an automated way of adding/deleting neighbour cells. ANR relies on user equipment (UE) to detect unknown cells and report them to eNBs. Its operation can be summarized into: measurements, detection, reporting, decision (add/delete cell) and updating.

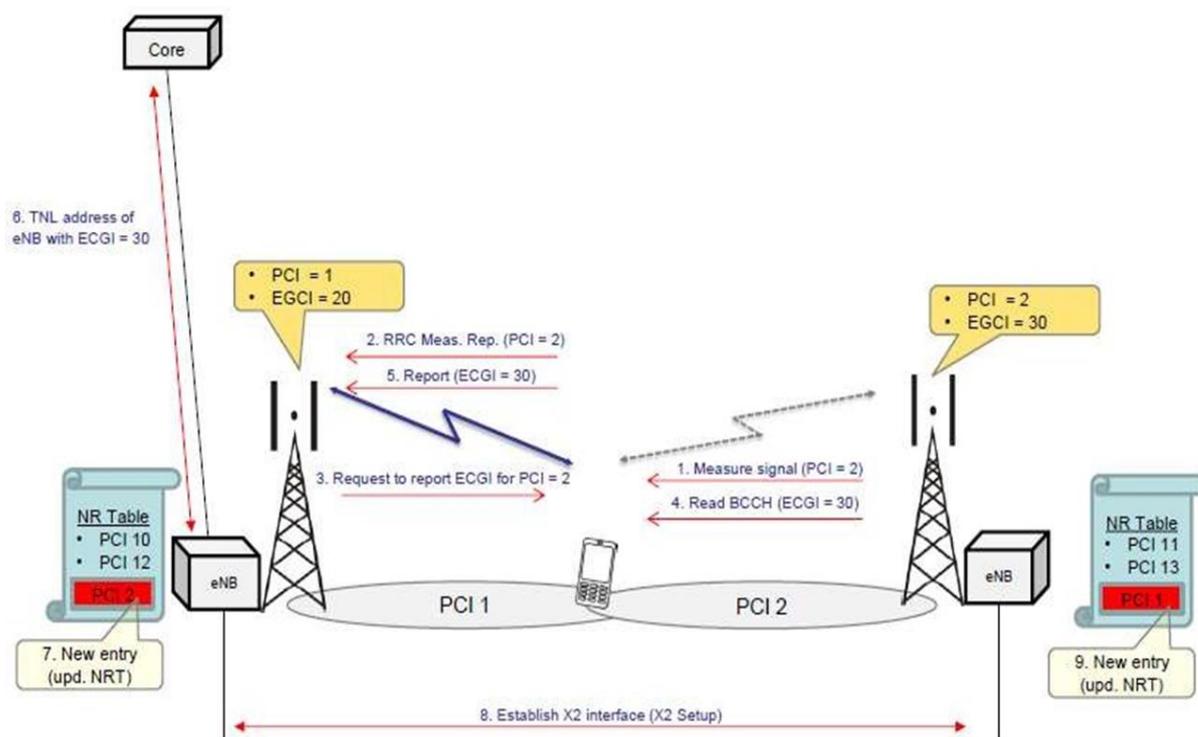


Figure 102: ANR with help of UE Measurement

The step-by-step ANR procedure is outlined:

1. During measurements, the UE detects PCI from an unknown cell.
2. The UE reports the unknown PCI to the serving eNB via Radio Resource Controller (RRC) reconfiguration message.
3. The serving eNB requests the UE to report the E-UTRAN Cell Global ID (ECGI) of the target eNB. The eNB is able to detect devices faster that way.
4. The UE reports ECGI by reading the broadcast channel (BCCH) channel.
5. Based on the ECGI, the serving eNB retrieves the IP address from the Mobility Management Entity (MME) to further set-up the X2 interface, since an initial X2 interface set-up would have happened during the target eNB's self configuration.
6. Function is extended to inter-RAT and inter-frequency cases with suitable messaging.

11.3.4 ANR WITH OPERATION ADMINISTRATION & MANAGEMENT (OAM) SUPPORT

ANR with OAM support is a more centralized system of operation. The OAM is the management system of the network. ANR procedures with OAM support are outlined:

- The new eNB registers with OAM and downloads the neighbour information table which includes the PCI, ECGI and IP addresses of the neighbouring eNBs.
- The neighbours update their own tables with the new eNB information.
- The UE reports the unknown PCI to the serving eNB.
- The eNB sets-up the X2 interface using the neighbour information table formed previously.

11.3.5 AUTOMATIC CONFIGURATION OF PHYSICAL CELL IDENTIFICATION (PCI).

The automatic configuration of physical cell ID (PCI) for eNBs in LTE was standardised in 3GPP release 8 as part of “eNB self configuration.” PCI is a locally defined identifier for eNBs with a restricted range (up to 504 values) and must be reused throughout the network. The PCI numbering of eNBs must locally be unique so that the UEs may be able to communicate and possible perform handovers. The goal of PCI configuration is to set the PCI of a newly introduced cell. The PCI is contained in the SCH (synchronization channel) for user equipment (UE) to synchronize with the cell on the downlink. When a new eNB is established, it needs to select PCIs for all the cells it supports. Since the PCI parameters have a restricted value range, the same value needs to be assigned to multiple cells throughout the network and must be configured collision free, that is, the configured PCI needs to be different from the values configured in all the neighbouring cells.

In today’s algorithms for automatic PCI assignments, conflicts may occur in the way they are allocated. Therefore, to achieve the aim of SON, work is currently being done to ensure automatic configuration of PCIs become a part of the standardized configuration.

PCI configuration must satisfy two rules:

- Collision Free: The PCI of one cell should not be the same as those of his neighbor cells.
- Confusion Free: The PCI of the neighbor cells should not be the same.

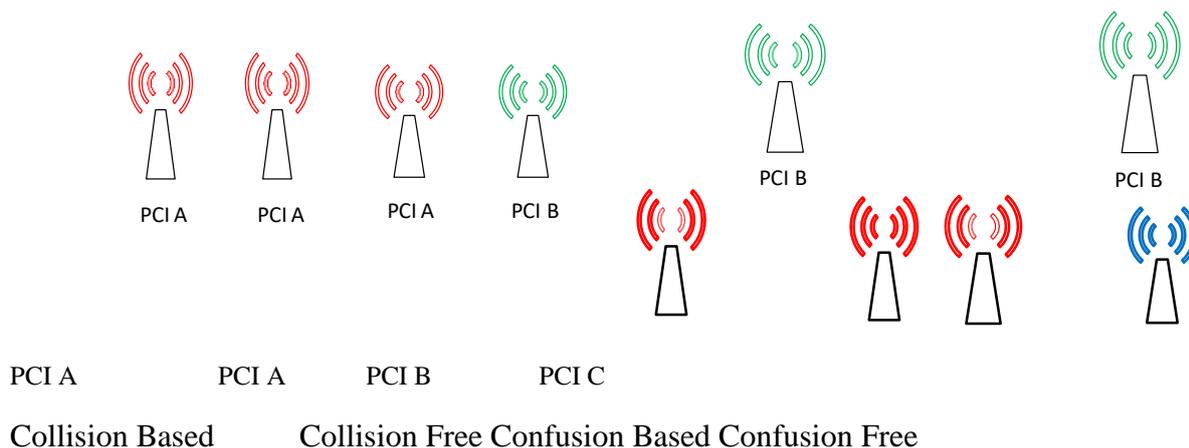


Figure 103: PCI Solution

11.3.6 SELF OPTIMIZATION

SON self-optimization functions are aiming at maintaining network quality and performance with a minimum of manual intervention from the operator. Self-optimization functions monitors and analyzes performance data and automatically triggers optimization action on affected network element(s) when necessary. This significantly reduces manual interventions and replaces them with automatic adjustments keeping the network optimized at all times. Self-optimizing SON functions make it possible to introduce new automatic processes that are too fast, and/or too complex to be implemented manually. This will improve the network performance by making the

network more dynamic and adaptable to varying traffic conditions and improve the user experience.

Self configuration alone is not sufficient to guarantee effective management of the end-to-end network, the need for knowledge-based end-to-end monitoring is also very crucial. After configurations, automated processes/algorithms should be able to regularly compare the current system status parameters to the target parameters and execute corrective actions when required. This process ensures optimum performance at all times. This process is known as Self Optimization.

Some of the most important self-optimization SON use cases are:

- (i) Physical cell ID(PCI);
- (ii) Automatic neighbour relations(ANR);
- (iii) Inter-cell Interference coordination(ICIC);
- (iv) Mobility robustness optimization(MRO);
- (v) Mobility load balancing optimization (MLB).

The two first use cases, PCI and ANR, may as well be categorized as self-configuration algorithms since they will be part of initial configuration procedures, but will also play an important part in normal operation and therefore may be viewed as being self optimization procedures.

11.3.7 PHYSICAL CELL ID CONFIGURATION (PCI)

The PCI automatic configuration was one of the first SON functions to be standardized by 3GPP. The self- configuration feature seems to be quite mature and all of the main vendors have this function implemented in their eNBs. Some vendors report tests with 100% handover success rate in networks where new eNB are introduced and the Automatic PCI Optimization are applied. The physical cell ID configuration is a SON function that should be implemented at eNB rollout.

11.3.8 AUTOMATIC NEIGHBOUR RELATIONS (ANR)

One of the more labour intense areas in existing radio technologies is the handling of neighbour relations for handover. A neighbour relation is information that a neighbour cell is a neighbour to an eNB. Each eNB holds a table of detected neighbour cells which are used in connection with handovers. Updating automatic neighbour relations (ANR) is a continuous activity that may be more intense during network expansion, but is still a time consuming task in mature networks. The task is multiplied with several layers of cells when having several networks to manage. With LTE, one more layer of cells is added; thus, optimization of neighbour relations may be more complex. Due to the size of the neighbouring relation tables in radio networks, it is a huge task to maintain the neighbour relations manually. Neighbour cell relations are therefore an obvious area for automation, and ANR is one of the most important features for SON. To explore its full potential, ANR must be supported between network equipment from different vendors. ANR was therefore one of the first SON functions to be standardized in 3GPP.

11.3.9 INTER-CELL INTERFERENCE COORDINATION (ICIC).

The main idea behind inter-cell interference coordination (ICIC) is to coordinate transmissions in different cells in such a way that the inter-cell interference and/or the effect of it is reduced. With the currently proposed solutions this is achieved by letting each cell omit using some of the spectrum resources (frequency/time slots/power) in order to reduce interference. Omitting to use spectrum resources implies that some capacity is lost, so the gains obtained by operating in an environment with less interference must more than compensate for this loss. The most important gain that can be achieved by ICIC is the ability to provide a more homogeneous service to users located in different regions of the network, especially by improving the cell-edge performance.

Mutual interference may occur between the cells in an LTE network. Interference unattended to leads to signal quality degradation. Inter-cell interference in LTE is coordinated based on the Physical Resource Block (PRB). It involves coordinating the utilization of the available PRBs in the associated cells by introducing restrictions and prioritization, leading to significantly improved Signal to Interference Ratio (SIR) and the associated throughput. This can be accomplished by adopting ICIC RRM (Radio Resource Management) mechanisms through signalling of Overload Indicator (OI), High Interference Indicator (HII), or downlink transmitter power indicator.

Multi-layer heterogeneous network layout including small cell base stations are considered to be the key to further enhancements of the spectral efficiency achieved in mobile communication networks. It has been recognized that inter-cell interference has become the limiting factor when trying to achieve not only high average user satisfaction, but also a high degree of satisfaction for as many users as possible.

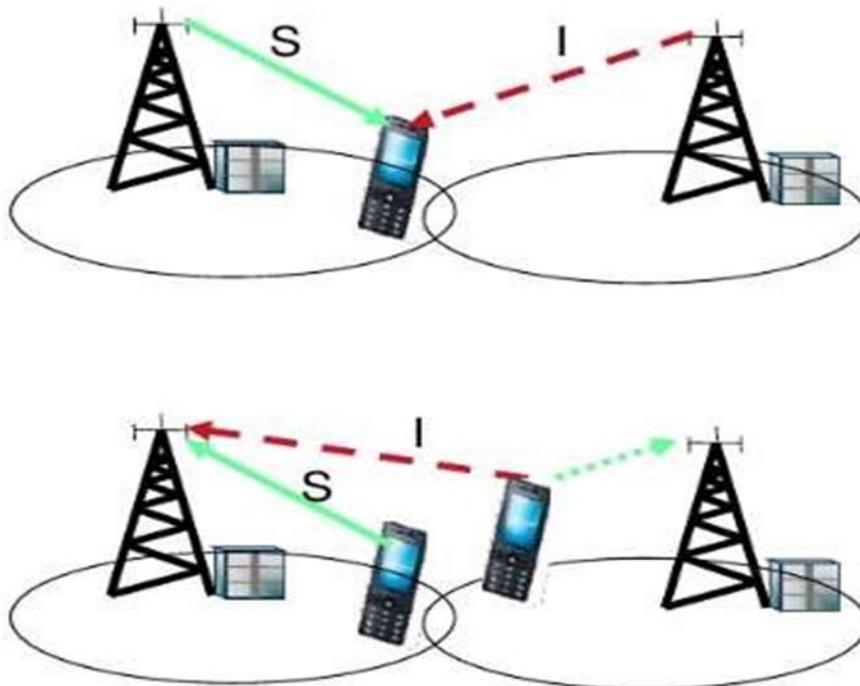


Figure 104: ICIC Use Case

The servicing operator for each cell carries out interference coordination, by configuring the ICIC associated parameters such as reporting thresholds/periods and prioritized resources. The ICIC SON algorithm is responsible for the automatic setting and updating of these parameters.

The ICIC SON algorithm work commenced in Release 9 but was not completed here. It is targeted at self configuration and self optimization of the control parameters of ICIC RRM strategies for uplink and downlink. To achieve interference coordination, the SON algorithm leverages on exchange of messages between eNBs in different cells through the X2 interface. The SON algorithm enables automatic configuration/adaptation with respect to cell topology, it requires little human intervention and leads to optimized capacity in terms of satisfied users.

11.3.10 MOBILITY ROBUSTNESS / HANDOVER OPTIMIZATION (MRO).

Handover coordination is very necessary in ensuring seamless mobility for user devices within a wireless network. In 2G/3G systems, setting handover parameters is a manual and time consuming task and sometimes too costly to update after initial deployment. Mobility Robustness Optimization (MRO) automates this process to dynamically improve handover operations within the network, provide enhanced end user experience and improved network capacity.

To achieve this aim, the question to be critically answered is “What triggers handover?” Therefore, 3GPP categorize handover failures into:

- Failures due to too late handover triggering
- Failures due to too early handover triggering
- Failures due to handover to a wrong cell

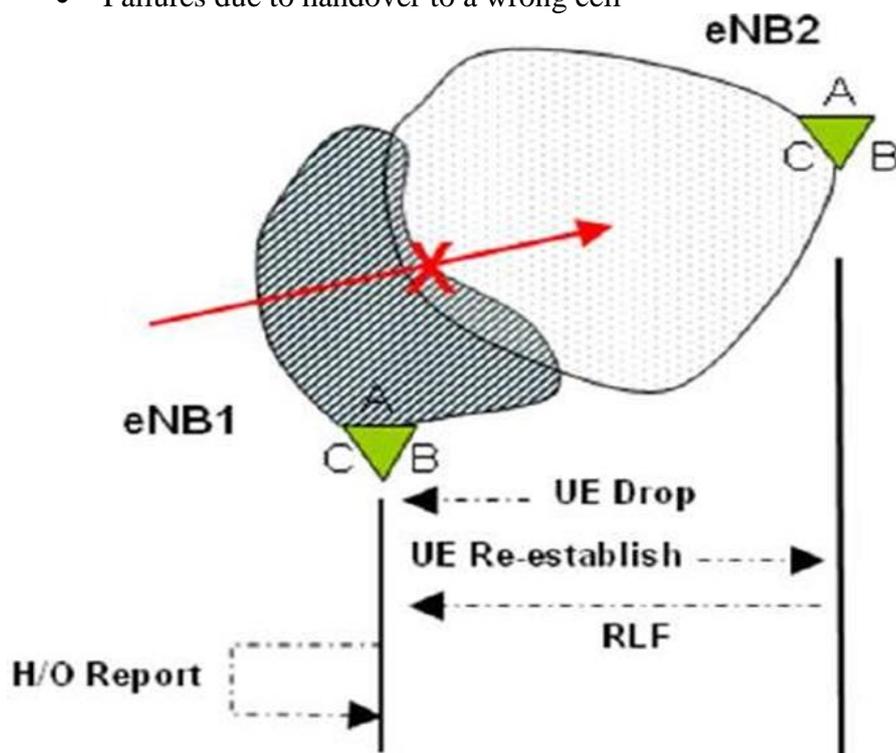


Figure 105: Too Late Handover

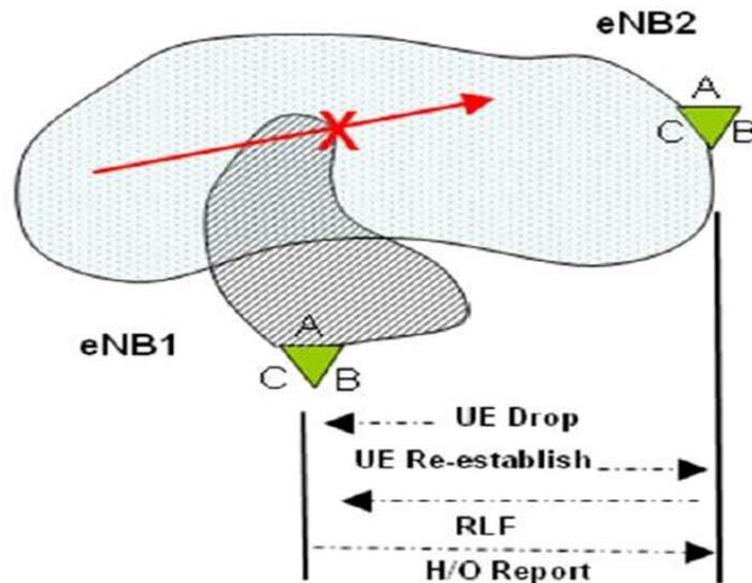


Figure 106: Too Early Handover

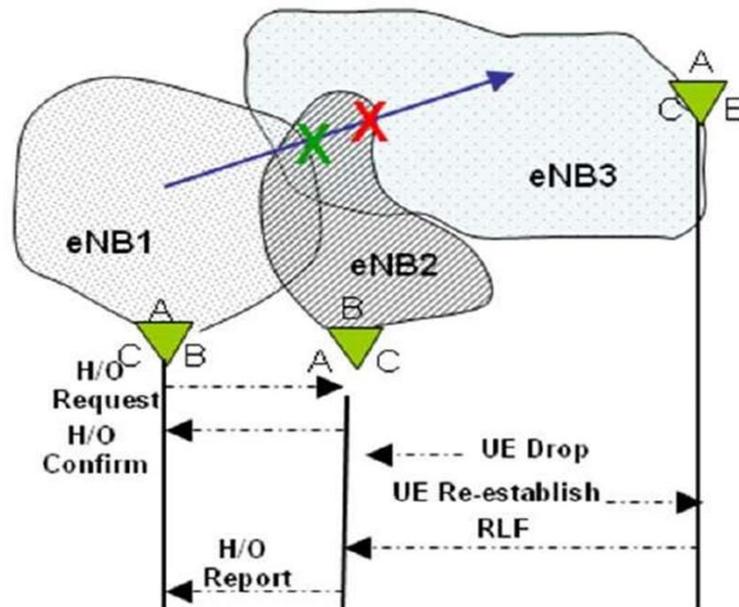


Figure 107: Wrong Handover

Also, unwanted handovers may occur subsequent to connection set-up, when cell-reselection parameters are not in agreement with the handover parameters.

Therefore, the MRO algorithm is aimed at detecting and minimizing these failures as well as reducing inefficient use of network resources caused by unnecessary handovers and also reducing handovers subsequent to connection set-up.

As specified by 3GPP, enabling MRO requires that:

- a) The relevant mobility robustness parameters should be automatically configurable by the eNB SON entities;
- b) OAM should be able to configure a valid range of values for these parameters; and
- c) The eNB should pick a value from within this configured range, using vendor-specific algorithms for handover parameter optimization.

For efficient/effective MRO, there must be linkage to policies to ensure other parameters/QoE is not affected. This implies that all parameter modifications must align with other similar interacting SON algorithms (such as Load Balancing). Therefore, there is a need for communication between SON algorithms to resolve probable conflicts and ensure stability.

During roll-out of an LTE network, there will be areas having limited LTE coverage. Enabling handover from LTE to existing 2G/3G systems will therefore become an important feature. In this scenario, it will be very important to maintain a low drop rate for UEs moving from LTE to 2G/3G.

A SON MRO mechanism was introduced in release 10 for the purpose of detecting unnecessary inter-RAT handover. During the handover preparation the source RAT (LTE) requests optionally the target RAT (GSM/UMTS) to perform UE measurements of the source RAT. The measurements start following the successful handover, and the measurement duration is one of the parameters provided by the source RAT (max 100 seconds). The measurements stop if a new inter-RAT HO takes place during this time interval.

If during this period the UE measurements shows that the source RAT quality remains better than a configurable threshold, the target RAT will report to the source RAT that the handover could have been avoided. The source RAT may then take corrective action, for example, adjust the handover threshold or increase time-to-trigger setting for handovers to the concerned inter-RAT target cell.

MRO is very useful in the LTE network deployment process, reducing the need for extensive drive-testing. Since the LTE coverage often will be spotty in the beginning, inter- RAT MRO will also be very useful. For networks in operation MRO will ensure that the handover thresholds are optimal at all times and remove the need for manual task such as drive- testing, detailed system log, and post processing.

The benefits of MRO will be especially useful in HetNets, which are more dynamic where small cells appear and disappear. However, MRO solutions for HetNets are still not fully developed.

MRO is not critical for the operation of LTE networks today. The networks are usually stable macro networks with low to moderate traffic load, and most of the terminals are PC dongles and hence usually stationary when used. However, MRO will become more important as the penetration of handheld terminals becomes larger, the traffic load increases and micro-, pico-, and femto-cells are introduced in the network. It will be beneficial to include MRO in LTE networks from the start but it will not be a critical function when the network is a stable macro network, but will offer reduced installation time and reduced OPEX costs. As the number of small cells in the network increase, MRO will be become more important and an MRO function capable of handling HetNet scenarios should be included.

11.3.11 MOBILITY LOAD BALANCING OPTIMIZATION (MLB)

The objective of mobility load balancing (MLB) is to intelligently spread user traffic across the system's radio resources in order to optimize system capacity while maintaining quality end-user experience and performance. Additionally, MLB can be

used to shape the system load according to operator policy, or to empty lightly loaded cells which can then be turned off in order to save energy. The automation of this minimizes human intervention in the network management and optimization tasks.

Basic functionality of mobility load balancing was defined in Release 9. Release 10 added enhancements that addressed inter-RAT scenarios and inter-RAT information exchange.

Support for mobility load balancing consists of one or more of following functions:

- (i) load reporting;
- (ii) load balancing action based on handovers;
- (iii) adapting handover and/or reselection configuration.

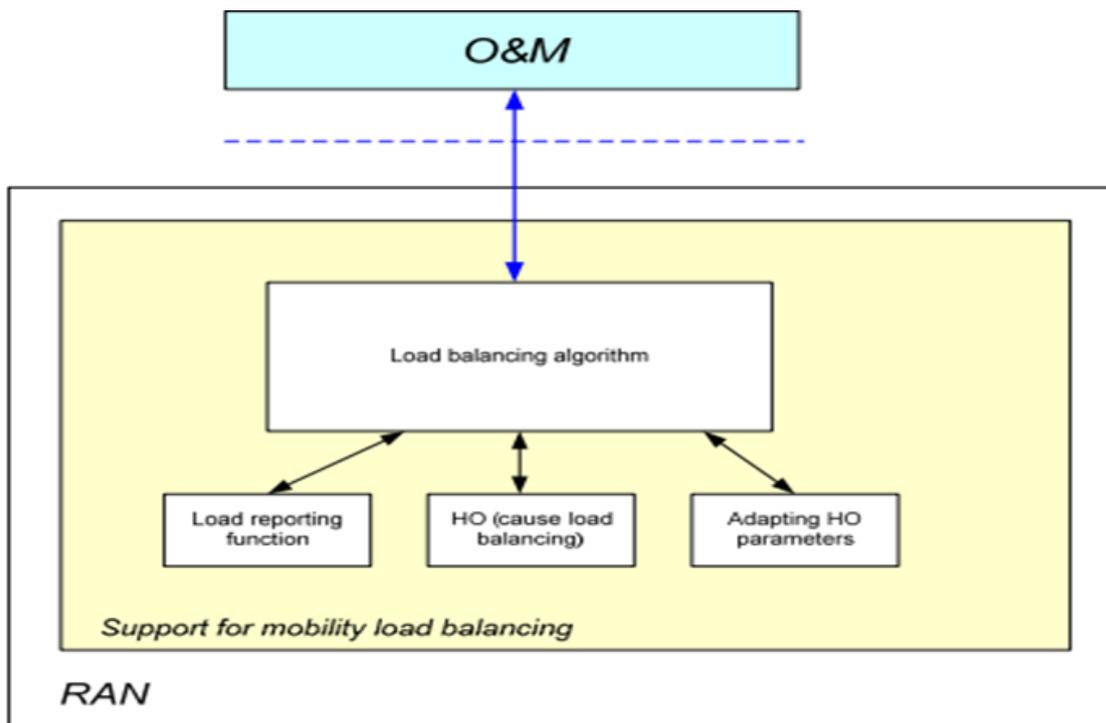


Figure 108: Mobility Load Balancing

Triggering of each of these functions is optional and depends on implementation. Current implementations of the MLB function are relatively simple. Moving load between cells are achieved by adjusting the handover thresholds and hence the position of the cell boundaries. As this can affect the handover performance, this must be coordinated with the MRO SON function. This can, for example, be achieved by letting the MRO function define an allowed interval for the handover threshold. The MLB function can then adjust the handover threshold within this interval.

One of the weaknesses of current MLB implementations is that the UEs that are moved from one cell to another do not usually constitute the optimal choice and can even cause problems in the target cell. For example, moving an UE that uses a lot of capacity can cause overloading in the target cell. This will lead to new MLB-based handovers and, if necessary precautions are not taken, even to ping-pong effects.

It should be notated that estimating what load an UE will represent in the new cell is not straightforward. The radio conditions in the new cell will be different from what it was in the original cell, hence the radio resources (i.e., the air time) required for a certain capacity will also be different. In the downlink the estimation can be done based on RSRP/RSRQ (reference signal received quality) reports from the UE. However, similar information is not available for uplink and extended information exchange between the eNBs is required.

MLB of idle mode UEs is more difficult than for active mode UEs. There is currently no way to know exactly on which cell an idle mode UE is camping. The only time the system becomes aware of the exact cell an UE is in, while in idle mode, is when the tracking area of the user changes and a tracking area update message is sent by the UE. Therefore, while parameters that control how and when a UE performs cell reselection (idle handover) are modifiable, there is no direct measurement mechanism for the system to determine when there are “too many” idle users. In current implementations the idle mode load balancing is usually done by adjusting the cell reselection parameters for the idle users based on the current active user condition.

The load balancing can be operated in different ways. One possibility is to only activate MLB when a cell becomes congested. Another possibility is to let MLB be a more continuous process trying to keep the load in different cells balanced at all times. In the latter case careful consideration should be given to the network signalling load. Currently, the rear eliminated knowledge on the advantages and disadvantages of operating MLB in different ways, and further studies and field trials should be performed. The way of operation should be configurable by the operator through the network management system.

To increase the effectiveness of the MLB function, especially in HetNet scenarios with many small cells, it will be necessary to develop more advanced algorithms. One potential improvement is to choose which UEs should be moved from one cell to another more carefully. The choice could be based on such parameters as capacity and QoS requirements, possibly including predicted values for these parameters based on historical information. The decision on what cells UEs should be moved to and from could also be performed more optimally, for example, based on current and historical statistical data on the load in different cells.

Basing the MLB related decisions on more information requires extended exchange of data between eNBs, which requires standardization of the necessary signalling support. Another area for improvement of MLB is its interworking with other SON functions, especially with MRO. In most current MLB implementations, MRO has priority and MLB has to adapt to the adjustments done by MRO. This significantly limits the MLB operation. For inter-RAT and inter-frequency handovers, MLB should probably have priority over MRO.

MLB also significantly overlap with the traffic steering and must be coordinated closely with this function.

In newly deployed LTE networks the traffic load will be modest and there will be little need for load balancing between LTE cells and between LTE and 2G/3G cells. As traffic increases, the usefulness of the MLB function also increases. It is therefore not necessary to include MLB in LTE deployments from the start. The usefulness of MLB

increases as the network load increase and becomes important when the network develops in to a HetNet with many small cells.

11.3.12 COVERAGE AND CAPACITY OPTIMIZATION.

Coverage and Capacity Optimization (CCO) is a self optimization technique used in managing wireless networks according to coverage and capacity. CCO measures the health of the network and compares with performance target and policies as defined by individual operators. It has been identified by 3GPP as a crucial optimization area in which the SON algorithm determines the optimum antenna configuration and RF parameters (such as UL power control parameters) for the cells that serve a particular area and for a defined traffic situation, after the cells have been deployed.

For successful implementation of CCO SON algorithms, there is need to take into serious consideration, the difference between coverage optimization and capacity optimization. Coverage optimization involves identifying a “hole” in the network and then adjusting parameters of the neighbouring cells to cover the hole. However, increasing cell coverage affects spectral efficiency negatively due to declining signal power, which results in lesser capacity. It is therefore not possible to optimize coverage and capacity at the same time, but a careful balance and management of the trade-offs between the two will achieve the optimization aim.

Adapting to network changes (such as addition/removal of eNBs and change in user distribution) manually is costly and time consuming. Hence, the CCO algorithms operate endlessly, gathering measurements and executing actions if needed. CCO is a slow process in which decisions are made based on long-run statistics.

Below is a list of functions the CCO algorithm is to perform as identified by 3GPP; but 3GPP does not specify how to perform these functions but are operator-defined:

- E-UTRAN coverage holes with 2G/3G coverage.
- E-UTRAN coverage holes without any other coverage.
- E-UTRAN coverage holes with isolated island coverage.
- E-UTRAN coverage holes with overlapping sectors.

11.3.13 RANDOM ACCESS CHANNEL (RACH) OPTIMIZATION.

RACH configuration within a network has major effects on the user experience and the general network performance. RACH configuration is a major determinant for call setup delays, hand-over delays and uplink synchronized state data resuming delays. Consequently, the RACH configuration significantly affects call setup success rate and hand-over success rate. This configuration is done in order to attain a desired balance in the allocation of radio resources between services and the random accesses while avoiding extreme interference and eventual degradation of system capacity. Low preamble detection probability and limited coverage also result from a poorly configured RACH. The automation of RACH configuration contributes to excellent performance with little/no human intervention; such that the algorithm monitors the current conditions (e.g. change in RACH load, uplink interference), and adjusts the relevant parameters as necessary. RACH parameter optimization provides the following benefits to the network:

- Short call setup delays resulting in high call setup rates

- Short data resuming delays from UL unsynchronized state
- Short handover delays resulting in high handover success rate

More generally, RACH optimization provides reduced connection time, higher throughput, and better cell coverage and system capacity. All the UE and eNB measurements are provided to the SON entity, which resides in the eNB. An eNB exchanges information over the X2 interface with its neighbors for the purpose of RACH optimization. The PRACH Configuration is exchanged via the X2 setup and eNB configuration update procedures. An eNB may also need to communicate with the O&M in order to perform RACH optimization.

11.3.14 ENERGY SAVING

Mobile network operators are very keen on finding network energy saving solutions to minimize power consumption in telecommunication networks as much as possible. This will lead to reduced OPEX (since energy consumption is a major part of an operator's OPEX) and enable sustainable development on the long-run. Energy saving is very crucial today, especially with the increasing deployment of mobile radio network devices to cope with the growing user capacity.

OPEX due to energy consumption within a network can be significantly controlled by: a) the design of low-powered network elements; b) temporarily powering off un-used capacity; and c) working on the power amplifiers, since they consume majority of the available energy in a wireless network.

The normal practice is the use of modems to put the relevant network elements in stand-by mode. These modems have a separate management system. To achieve an automated system of saving energy, the network elements should be able to remotely default into stand-by mode using the minimum power possible when its capacity is not needed, and also switch-off stand-by mode remotely when needed, without affecting user experience.

The energy saving solutions in the E-UTRAN, which are being worked on by 3GPP, to be used as the basis for standardization and further works are: Inter-RAT energy savings; Intra-eNB energy savings; and Inter-eNB energy savings. 3GPP has also stipulated the following conditions under which any energy saving solutions should operate, since energy savings should ideally not result in service degradation or network incompetence:

- User accessibility should be uncompromised when a cell switches to energy saving mode.
- Backward compatibility and the ability to provide energy savings for Rel-10
- Network deployment that serves several legacy UEs should be met.
- The solutions should not impact the physical layer.
- The solutions should not impact the UE power consumption negatively.

11.3.15 SELF-HEALING

Self-healing functionality was not initially defined a part of the 3GPP SON functionality, but it was taken into the SON standards in release 9 and 10, by 3GPP .

Self-healing is a collection of SON procedures which detects problems and solves or mitigates these to avoid user impact and to significantly reduce maintenance costs. Self healing involves automatic detection and localization of failures and the application of the necessary algorithms to restore system functionality. Self- healing is triggered by alarms generated by the faulty network elements. If it finds alarms that it might be able to correct or minimize the effects of, it gathers more necessary correlated information (e.g., measurements, testing results, and so forth), does deep analysis, and then trigger the appropriate actions.

The two major areas where the self-healing concept could be applied are as follows.

- (1) Self-diagnosis: create a model to diagnose, learning from past experiences.
- (2) Self-healing: automatically start the corrective actions to solve the problem.

Making use and analyzing data from the current optimization tools (alarm supervision system, OAM system, network consistency checks), optimizers can decide if network degradation occurs, which is the most likely cause, and then perform the needed corrections to solve the problem. The experience of optimizers in solving such problems in the past, and the access to a database of historic solved problems is very useful to improve the efficiency in finding solutions.

This whole optimization process could be enhanced in two steps as follows.

- (i) Diagnosis model creation based on the experience of already solved problems, using a database with faults and their symptoms. Automatic troubleshooting action can be done without human intervention.
- (ii) Self-test results from the periodic execution of consistency checks would help during the self diagnosis phase, to address better the healing process.

In the recommendation three different Self-healing SON functions are defined:

- (i) cell outage,
- (ii) self-recovery of network element (NE) software and
- (iii) self-healing of board faults.

11.3.16 CELL OUTAGE.

This SON function has two basic components, namely, Cell Outage Detection (COD) and Cell Outage Compensation (COC) .

COD uses a collection of evidence and information to determine if a particular cell is not working correctly. The equipment usually detects faults in itself automatically. But in a situation where the detection system itself is faulty and has therefore failed to notify the OAM, such unidentified faults of the eNBs are referred to as sleeping cells. Cell Outage Detection and Compensation automatically handles these eNB failures by combining several individual mechanisms to determine if an outage has occurred, and then compensating for the failures after soft recovery techniques fail to restore normal service. The automated detection mechanism ensures the operator knows about the fault before the end user. The SON compensation system temporarily mitigates the problem.

11.4 3GPP SON EVOLUTION

Self Organizing Networks (SON) developed by 3GPP, using automation, ensures operational efficiency and next generation simplified network management for a mobile wireless network. The introduction of SON in LTE therefore brings about optimum performance within the network with very little human intervention.

3GPP standardization in line with SON features has been targeted at favouring multi-vendor network environments. Many works are on-going with- in 3GPP to define generic standard interfaces that will support exchange of common information to be utilized by the different SON algorithms developed by each vendor. The SON specifications are being developed over the existing 3GPP network management architecture defined over Releases 8, 9, 10 and beyond.

Release 8 marked the first LTE network standardization; therefore, the SON features here focused on processes involved with initial equipment installation and integration. Release 8 SON activities include:

- eNB Self Configuration: This involves Automatic Software Download and dynamic configuration of X2 and S1 interfaces.
- Automatic Neighbour Relation (ANR)
- Framework for PCI selection
- Support for Mobility Load Balancing

Release 9 marked enhancements on Release 8 LTE network; therefore, SON techniques in Release 9 focused on optimization operations of already deployed networks. Release 9 SON activities include:

- Automatic Radio Network Configuration Data Preparation
- Self optimization management
- Load Balancing Optimization
- Mobility Robustness/Handover optimization (MRO)
- Random Access Channel (RACH) Optimization
- Coverage and Capacity optimization (CCO)
- Inter-Cell Interference Coordination (ICIC)

Release 10 SON in LTE activities include enhancements to existing use cases and definition of new use cases as follows:

- Self optimization management continuation: CCO and RACH
- Self healing management: Cell Outage Detection and Compensation
- OAM aspects of Energy saving in Radio Networks
- LTE self optimizing networks enhancements
- Enhanced Inter-Cell Interference Coordination (eICIC)
- Minimization of Drive Testing

Release 11 SON activities include:

- UTRAN SON management: ANR
- LTE SON coordination management
- Inter-RAT Energy saving management
- Further self optimizing networks enhancements: MRO, support for Energy saving.

Release 12 SON activities include:

- Enhanced Network-Management-Centralized CCO
- Multi-vendor plug and play eNB connection to the network.
- The 3GPP SON standardization is a work in progress and is expected to cover all focus areas of wireless technology evolution, as it relates to network management, optimization and troubleshooting in multi-tech, multi-cell, multi-actor and heterogeneous networks.

11.5 CONCLUSION

Manual tuning of radio network is not possible as it involve lot parameter management and leads to false decision and poor network. SON is the best practice, but data inputted must be correct.

12 NETWORK OPTIMIZATION USING DTT REPORTS AND SON DATA MANAGEMENT

12.1 LEARNING OBJECTIVE

- Radio Network Optimization
- Drive Test Tool and its Setup
- LTE Drive Test Parameters
- UMTS Drive Test Parameters
- GSM Drive Test Parameters
- SON Architecture

12.2 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 regarding a 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.

12.3 DRIVE TESTING

12.3.1 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.

12.3.2 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.

12.3.3 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

12.3.4 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.

12.3.5 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

12.3.6 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 109: Connectivity of Drive Test Tool

12.3.7 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

12.3.8 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).

BW	1,4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20MHz
#RB	6	15	25	50	75	100
Scaling: [-10log(12N)]	-18,57	-22,55	-24,77	-27,78	-29,54	-30,79

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

Table 13. LTE signal strength values

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 :

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

Table 14. 15 different CQI values

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

Table 15. 15 different CQI values

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.

12.3.9 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.

12.3.10 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.

12.3.11 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.

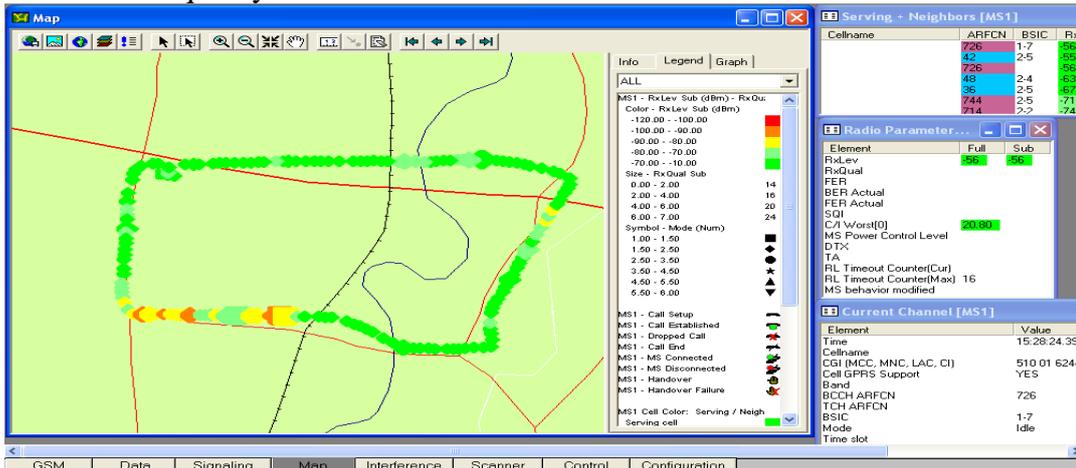


Figure 110: Screenshot of a Drive test window

12.4 SON ARCHITECTURE

The SON architecture defines the location of SON within the network. When implemented at a high level in the network (OAM), it is called Network Management System (NMS); while implementation at lower levels (network elements) like the eNBs is called Element Management System (EMS). For self-configuration techniques of SON, a self configuration subsystem is created in the OAM which handles the self configuration process. For self optimization, the subsystem can be created in the OAM or the eNB or both. Therefore, depending on the location of SON algorithms, SON architecture may be described as being centralized, distributed or hybrid (a combination of centralized and distributed).

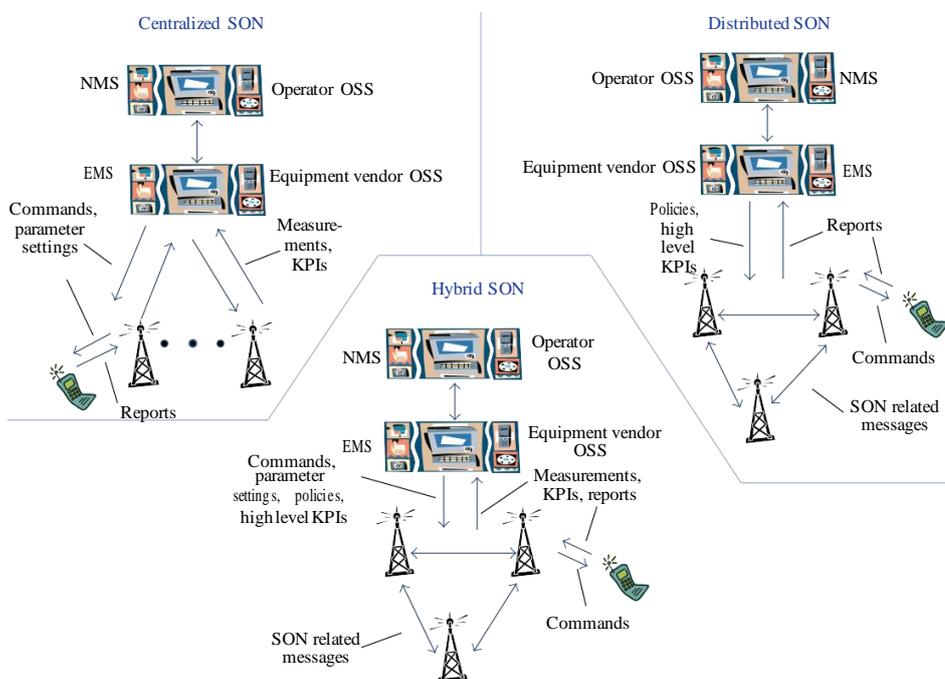


Figure 111: SON Architecture

12.4.1 CENTRALIZED SON

In a centralized SON architecture, the algorithms are executed at the network management level. Commands, requests and parameter settings data flow from the network management level to the network elements, while measurement data and reports flow in the opposite direction.

This is an example of the Network Management System (NMS) where the algorithms are created and executed in the OAM. In this type of SON architecture, the algorithms are present in just a few locations thereby making it simple and easy to implement.

The main benefit of this approach is that the SON algorithms can take information from all parts of the network into consideration. This means that it is possible to jointly optimize parameters of all centralized SON functions such that the network becomes more globally optimized, at least for slowly varying network characteristics. Also, centralized solutions can be more robust against network instabilities caused by the simultaneous operation of SON functions having conflicting goals. Since the control of all SON functions is done centrally, they can easily be coordinated. Another advantage is that multivendor and third party SON solutions are possible, since functionality can be added at the network management level and not in the network elements where vendor specific solutions are usually required.

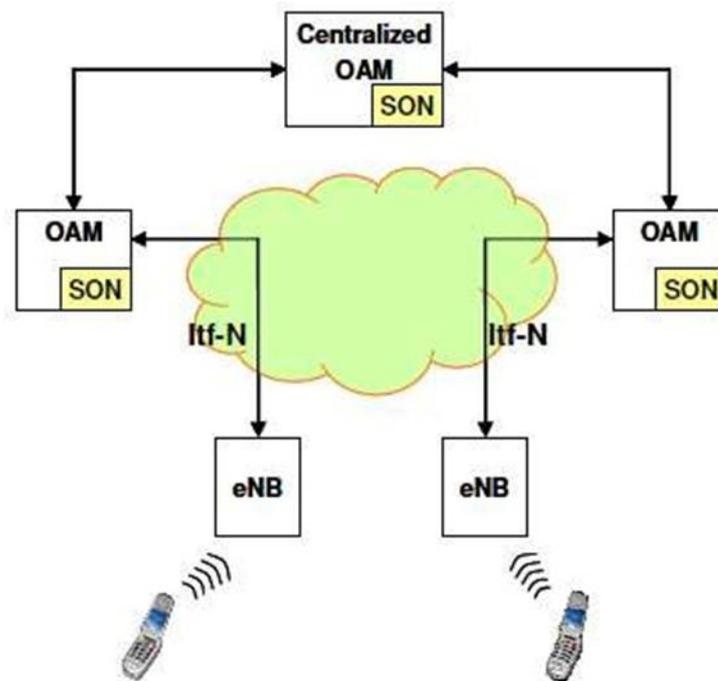


Figure 112: Centralized SON Architecture

The main drawbacks of the centralized SON architecture are longer response times, increased backbone traffic, and that it represents a single point of failure. The longer response time limits how fast the network can adapt to changes and can even cause network instabilities. The backbone traffic increase since measurement data have to be sent from the network elements to the network management system and instructions must

be sent in the opposite direction. This traffic will increase as more cells are added to the network. If there are many pico- and femto-cells this traffic will be very significant. Also, the centralized processing power needed will be large.

12.4.2 DISTRIBUTED SON

In a distributed SON architecture, the SON algorithms are run in the network nodes and the nodes exchange SON related messages directly with each other. This architecture can make the SON functions much more dynamic than centralized SON solutions, so that the network can adapt to changes much more quickly. It is also a solution that scales very well as the number of cells in the network increases.

The main drawbacks are that the sum of all the optimizations done at cell level do not necessarily result in optimum operation for the network as a whole and that it is more difficult to ensure that network instabilities do not occur. Another drawback is that the implementation of the SON algorithm in the network elements will be vendor specific, so third party solutions will be difficult. Even if the algorithms themselves are executed in the network elements, the network management system is usually able to control the behavior of the SON function, for example, by setting the optimization criteria, receiving periodic reports, and being able to turn it off if necessary.

An example of the EMS in which the algorithms are deployed and executed at the eNBs is distributed SON. Therefore the SON automated processes may be said to be present in many locations at the lower level of the architecture. Due to the magnitude of deployment to be carried out caused by a large number of eNBs, the distributed SON cannot support complex optimization algorithms.

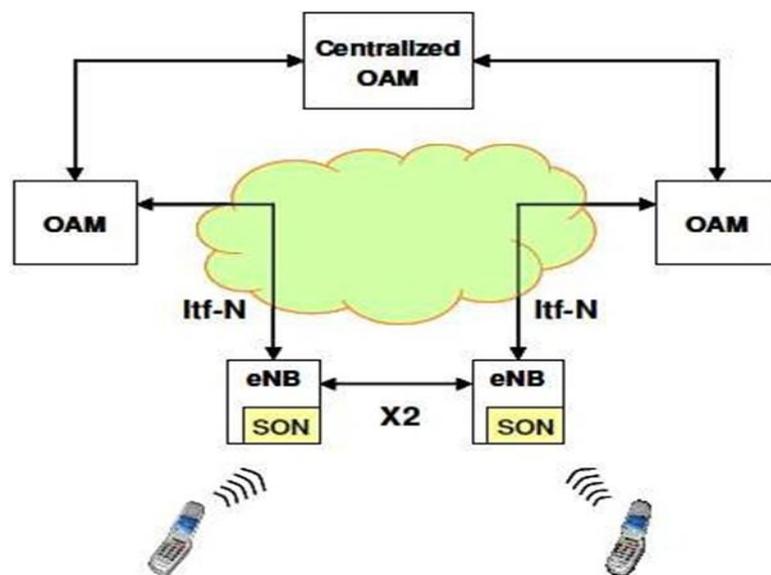


Figure 113: Distributed SON Architecture

In order to fully benefit from this architecture type, work is being done towards extending the X2 interface (interface between the eNBs). However, distributed SON offers quick optimization/ deployment when concerned with one/two eNBs. An example of this is in ANR and load balancing optimizations.

12.4.3 HYBRID SON

An architecture in which the optimization algorithms are executed in both OAM and the eNBs is called Hybrid SON. Hybrid SON solution means that part of the SON algorithm is run on the network management level and part is run in the network elements. The solution represents an attempt to combine the advantages of centralized and distributed SON solutions: centralized coordination of SON functions and the ability to respond quickly to changes at the network element level.

The hybrid SON solves some of the problems posed by other architecture alternatives. The simpler optimization processes are executed at the eNBs while the complex ones are handled by the OAM; therefore, it supports various optimization algorithms and also supports optimization between different vendors. However, the hybrid SON is deployment intensive and requires several interface extensions.

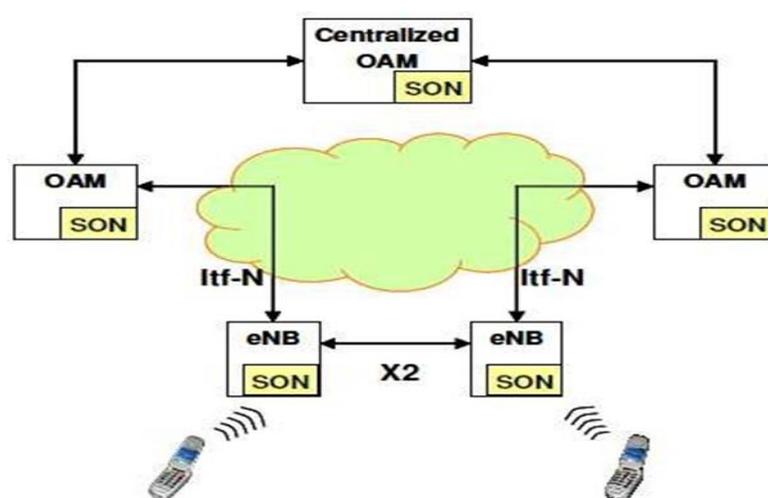


Figure 114: Hybrid SON Architecture

Unfortunately, the drawbacks of both centralized and distributed SON are also inherited. The SON related traffic in the backbone will be proportional to the number of network elements in the network, which means that it might not scale well. The same holds for the SON related processing required at the network management level. Also, since parts of the SON algorithms are running in the network elements and the interface between the centralized and distributed SON functions will be proprietary, third party solutions will be difficult.

It should be noted that the term “Hybrid SON” is not clearly defined and is used differently by different vendors. Some vendors classify their solutions as “hybrid” if the network management system can control the SON function by setting main parameters/policies, receiving reports and being able to turn it off if necessary.

12.5 CONCLUSION

RF Planning and Optimization plays a vital role in mobile radio network without it is merely impossible to rollout and manage radio network. RF Planning and optimization plays an important role in Network health as it gives health as well as monitoring of current network conditions.

13 SITE PLANNING, RELOCATION AND RRH

13.1 LAERNING OBJECTIVE

After completion of this chapter the participant will be able to understand about Site planning process, RRH and its utility, C-RAN architecture and its deployment.

13.2 SITE PLANNING :

cell sizes and types, heterogeneous networks (HetNets), energy efficiency, self-organizing network features, control and data plane split architectures (CDSA), massive multiple input multiple out (MIMO), coordinated multipoint (CoMP), cloud radio access network, and millimetre-wave-based cells plus the need to support Internet of Things (IoT) and device-to-device (D2D) communication require a major paradigm shift in the way cellular networks have been planned in the past.

13.2.1 SITE PLANNING PROCESS

The cell planning process consists of three phases: preplanning, or dimensioning; detailed planning; and post planning, or optimization. The output of the dimensioning phase is an approximate number of BSs required to cover an area of interest. The detailed planning phase allows determining the actual positions of the BSs within the area to be served. In the optimization phase, which occurs after the network has been deployed and is running, the network performance is analysed, potential problems detected, and improvements made to enhance network operation.



Figure 115: Cell planning process

13.3 CELL PLANNING OBJECTIVES

The objectives of CP heavily depends on the business strategy of the operators. The coverage target for different services, the pricing and throughput policies, regulatory constraints, market share goals and competition are some factors among many that dene the CP objectives. Ultimately, CP objectives can be boiled down to the following set of optimization targets identified in the cell planning problem:

- 1) **Minimize TCO** : In addition to minimizing the overall network cost, this objective may also include minimizing economic costs related to deployment costs and parameter optimization.
- 2) **Maximize capacity**: For a single service, this objective can be defined as the number of users who can be served at one time. In the case of multi-service traffic, capacity can be approximated in terms of global throughput.

3) Maximize Coverage: This includes satisfying coverage policy requirements for various services. Up Link (UL) and Down Link (DL) coverage must be balanced. Both traffic channels and coverage of common channels must be considered.

4) Minimize Power Consumption: Health concerns have motivated the radiated power minimization objective. However, recent awakening of a desire for greener wireless systems has added more depth to this objective. Consequently, power consumption, including fixed circuit power as well as variable transmission power, must be minimized.

5) Optimise handover (HO) zones: In a well-planned cellular system, a certain proportion of the area of each cell should overlap with neighbouring cells to satisfy HO conditions. HO zones are essential to guarantee continuity of service between the sectors. It also strengthens the radio link against fast fading and shadowing.

However, too much overlap may result in wastage of power, and radio resources, and increase in interference and electro-smog, making it a tricky planning objective.

13.3.1 CELL PLANNING INPUTS

Different inputs are required to solve the cell planning difficulty depending on objectives in focus and phase of planning. Usually, the following inputs need to be known :

1) Traffic Models: User traffic distribution is a main factor that ultimately determines the cellular system plan and, hence, is a key input in the CP process. In GSM (mono-service systems), for instance, geographical characterisation of traffic distribution is sufficient. However, with multi-service systems supporting data, traffic characterisation based on types and level of service is needed . Test point based traffic models are often used for CP traffic modelling, for the sake of practicality . In this model, an area is characterized over a time interval and all located mobile terminals are bundled into a single test point. This point represents the cumulative traffic, or traffic intensity from all these terminals, over the determined interval.

2) Potential Site Locations: Theoretically, a base station can be installed anywhere. However in the real world, a set of candidate sites is first pre-determined and used as input to the CP, to incorporate the real estate constraints. The objective, thus, is to find the optimum subset of BS locations. These potential BS locations are determined by taking into account the constraints such as, socio-economic feasibility and availability of site(s), traffic density, building heights, terrain height(s) and pre-existence of a site(s) by the same or other operators.

3) BS Model: There are many parameters that define the BS model such as: antenna type and height, receiver sensitivity, load capacity, transmit power and capital and operational cost. Moreover, heterogeneous networks necessitate modelling of new types of nodes; for instance relay stations (RS), pico-cells, femto-cells, and small cells.

4) Propagation Prediction Models/Maps: A key input to the planning process is the signal propagation model. The potential of this model is to incorporate reflection, differentiation, absorption, and propagation of the signal in real environment. Taking into account the natural

and man-made structures, vegetation and topography of an area, highly determines the accuracy of the CP outcomes [38]. Very sophisticated planning tools rely on actual measurement based propagation maps, or ray tracing based complex analysis, to predict the propagation. However, obtaining complete propagation maps of a large area using these methods is a very cumbersome, time consuming, and expensive process. For this reason, different empirical models have been proposed in the literature. Such models abstract the experimental and statistical data in the form of deterministic expressions, that can easily be used in the CP. Okumura Hata and COST 231 are a few examples of such well known propagation models used in CP to depict propagation loss in different

environments and scenarios. A fine tuning of these models is done by setting parameters within these models to recent the real-world conditions as closely as possible. While propagation models for sub 5 GHz frequencies are well established, research on developing such models for higher frequencies such as mm Waves is still in progress.

13.4 CELL PLANNING OUTPUTS

The goal of the CP process is to provide one or more of the following outputs:

- 1) The optimal number of base stations;
- 2) The best locations to install base stations;
- 3) The types of base station optimal for each location;
- 4) The configuration of parameters such as antenna height, number of sectors and sector orientation, tilt, power;
- 5) Frequency reuse pattern;
- 6) Capacity dimensioning, e.g. number of carriers or carrier components per sector.

13.4.1 TYPES OF CELL PLANNING AND OTHER COMPLEXITY

The objectives, input and output of the CP process also depend on the type of planning. There are generally two types of CP, roll out and incremental, as explained below:

1) Roll-out CP: This is the CP where no prior networks exists and a plain state approach can be used to meet all the objectives of interest. In terms of input parameters, in this phase the traffic distribution is not exactly known yet. Estimates of traffic based on geo-marketing forecasts are used for planning in this phase

2) Incremental Planning: This type of CP is generally carried out after the first roll-out planning to meet the increasing demand. Unlike the plane state approach, planning in this phase is bounded by additional constraints imposed by existing sites. However, in this phase the traffic distribution can be modelled now with much better accuracy using the measurements from existing network reports. It is anticipated that 5G deployment will mostly require incremental planning by building on LTE/UMTS/GSM network.

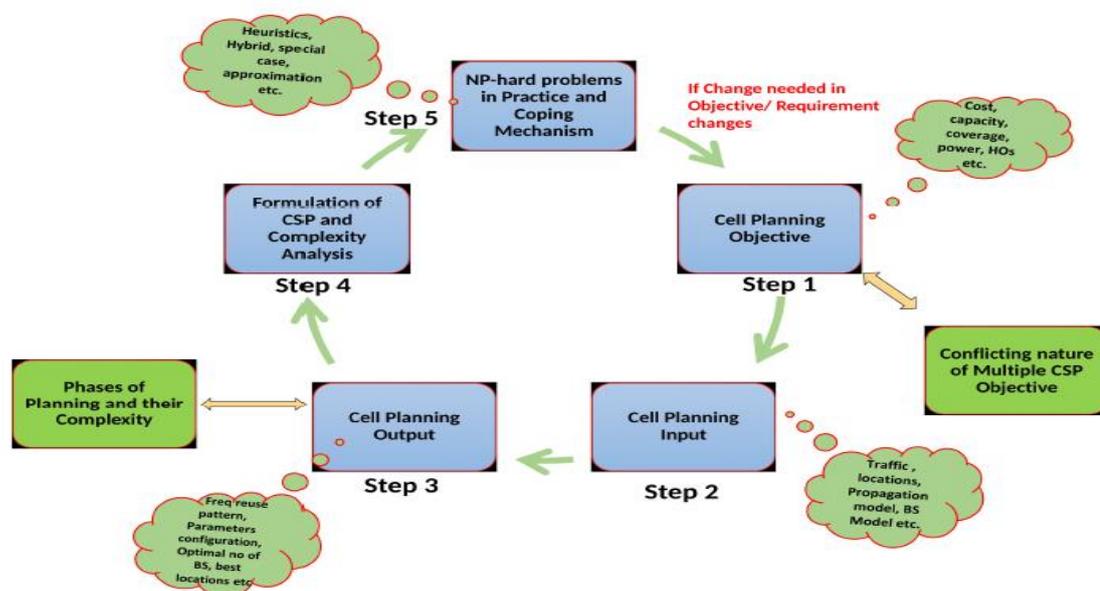


Figure 116: Cell planning Steps

13.5 SITE RELOCATION AND RRH

To answer the need for more throughput at lower cost, wireless network providers are moving to using a remote radio head (RRH) where the radio equipment is connected to the baseband unit (BBU) by a fiber optic cable. This provides a new level of flexibility in how the cell site is deployed, including siting the RRH at the masthead (for low RF losses) or locating the BBU at a remote location (for improved operational efficiencies).

Remote radio heads (RRHs) have become one of the most important subsystems of today's new distributed base stations. The RRH concept constitutes a fundamental part of a state-of-the-art base station architecture. The move to RRH based cell sites has delivered flexibility, performance improvements and cost savings.

13.5.1 RRH TECHNOLOGY

The remote radio head contains the base station's RF circuitry plus analog-to-digital/digital-to-analog converters and up/down converters. RRHs also have operation and management processing capabilities and a standardized optical interface to connect to the rest of the base station. Modern interfaces standards for RRH interconnect are Open Base Station Architecture Initiative (OBSAI) and Common Public Radio Interface (CPRI) which enable interoperability between hardware items and faster time-to-market for complete solutions. Remote radio heads make MIMO operation easier; they increase a base station's efficiency and facilitate easier physical location for gap coverage problems.

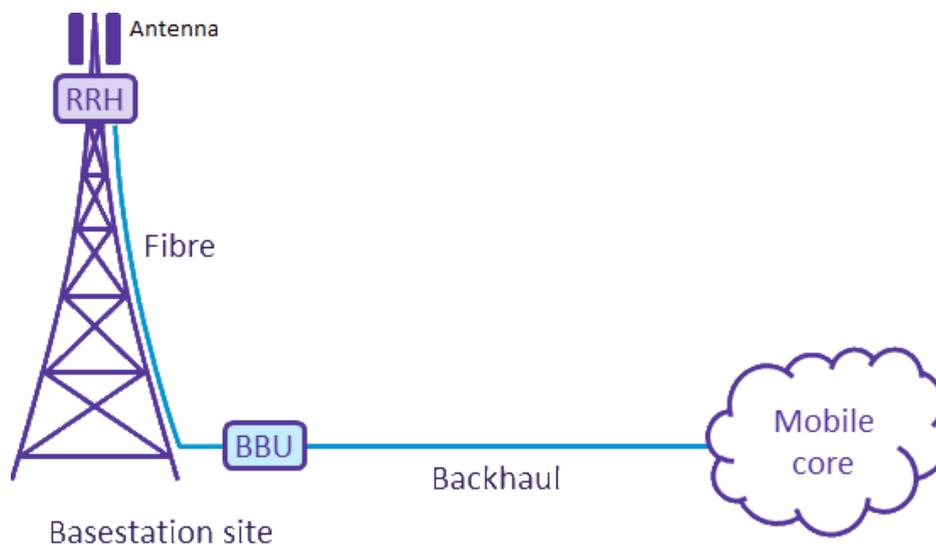


Figure 117: Remote radio Head

RRH is sitting on top of cell tower that mainly performs following functions:

- Convert optical signal to electrical signal and vice versa using CPRI
- In transmitter section of RRH, it converts digital signal to RF and amplifies that signal to the desire power level and Antenna connected to it, radiates the RF signal in air
- In Receiver section of RRH, it receives the desired band of signal from antenna and amplify it.
- And convert RF signal back to digital signal in the receiver chain.

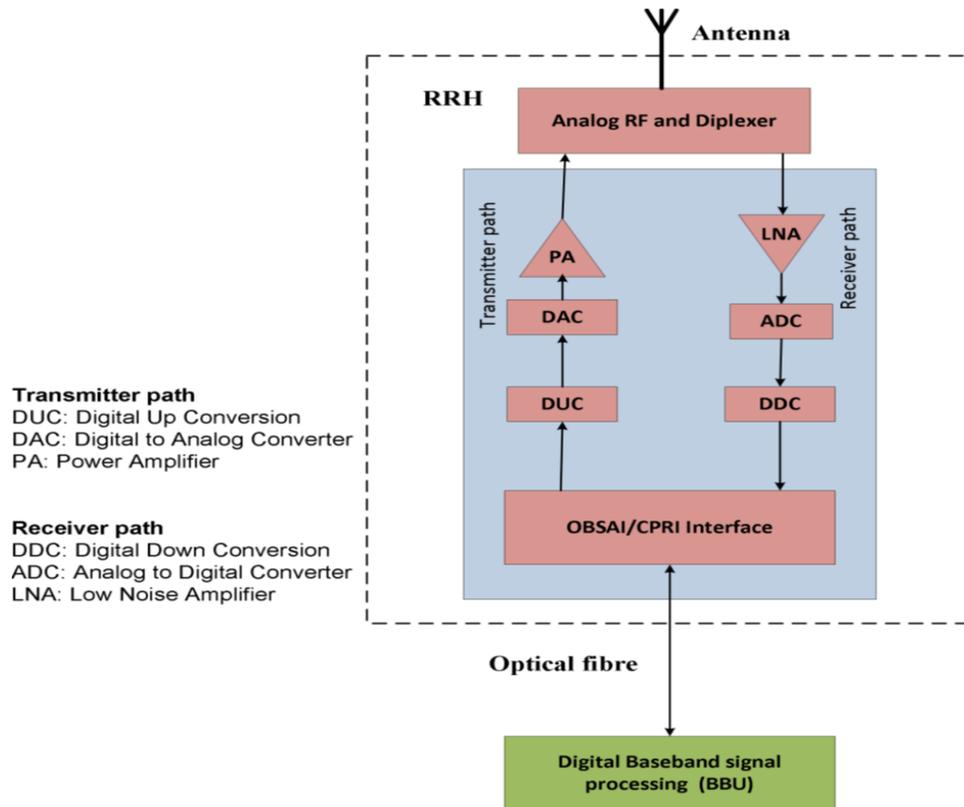


Figure 118: RRH Architecture

The RRH is connected to the Base band unit (BBU) via fibre optical cable which uses CPRI format signals. Optical cable is used because it has less loss and it is cheaper as compared to RF Coaxial cable, especially at the CPRI bit rates which can be 6Gbps up to 10Gbps or more. One base-band unit is connected to multiple RRHs depending upon the capability of base-band unit. The following example shows 3 RRH's connected to one baseband unit to provide 3 sectors of coverage:

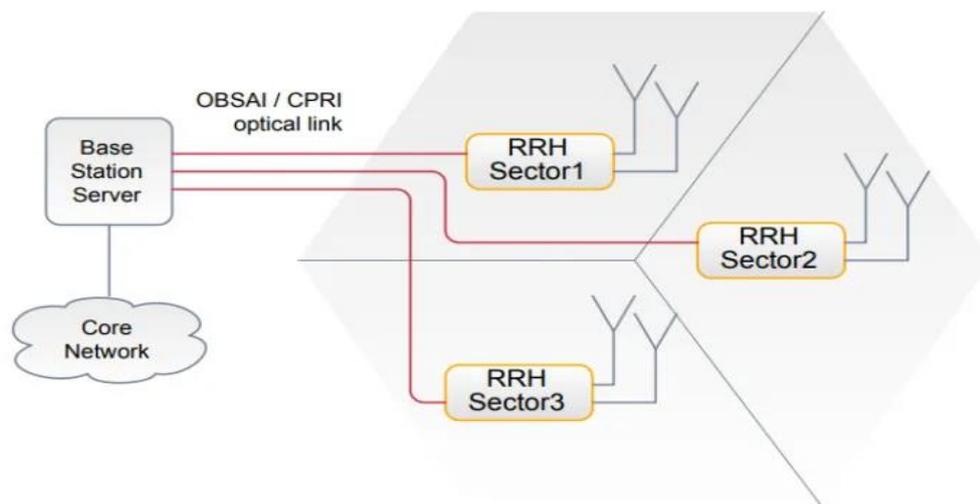


Figure 119: RRH Connectivity

The key advantages of using RRHs are listed in below

- Smaller footprint : Easier installation, reduced wind load, lower site rental costs, optimized coverage.

- Flexibility in Software : Remote upgrades and frequency-agile operations, easier capacity upgrades.
- Higher performance: High power efficiency, spectral emissions requirements, sensitivity, capacity
- Multi-mode operations: Combined and concurrent multi-standard operations reduce equipment needs.
- Flexible multi-carrier capability: Frequency agility, easier capacity upgrades

13.5.2 THE EVOLUTION OF CELL SITES AND RRH

Mobile data traffic has been soaring ever since smartphones were first introduced and spread throughout the world. Mobile base stations are being transformed accordingly. RRHs are more commonly used because they can minimize radio transmission loss by allowing radio parts, which used to be installed indoor, to be placed closer to antennas.

Most RRHs and antennas today are placed pretty close to each other on a building's rooftop, tower, etc., but they still need a 2~3-meter-long connection cable between them to exchange signals with each other. As RRHs are moved out of a building and onto a rooftop, where only antennas used to be placed, operators are facing new challenges - securing space for a variety of products from different manufacturers that are run by different operators for different frequency bands, and achieving reliability of the frame structures where those products are mounted.

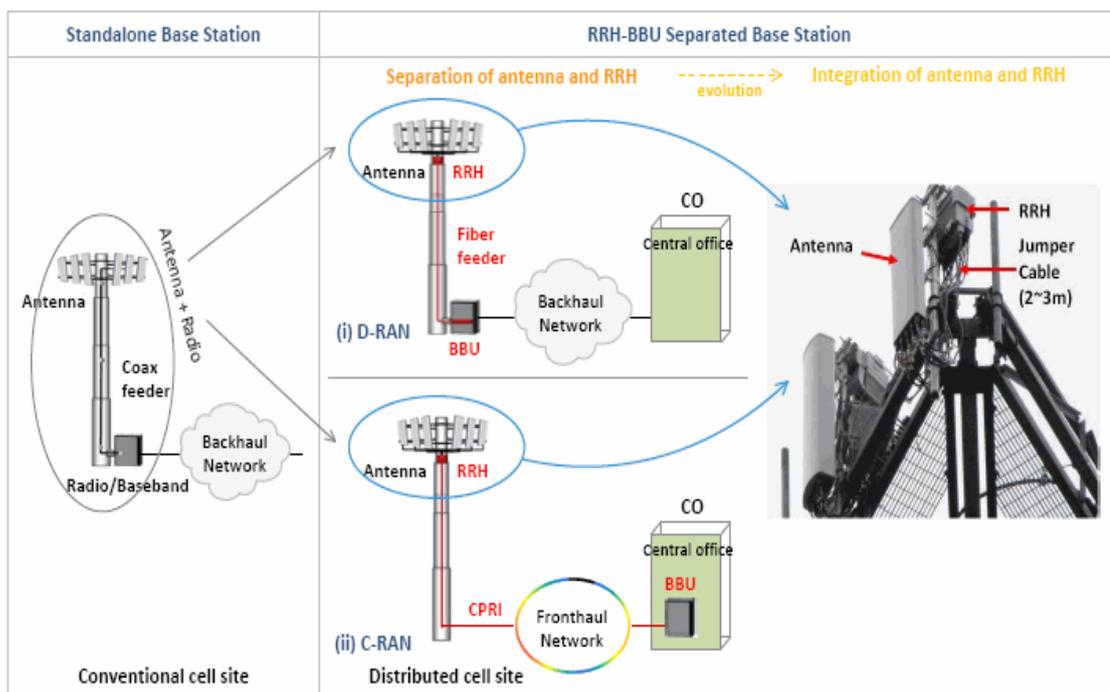


Figure 120: Evolution of base station and RRH tower

Particularly installing RRHs and antennas on building rooftops or small towers in big cities can be not only undesirable from an aesthetic point of view, but also an obstacle in building a network from operators' point of view.

To solve these issues in distributed cell sites, antenna-integrated RRH solution was introduced. Fourth-generation (4G) and beyond infrastructure deployments will include the implementation of Fiber to the Antenna (FTTA) architecture. FTTA architecture has enabled lower power requirements, distributed antenna sites, and a reduced base station footprint than conventional tower sites. The use of FTTA will

promote the separation of power and signal components from the base station and their relocation to the top of the tower mast in a Remote Radio Head (RRH).

13.5.3 FEATURES OF ANTENNA-INTEGRATED RRH

These types of antenna-integrated RRHs have the following four characteristics:

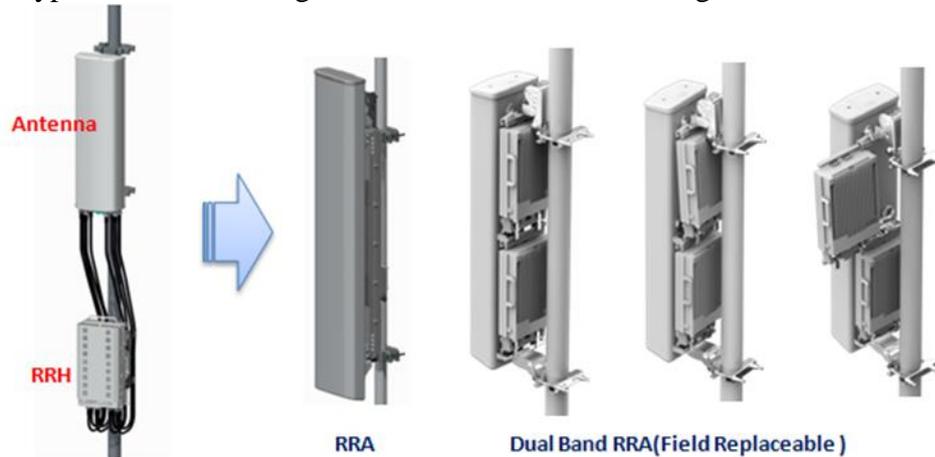


Figure 121: Antenna Integrated RRH

Less signal transmission loss between antenna and RRH

In a conventional cell site, an antenna and RRH are connected usually with a 2~3-meter-long connection cable, and this contributes to transmission loss of about 0.6~0.7 dB. An antenna-integrated RRH solution however can eliminate this loss, resulting in more energy savings.

Less CAPEX/OPEX burden on operators

In conventional structures, antennas and RRHs have to be installed separately, which means higher installation costs and more space to lease. On the other hand, an antenna-integrated RRH gives operators advantage of lower costs of installation and space lease because it only takes one installation of an antenna.

Reduction of physical load on frame structures

Frame structures on towers or rooftops of a building are affected not only by weight of the installed products, but also by wind loads. Because RRA allows RRHs to be attached right to the back of an antenna, wind loads on the face of RRHs can be eliminated. This can help to install more RRHs in limited space on towers or rooftops of buildings.

Passive Inter-modulation (PIMD) quality

Connecting an antenna with RRHs in a tower is a pretty demanding and dangerous job that can be done by only those with experiences. Improper connection by a less-experienced person can cause poor PIMD and waterproofing issues. When more than two frequencies are combined, a new unwanted frequency can be generated as a result of the synthesis of fundamental and harmonic waves of the two original frequencies. This distortion is called PIMD. Distorted signals detected within the receiving frequency band can affect the receiving performance of system. This is why PIMD is considered as an important factor in RF products. So, if we can just skip this whole troublesome connecting process, there will be no problem to take care of at all.

13.5.4 CLOUD RAN AND RRH :

In recent years, cellular networks are facing extreme traffic loads because of sharp increasing in connected smart devices (e.g., smart phone, tablet, Internet of Things (IoT) devices, etc.) and the introduction of new applications and services. This increasing is a

considerable challenge for the mobile network that will lead to increase the complexity of management and operation of network, as well as high upgrade costs, and slow time-to-market for new innovations and services.

Therefore, the cellular companies should increase the network capacity to meet the demand of growing user data rate. Furthermore, Long Term Evolution (LTE) is used as an approach to increase network capacity by either, creating a complex structure of Heterogeneous and Small Cell Networks (HetSNets), adding more cells or by implementing techniques such as multi user Multiple Input Multiple Output (MIMO) and 3D Massive MIMO.

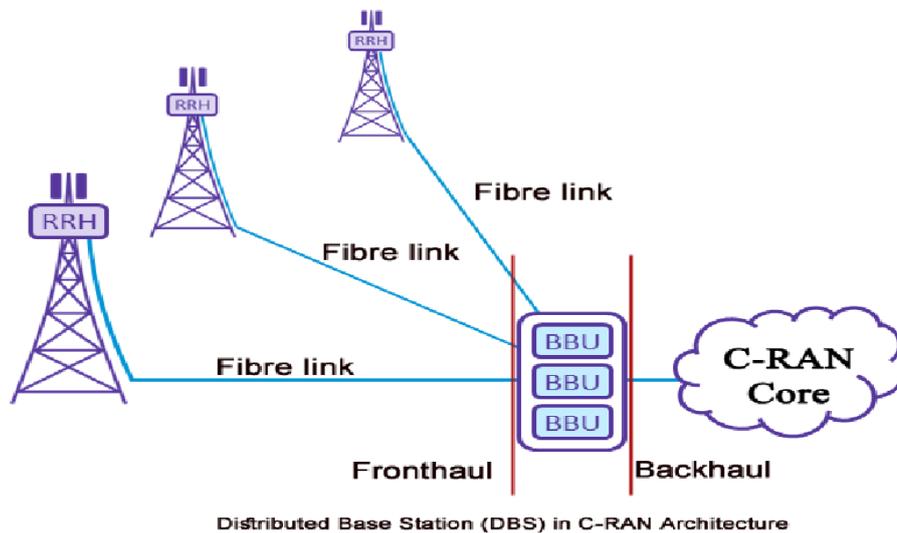


Figure 122: Distributed Base Station in C-RAN

Cloud RAN is a specific concept that is rapidly being developed and prepared for commercial deployment. This aims to centralize the functions of the RAN network (e.g. eNodeB for LTE, NodeB & RNC for 3G) within the cloud servers, such that only the physical transceiver and antenna elements of the eNodeB need to be physically located at the cell site. This provides for a more cost efficient deployment, especially for “small cells” or local cell sites used to boost capacity or fill gaps in coverage. The Cloud RAN concept is taking advantage of technologies such as CPRI, that allow the baseband to TRX link of the base station to be carried on dedicated high speed optical fiber links. This technology has already been developed for Remote Radio Head use (RRH), where the TRX/ Antenna is separated from the base station baseband by several meters (top and bottom of cell site mast) up to separation of hundreds of meters or of kilometers (e.g. for in building or shopping mall deployment, where a single baseband serves all TRX/antenna sites). So Cloud RAN is extending the same concept further such that all TRX/Antenna sites in a network region can be connected by a fiber ring to a centralized baseband server. Off course this technology currently relies on having dedicated fiber access to each cell site, and this can limit deployment in some scenarios.

In C-RAN, Base Band Unit (BBU) is centralized in a BBU pool and connected to the RRHs. Therefore, few BBUs are needed in C-RAN compared to the traditional architecture. C-RAN has ability to decrease the cost of network operation and power consumption compared to the traditional architecture. A new architecture can be upgraded easily, that lead to improving the scalability also enabling network maintenance easy.

Recently, virtualization technology is used in the BBU pool to decrease power consumption. Generally, it consists of two parts; physical servers working with a set of hardware components, and software platform applied by the operating system. Virtualized

BBU pool can be shared the resources, as well as can be shared by different network operators by letting them rent Radio Access Network (RAN) as a cloud service. For example, BBUs from different operators are placed in one cloud service. They can interact with increased spectral efficiency, lower delays, and throughput. Furthermore, the performance of the network is improved, by reducing handover delay during intra-BBU pool. Additionally, the virtualization technology has many benefits in C-RAN architecture, such as reducing costs, minimizing the investment capital, reducing power consumption as well as more reliability and flexibility in utilizing the server/network resource.

13.5.5 BASE STATION ARCHITECTURE EVOLUTION

C-RAN architecture can be defined as centralized different BBUs of deployed traditional BSs together to form of a single pool. Therefore, they can be managed and dynamically share resources on demand among all BBUs. C-RANs have many benefits over traditional cellular networks, such as low power consumption, increased resource utilization efficiency, better hardware utilization and light interference. Centralized processing has many methods and technology to turn RRHs on/off in the in a time-varying data traffic in different scenarios. However, this section explains the basic concept of C-RAN as well as the traditional BS evolution. The BS functions can be divided into radio functionalities and baseband processing. Furthermore, the baseband processing functions are Modulation, Coding, Mapping, Fast Fourier Transform (FFT), etc. However, the radio unit is the response to frequency, digital processing, and power amplification.

Traditional Cellular Network Architecture

In the traditional architecture the functions of the radio and BBU processing are co-located in BS (i.e. in the same cell site). Generally, the antenna is located near to the radio unit, the coaxial cables are used to connect the antenna with radio unit. Furthermore, X2 interface and S1 are used between BSs and connect the BSs to the mobile core network, respectively.

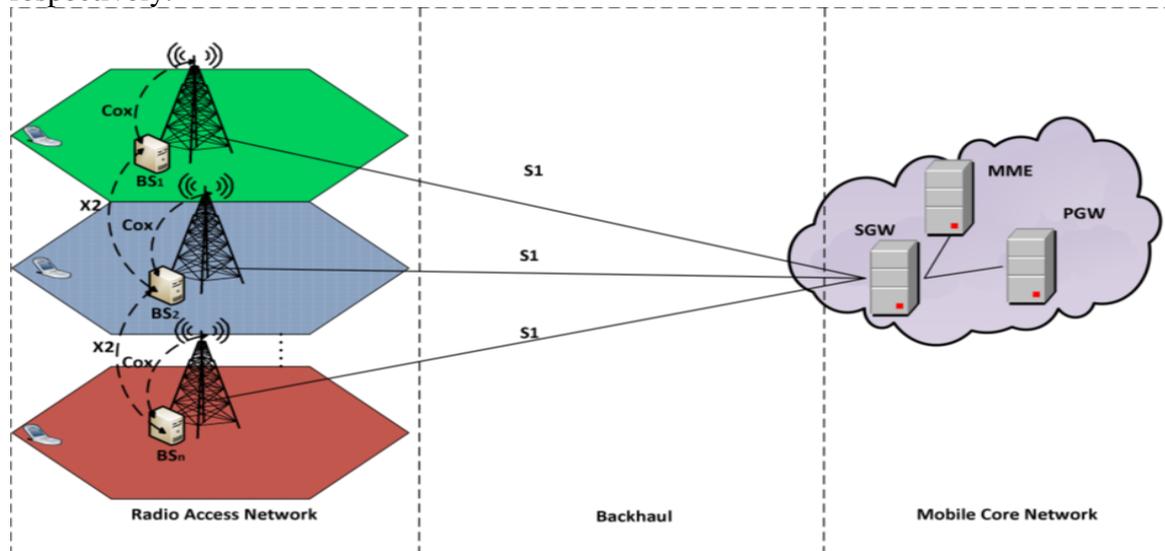


Figure 123: Traditional architecture of cellular network

13.5.6 C-RAN ARCHITECTURE

In this context, the BS is separated into two parts; a baseband signal processing unit and a radio unit. The radio unit is called an RRH, and it has many functions such as Digital to Analogue Conversion (DAC), Analogue to Digital Conversion (ADC), digital

processing, filtering, power amplification and interface to the fibre . The baseband signal processing is called a BBU, which is located in a central unit called BBU pool. The Interconnection and split function between the BBU and RRH depend on type of the network deployment. The distance between an RRH and a BBU pool is up to 40 km [28], distance limitation is coming from the propagation delay of fibre and processing signal in BBU. However, a fronthaul can be optical fibre or microwave. Generally, the optical fibre is a candidate to be used in the next generation to meet the requirements of data rate demands. Moreover, RRHs designed to be small and light, so easy to install on poles or rooftops with very efficient cooling. Open Base Station Architecture Initiative (OBSAI) [29] and Common Public Radio Interface (CPRI) are the radio interface candidate protocols to use between RRHs and BBUs.

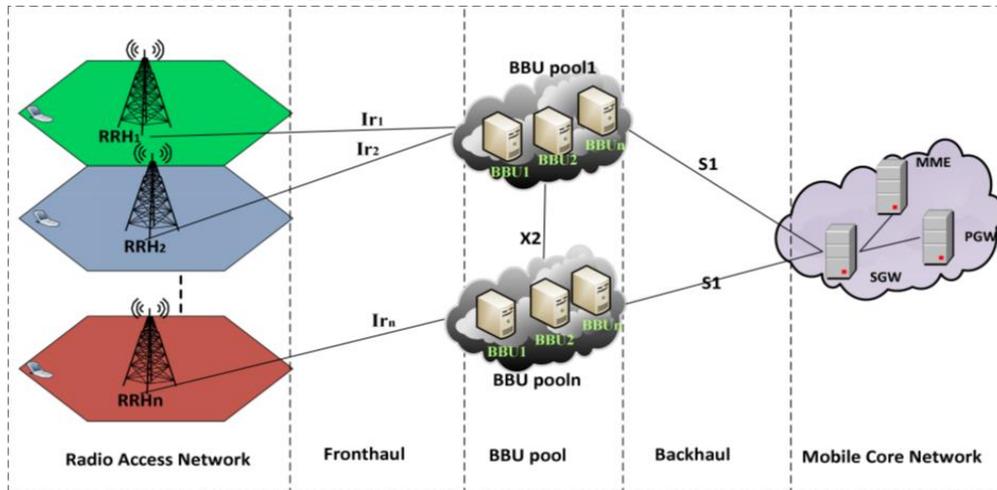


Figure 124: C-RAN Architecture based on Virtualization

In C-RAN, the BBUs are centralized into one place that is called a BBU pool to optimize BBU utilization between light and heavy data traffic demand to save energy. In this architecture, virtualization technology is used, where the BBU's functions installed as software on the physical servers called the virtual BS.

Furthermore, the fronthaul interface is used as a medium to connect the RRHs with the BBU pool within high-performance processors, low latency, and high bandwidth optical fibre medium. The backhaul interface is used as a medium to connect the BBU pool with the mobile core network .

C-RAN Components

In general C-RAN architecture comprises of three main parts, namely (i) BBU pool which consists of a large number of BBUs with centralized processors located at the CO, (ii) RRHs with antennas system located at the cell sites, and (iii) fronthaul transport link which connects the BBU pool to the RRHs and needs low latency and high bandwidth to meet the 5G requirements.

1. Base Band Unit Pool

BBU pool consists of multiple BBUs in a form of a cloud, each capable to serve many RRHs. BBUs can be located at Central Office (CO) or Data Centres (DCs) of system. BBUs operate as virtual base stations which comprise of parts that process and schedule the incoming signals from different RRHs and optimizing radio resource allocation . BBUs are responsible for functions from layer 1 to layer 3 depending on functional split between the BBUs and RRHs that used in level of C-RAN architecture.

Based on data traffic demand and time varying environment, the signal processing radio resources can be fully shared among different BBUs in the BBU pool. The BBU pool is connected by optical fibre to RRHs using Radio over Fibre (RoF) technology. In term of power consumption in the BBU pool, the power consumption model for the BBU

pool is calculated as a sum of the active BBUs. Computing resources and processing of the BBU can be measured in by Million Operations Per Time-Slot (MOPTS) or Giga Operations Per Second (GOPS) translated into power figures. Many components and functions in BBU have significant effect in power consumption calculation such as the frequency and time domain processing, central processing units (CPU), Forward Error Correction (FEC) and processing related to CPRI.

2. Remote Radio Head

RRH is located at the cell site, it provides the wireless signal coverage for the cell site area and comprises of Analogue to Digital Conversion (ADC) and Digital to Analogue Conversion (DCA), Power Amplifier (PA), antennas system, interface adaptation, voltage suppliers and Low Noise Amplifier (LNA). By moving most of the baseband processing from cell site to BBU pool to reduce both CAPEX and OPEX, which allows a more optimized energy consumption as well as less complexity and of course lowers their price.

Therefore, RRH can significantly help cellular network operators to resolve performance, cost, and efficiency challenges when deploying new base stations in 5G networks. Moreover, RRHs distributed in certain areas such as urban areas with high traffic loads offer efficient cost. They are located at the cell sites and used to transmit the RF signals to users and forward the baseband signals from the users to the BBU pool.

3. Front haul Network

It can be defined as a connection between RRHs and BBUs to provide low latency and high capacity. C-RAN front haul is realized by different technologies such as wireless, and wire represented by optical fibre networks. Generally, Wireless front haul link are cheaper and faster to deploy than optical fiber front haul links.

13.5.7 C-RAN DEPLOYMENT

C-RAN is a candidate architecture to implement for next generation of cellular network instead of traditional cellular network like LTE Advanced (LTE-A), LTE and UMTS. In C-RAN architecture, BSs can be implemented by separating BBUs and RRHs, and baseband processing resources for multiple BBUs in a CO can be scheduled in carrier level. Easy to deploy the RRHs due to they are light weight and small size. RRHs transmit and receive radio signals from and to the BBUs via optical fiber front haul links. RRHs can be installed in cell sites far from the BBU pool (e.g. 1- 40 km) . The front haul network between BBUs and RRHs can be standardized like CPRI or OBRI. The centralized BBUs should have a low latency, high bandwidth, corresponding protocol and switch matrix to support the effective cooperation among multiple BBUs in BBU pool.

The radio signals from deployed RRHs can be switched to any BBU in the BBU pool. Thus, the centralized concepts can use load balance technique to avoid overloading in some BBUs during peak hours while some BBUs operate in low load. This can reduce power consumption, improve the usage efficiency of devices, and improve system reliability. Deployment of C-RAN will be an unique scenarios for micro, macro, picocell, and indoor as well as the deployment candidate to be a heterogeneous arrangement. Generally, C-RAN supports many significant scenarios such as greenfield deployments, C-RAN for capacity boosting and different stages of C-RAN deployment. C-RAN deployment still is limited by the maximum distance between RRH and BBU (up to 40 km) due to propagation signals in front haul link and processing delays in BBU. The path towards complete C-RAN deployment, where BBUs are pooled to support RRHs, and how many pool needed to serve specific network becomes required. Multiple BBU pools may be needed to serve a metropolitan area.

- **Green Field Deployment:** In term of this field, the placement of the RRH and BBU pool is subjected to network planning. The transport solution and physical medium can be designed with respect to C-RAN architecture requirements. In general, the main aim of the network deployment is to reduce cost of deployment and minimize Total Cost of Ownership (TCO) a ratio with high system performance. However, C-RAN architecture is promising for small scale deployments for metropolitan areas with high density RRHs.

- **Small Cell Deployment:** A small coverage area cells are most likely for C-RAN architecture for capacity boosting. Release 13 of cellular network standards provide enhancement of small cell deployment. Adding new small cells to cellular network is promising to increase network capacity. Small cell deployment scenarios are candidate to be used with C-RAN. It also supports both user deployed cells and operator, co-existence operators, Self-Organizing Networks (SONs) mechanisms, and networking between different RATs. The small cells deployment scenario with C-RAN reduces signalling resources because they are supported by one central BBU pool, not many BSs as in tradition network . In future cellular networks many small cells can be deployed to improvements network capacity and quality in offices, public spaces and homes. When a user will move out from small cell to the other, the system needs to handover the user to the new small cell. In this case, the system needs a special coordination technique between small cells.

13.6 CONCLUSION

As the need of network is changing on day to day basis and the need of site reallocation will always be there. Proper Site Planning will remove the problem of relocation of site. RRH is an important network element for extension of network.