LTE Whitepaper - Santosh Kumar Dornal
http://wired-n-wireless.blogspot.com

Table of Contents

Revision History:-

Version	Date	Description	Author
1.0	8th Oct 2009	Initial Draft	Santosh Kumar Dornal

LTE Interfaces and Protocols

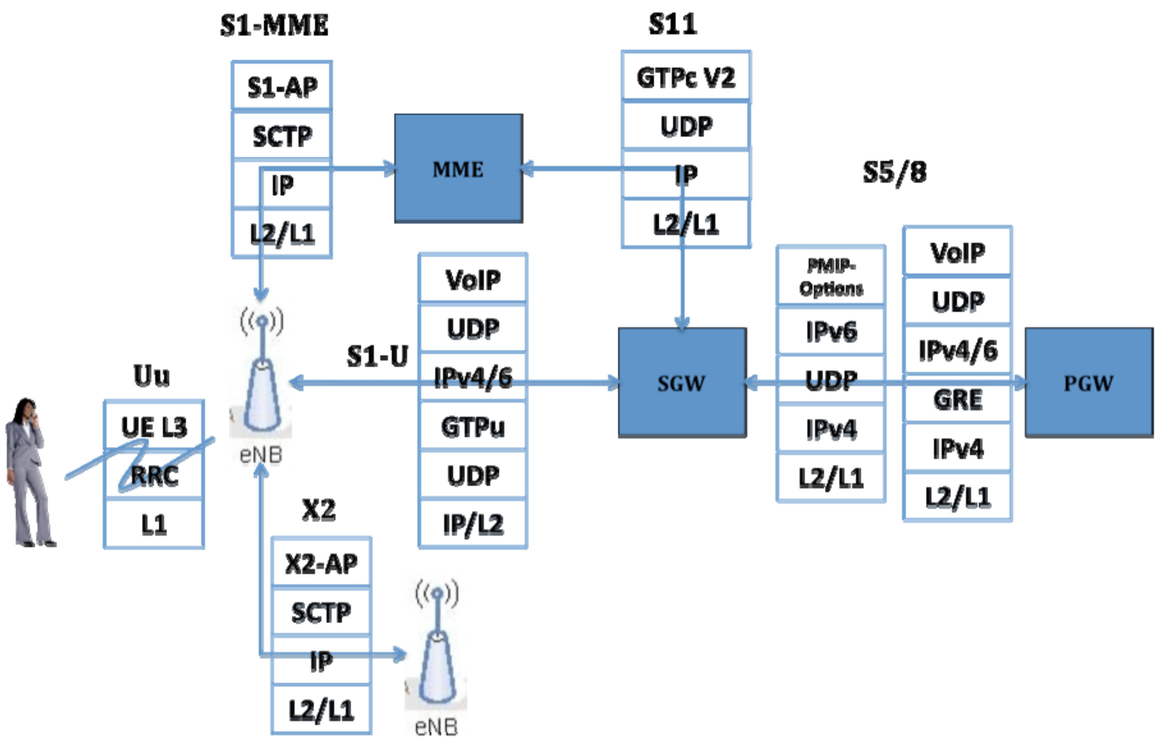

Figure 1: LTE Architecture

The picture shows main network elements, interfaces and the protocols used in LTE.

The main interfaces in LTE are Uu, S1-MME, X2, S1-U, S11 and S5.

LTE Uu: -

This is the air interface between UE and eNB. LTE layer 1 is dealt with later. RRC is the protocol that is used for communication between UE and eNB. Above RRC there is a NAS layer in UE. This NAS layer terminates at MME and eNB shall silently pass the NAS messages to MME.

LTE S1-MME: -

eNB and MME communicate using this IP interface. S1-AP is application layer interface. The transport protocols used here is SCTP. (Stream control transmission protocol)

LTE X2: -

This interface is used by a eNB to communicate to other eNB. This again is a IP interface with SCTP as transport. X2-AP is the application protocol used by eNB's to communicate.

LTE S11: -

An IP interface between MME and SGW! GTPv2 is the protocols used at the application layer. GTPv2 runs on UDP transport. This interface must and should run GTPv2.

LTE S5: -

This is the interface between SGW and PGW. This again is an IP interface and has two variants. S5 can be a GTP interface or PMIP interface. PMIP variant is used to support non-trusted 3GPP network access.

LTE S1-U: -

User plane interface between eNB and SGW! GTP-U v1 is the application protocol that encapsulates the UE payload. GTP-U runs on UDP.

All the above IP interfaces can be of IPv4 or IPv6. Few interfaces can be of IPv4 and few can be of IPv6. From the specification side there are no restrictions.

LTE Network Elements

LTE network comprises of two main segments.

1. LTE EUTRAN
2. LTE Evolved Packet Core.

LTE EUTRAN: -

EUTRAN consists of eNB.

EUTRAN is responsible for complete radio management in LTE. When UE comes up eNB is responsible for Radio Resource Management, i.e it shall do the radio bearer control, radio admission control, allocation of uplink and downlink to UE etc. When a packet from UE arrives to eNB, eNB shall compress the IP header and encrypt the data stream. It is also responsible for adding a GTP-U header to the payload and sending it to the SGW. Before the data is actually transmitted the control plane has to be established. eNB is responsible for choosing a MME using MME selection function.

As the eNB is only entity on radio side, the whole QoS is taken care by it. It shall mark the packets in uplink, i.e Diffserv based on QCI, and also schedule the data. Other functionalities include scheduling and transmission of paging messages, broadcast messages, and bearer level rate enforcements based on UE-AMBR and MBR etc.

LTE Evolved Packet Core (EPC)

LTE EPC comprises of MME, SGW and PGW.

MME: - Mobility Management Entity

MME is a control entity, which means it's completely responsible for all the control plane operations. All the NAS signaling originates at UE and terminates in MME. MME does tracking area list management, selection of PGW/SGW and also selection of other MME during handovers.

It is the first contact point for the 2G and 3G networks. MME is also responsible for SGSN selection during LTE to 2G/3G handovers.

The UE is also authenticated by MME. All signaling traffic flow through MME so the same can lawfully intercepted. MME is also responsible for bearer management functions including establishment of dedicated bearers.

SGW: - Serving Gateway

Serving gateway terminates the interface towards EUTRAN. For each UE associated with EPS, at a given point of time, there is a single Serving GW.

SGW acts a local mobility anchor for inter eNB handovers. It also acts a mobility anchor for inter 3GPP mobility.

SGW is responsible for packet routeing and forwarding, buffering the downlink packets and lawful interception. As eNB is responsible for uplink packet marking, SGW is responsible for downlink packet marking. One way to do this is mark the Diffserv field is IP packet based on QCI field.

If the S5/S8 interface is PMIP based then SGW acts a Mobility Anchor Gateway (MAG). All the MAG responsibilities can be assigned to SGW. It is also responsible for assigning a GRE key that can be used by PGW in downlink. For a MAG of non trusted 3GPP access SGW acts as LMA.

PGW: - PDN Gateway

PGW terminates SGi interface towards the PDN.

PGW is responsible for all the IP packet based operations such as deep packet inspection, UE IP address allocation, Transport level packet marking in uplink and downlink, accounting etc. PGW contacts PCRF to determine the QoS for bearers. It is also responsible for UL and DL rate enforcement based on APN-AMBR. It is synonymous to GGSN of pre release 8 networks.

For PMIP based S5/S8 interface PGW acts as LMA. It is responsible for assigning IP address to UE, and also GRE Key to SGW that should be used in uplink.

LTE Radio Network

LTE Physical Layer

LTE physical layer is quite complex and consists of mixture of technologies. With OFDMA as access technology, QAM as modulation scheme and multiple antennas we can achieve high speeds.

QAM: - Quadrature Amplitude Modulation

Going back to engineering basics, we have a simple modulation scheme called PSK. Phase shift keying, which is analog to digital modulation scheme (transmitter side). In PSK we have 1 bit per symbol .0 and 1. Each bit is associated with a Phase shift. With 4 Phase shifts we can transmit 2 bits per symbol. As with 64 QAM we shall be able to transmit 6 bits per symbol. If we look at this scheme in the given bandwidth, by changing the modulation scheme, we are able to transmit more and more bits. This is resulting in increase of data rates.

Looking at Shannon's theorem:

$$\text{Channel Capacity} = \text{Bandwidth} \times \log_2(1 + \text{SNR})$$

As I said above, changing the modulation scheme gives us more throughput. However high modulation schemes can be only be used when the signal to noise ratio is high. From above theorem, channel capacity is bandwidth multiplied by logarithm of SNR. Higher the SNR higher is the channel capacity, which means more throughput.

Second factor that increases channel capacity is bandwidth. Now bandwidth is directly proportional to symbol rate. Higher the symbol rate then higher is the bandwidth. But again, increasing the symbol rate doesn't increase the channel efficiency as channel bandwidth is fixed because available spectrum is finite. So there is a trade off between symbol rate and channel throughput. The basic idea is keeping on increasing the symbol rate (modulation scheme) doesn't always improve the efficiency. So considering these factors 64 QAM should be a suitable choice for LTE.

OFDM: - Orthogonal Frequency Division Multiplexing

Consider we have X amount of spectrum. This can be divided into channels of each Y amount of bandwidth. Each channel is separated by Guard band to avoid interference. This is basic idea in normal multiplexing schemes. In CDMA we identify each channel by a code. So what is happening is we have equally spaced channels occupying the entire bandwidth. Note that these channels are non-overlapping. Each channel has a subcarrier.

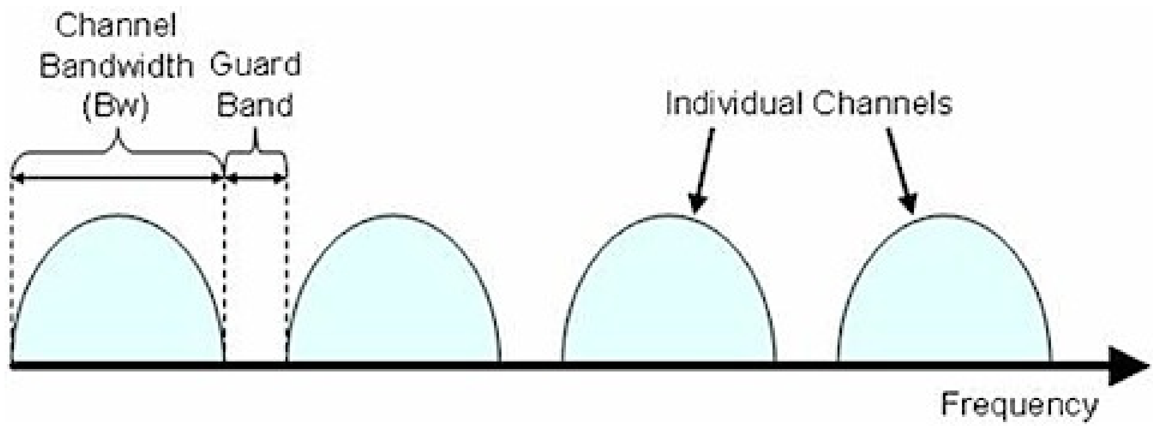

Figure 2: FDMA

With OFDM systems, it is possible to increase throughput in a given channel without increasing channel bandwidth or the order of the modulation scheme. This is done using digital signal processing methods that enable a single channel to be created out of a series of orthogonal subcarriers. As below figure illustrates, subcarriers are orthogonal to one another such that the maximum power of each subcarrier corresponds with the minimum power (zero-crossing point) of the adjacent subcarrier. In a typical system, the bit stream for a channel is multiplexed across various subcarriers. These subcarriers are processed with an inverse Fourier transform (IFT) and combined into a single stream. As a result, multiple streams can be transmitted in parallel while preserving the relative phase and frequency relationship between them.

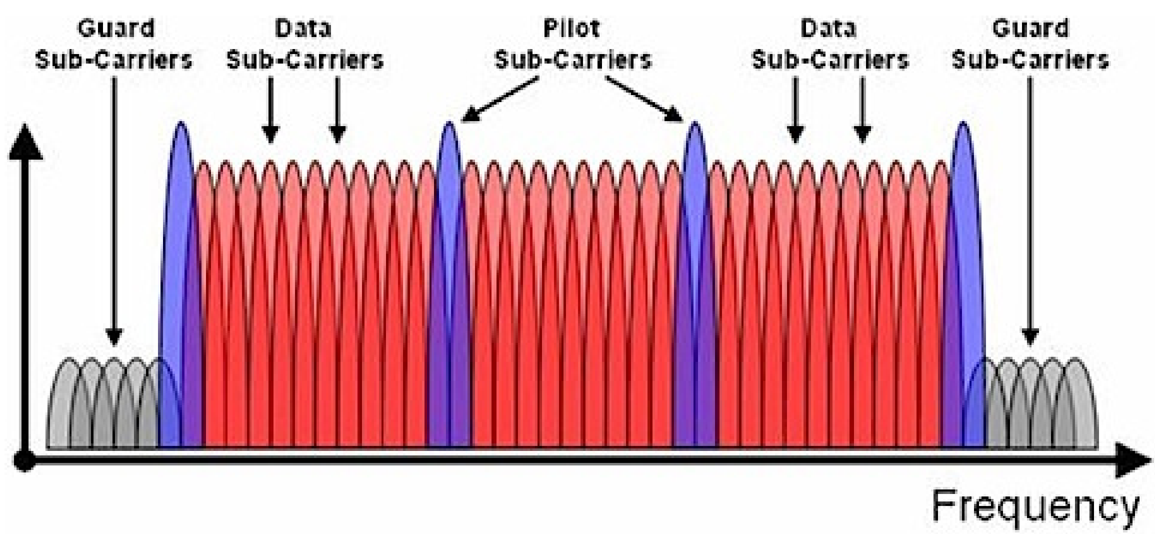

Figure 3: OFDMA

This way we can include more number of subcarriers in a given bandwidth thus increasing the overall system throughput.

MIMO: - Multiple Input Multiple Output

The Shannon's theorem above is assumed to have 1 transmitter and 1 receiver antenna. If we consider multiple antennas then the theorem could be modified as

$$\text{Channel Capacity} = \text{Antennae} \times \text{Bandwidth} \times \log_2(1 + \text{SNR})$$

Thus in theory increasing the antennas will effectively increase the channel capacity without any change in available bandwidth. Now what we can do with MIMO is increase SNR by transmitting a unique bit stream using multiple antennas in the same channel. This is called Spatial Multiplexing. With MIMO systems, the bit stream is multiplexed to multiple transmitters without changing the symbol rate of each independent transmitter. Thus, by adding more transmitters, we can increase the throughput of the system without affecting the channel bandwidth.

Thus the combination of OFDMA, MIMO and QAM will give us more bandwidth and higher data rates in LTE.

LTE Radio Network

- LTE Radio Interface User Plane protocols

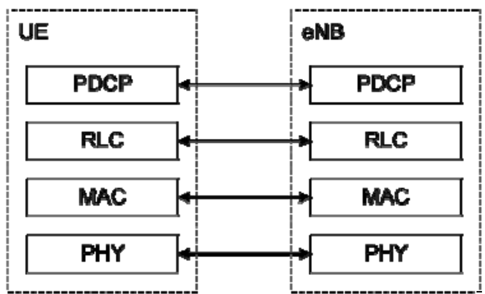

Figure 4: LTE Radio Network User Plane

In downlink data from SAE will enter eNB. The data is an IP packet. The IP packet is several protocols and is passed to UE.

- LTE Radio Interface Control Plane Protocols

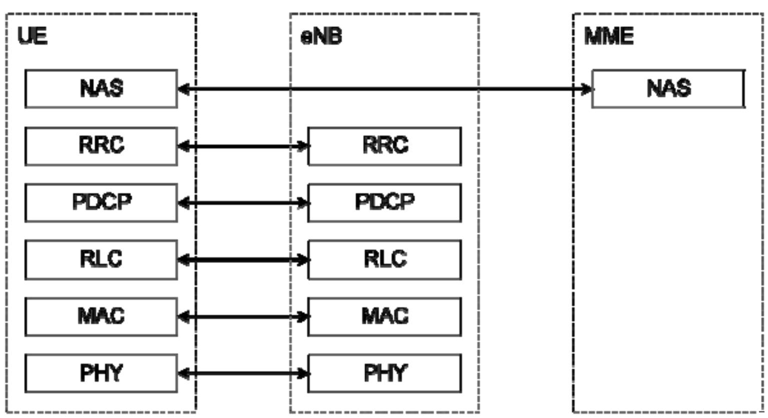

Figure 5: LTE Radio Network Control Plane

The control has two more layers over PDCP. RRC layer is terminated at eNB, while NAS layer goes all the way to MME.

Let's take a look at each layer individually: -

NAS: Non-Access Stratum

NAS is responsible for EPS bearer management, authentication, paging and mobility handling in ECM IDLE state.

RRC: Radio Resource Control

This layer is responsible for Broadcast and paging. It also takes care of RRC connection management, radio bearer control, mobility functions and UE measurement reporting and control.

PDCP: Packet Data Control Protocol

This layer is responsible for IP header compression to avoid unnecessary overhead in the payload. This layer is also responsible for ciphering and integrity protection check.

RLC: Radio Link Control

RLC is responsible for segmentation/concatenation, retransmission handling and in sequence delivery of messages to higher layers. RLC offers services to PDCP in form of radio bearer. These radio bearers are mapped to EPS bearers in EPC.

MAC: Media Access Control

Mac handles ARQ, uplink and downlink scheduling. The scheduling functionality is located in eNB. There is one MAC entity per cell for both uplink and downlink. The HARQ is present in both UE and eNB. MAC offers services to RLC inform of logical channels.

Physical Layer

It handles coding/decoding, modulation/demodulation, multiple antennas etc. It offers services to MAC layer inform of transport channels.

LTE Channels Overview

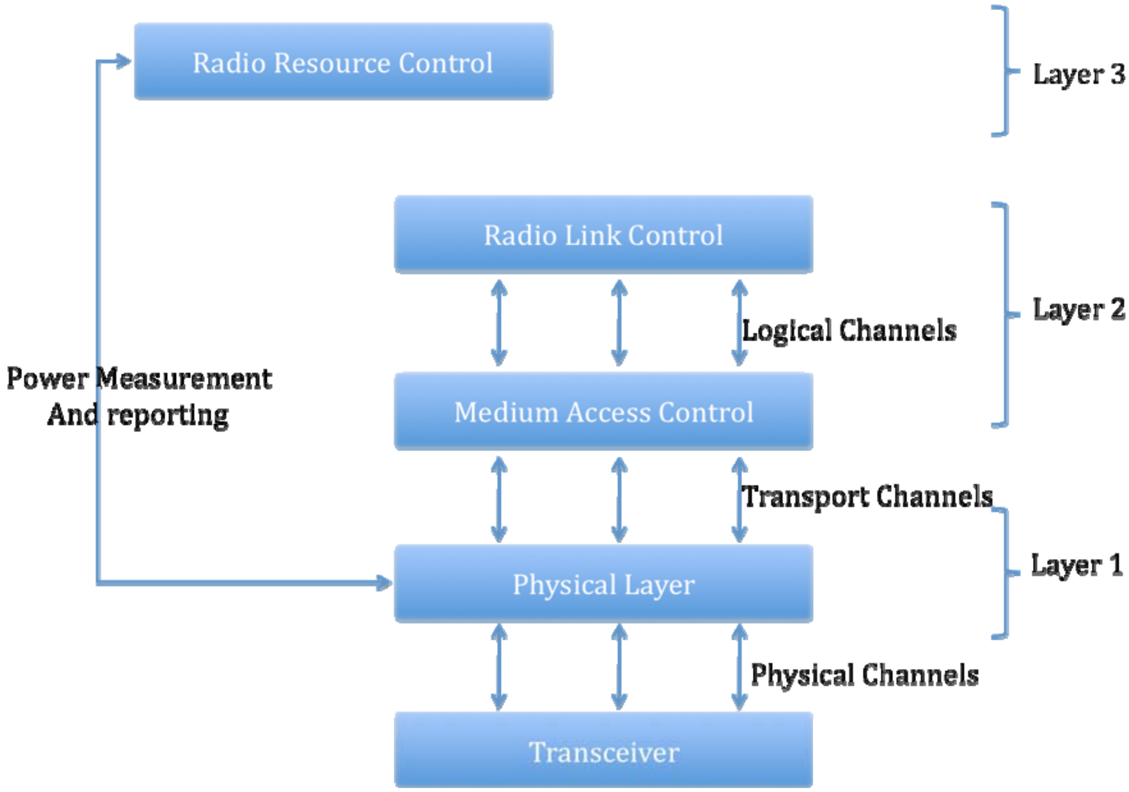

Figure 6: LTE Radio Channels

LTE Physical Channels: Downlink Channels

- Physical Broadcast Channel: **PBCH**
- Physical Control Format Indicator Format: **PCFICH**
  - This informs UE about number of OFDM symbols used for the PDCCH's.
  - This is transmitted in downlink.
- Physical Downlink Control Channel: **PDCCH**
  - Informs UE about resource allocation of PCH & DL-SCH and HARQ information related to DL-SCH
  - PCH: Paging channel. DL-SCH: Downlink Synchronization Channel.
- Physical Hybrid ARQ Indicator Channel: **PHICH**
  - Carries Hybrid ARQ Ack/NAK's in response to uplink transmission
- Physical Downlink Shared Channel: **PDSCH**
  - Carries DL-SCH and PCH
- Physical Multicast Channel: **PMCH**
  - Carries Multicast channel (MCH).

Uplink Channels

- Physical Uplink Control Channel: **PUCCH**
  - Carries HARQ ACK/NAK in response to downlink transmission
  - Carries scheduling request.
- Physical Uplink Share Channel: **PUSCH**

  - Carries UL-SCH
- Physical Random Access channel: **PRACH**
  - Carries random access preamble.

LTE Transport Channels

The physical layer offers information transfer services to MAC and higher layers. The physical layer transport services are described by **how and with characteristics** data is transferred over the radio interface. (What kind of data is transferred is dealt in logical channels)

Downlink Transport Channels:

- Broadcast channel: **BCH**
  - This channel is used to broadcast info in the entire cell.
  - It has fixed and pre defined Transport Format (not aware of TF's yet)
- Downlink Shared Channel: **DL-SCH**
  - This channel is used for transmitting downlink data.
  - It supports HARQ, dynamic link adaptation.
  - It I can be used to broadcast data in entire cell.
  - It supports UE discontinuous reception (DRX) to enable power saving in UE.
  - It also supports MBMS transmission.
- Paging Channel: **PCH**
  - Used for transmitting paging information.
  - PCH supports DRX so that UE can sleep and wakeup to receive PCH in specific time intervals.
- Multicast Channel: **MCH**
  - This channel is used to support MBMS.

Uplink Transport Channels:

- Uplink Shared Channel: **UL-SCH**
  - Supports HARQ
  - Counter part of DL-SCH
- Random Access Channel: **RACH**

Transport and Physical Channel Mapping

Downlink Channels:

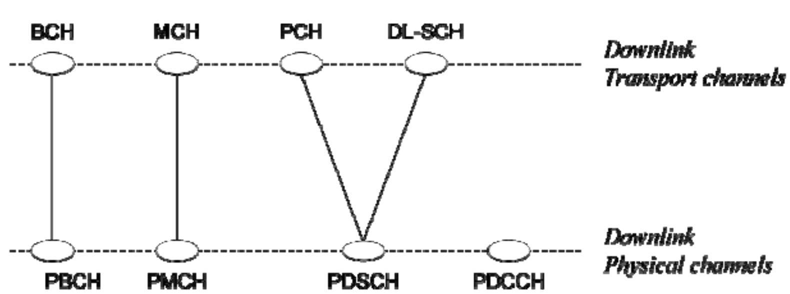

Figure 7: LTE Transport and Physical Channel Mapping in Downlink

Uplink Channels:

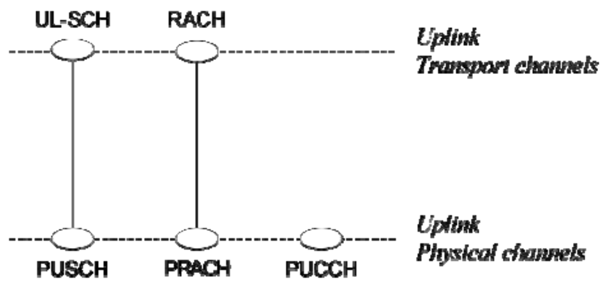

Figure 8: LTE Transport and Physical Channel Mapping in Uplink

LTE Uu Layer 2:

LTE layer 2 is split in MAC, RLC and PDCP.

Layer 2 Structure of downlink

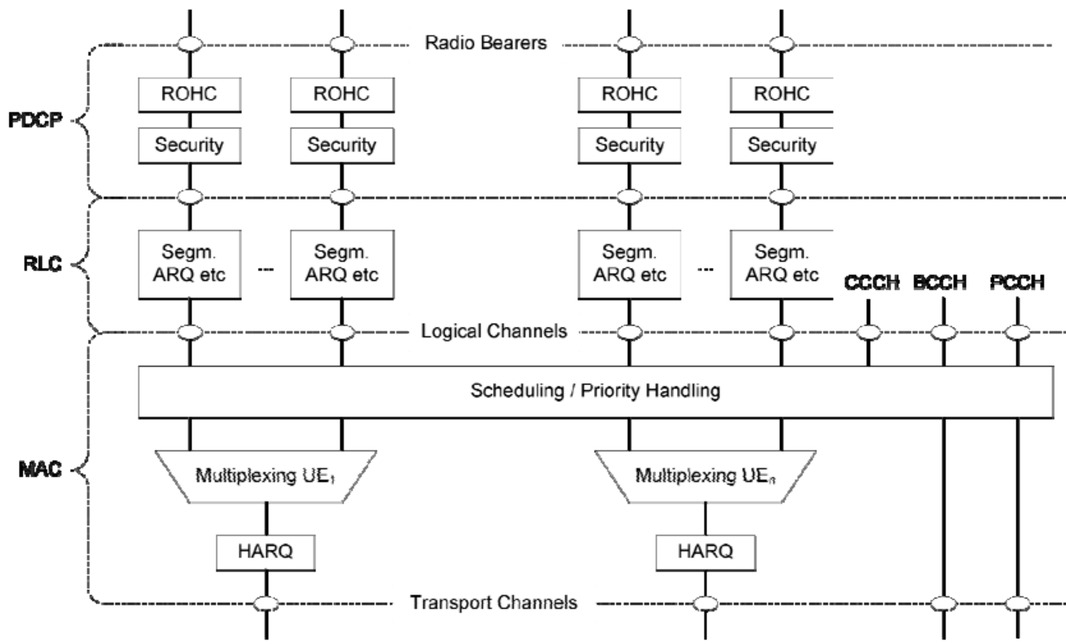

Figure 9: LTE Uu Layer 2 Downlink

Layer 2 Uplink Structure

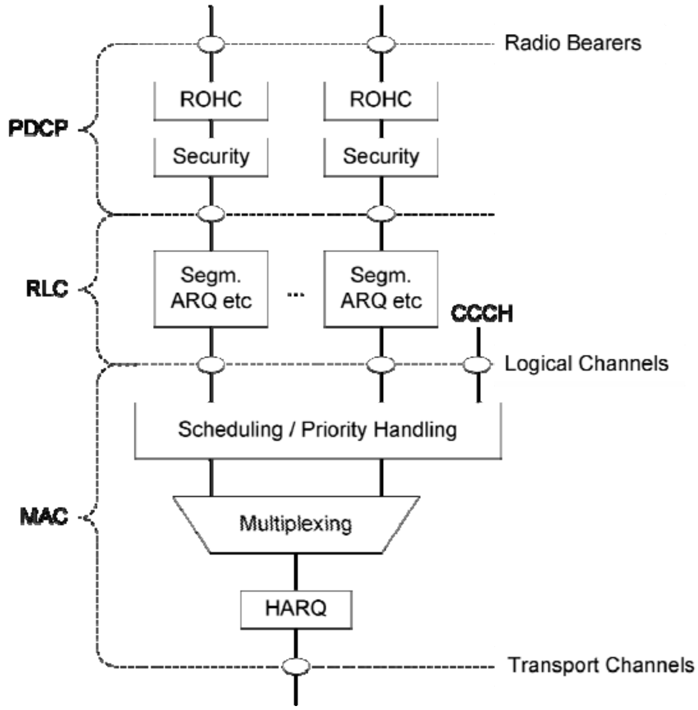

Figure 10: LTE Uu Layer 2 Uplink

The communication between two sub-layers is marked with circles. These are called Service Access Points (SAP). SAP between Physical layer and MAC sub-layer provides the transport channels. The SPA's between MAC and RLC provide logical channels. Multiplexing several logical channels (i.e radio bearers) to same transport channel is preformed by MAC sub-layer.

Logical Channels:

MAC sub layer offers different kind of data services to RLC inform of logical channels. Logical channels define **what type of data** is transferred between UE and eNB. Logical Channels are classified into **Control Channels** (for control plane information transfer) and **Traffic Channels** (for transfer of user plane data)

Control Channels:

- Broadcast Control Channel: **BCCCH**
    - This channel is used of broadcasting system control information.
    - This is downlink channel.
- Paging Control Channel: **PCCH**
    - Downlink channel.
    - Transfers paging information and system information change notification.
    - This channel is used for paging when the network does not know the location cell of the UE.
- Common Control Channel: **CCCH**

    - Channel of transmitting control information between UE and network.
    - This channel is used for UE's having no RRC connection with the network.
- Multicast Control Channel: **MCCH**
    - Point to Multi point downlink channel used for transmitting MBMS control information from the network to UE.
    - This channel is only used by UE's that receive MBMS.
- Dedicated Control Channel: **DCCH**
    - A point-to-point bi directional channel that transmits dedicated control information between a UE and the network.
    - Used by UE's having an RRC connection.

Traffic Channels:

- Dedicated Traffic Channel: **DTCH**
    - Uplink and downlink channel.
    - Point-to-point channel dedicated to one UE for transfer of user data.
- Multicast Traffic Channel: **MTCH**
    - Point-to-Multipoint downlink channel for transmitting traffic data from network to UE.

Mapping logical and transport channels:

Uplink

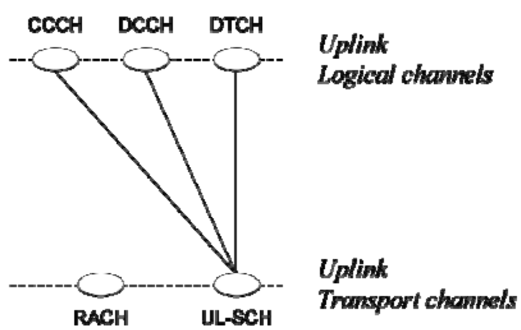

Figure 11: LTE Logical and Transport Channel Mapping in Uplink

Downlink

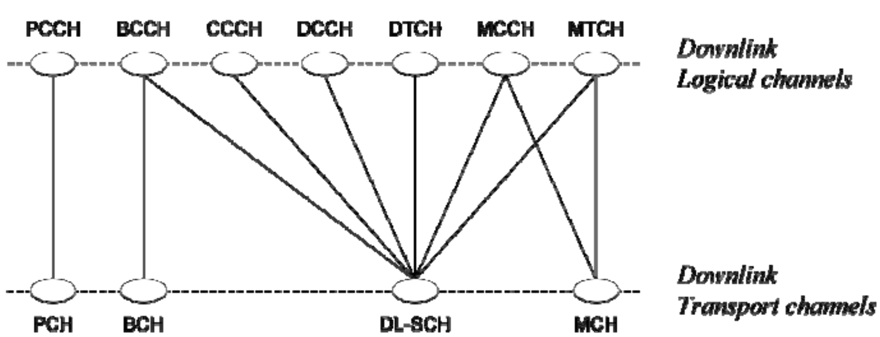

Figure 12: LTE Logical and Transport Channel Mapping in Downlink

LTE Cell Search:

When the UE is powered up it needs a network to attach itself. The first towards it is Cell search. Cell Search is a procedure by which a terminal can find a potential cell to attach to.

As a part of cell search procedure the terminal obtains the identity of cell and estimates the frame timing of the identified cell. LTE supports 510 different cell identifiers divided into 170-cell identity group of 3 identities each.

LTE provides two signals in downlink;

- Primary Synchronization Signal
- Secondary Synchronization signal.

In first step of cell search, UE uses primary sync signal to find the timing on 5 ms basis. This signal is transmitted twice in each frame (as LTE frame is of 10 ms).

Terminal can use this signal to identify the frame timing with a 5 ms ambiguity. Here terminal locks it local oscillator frequency to the base station carrier frequency. The terminal also finds an identity within the cell. It also obtains partial knowledge about reference signal structure.

In the next step terminal detects the cell identity group and determines the frame timing using secondary synchronization signal.

Random Access Procedure

To transmit data terminal needs a connection setup with the network. So a terminal has to ask for one. Random access procedure is used to establish uplink and unique terminal ID.

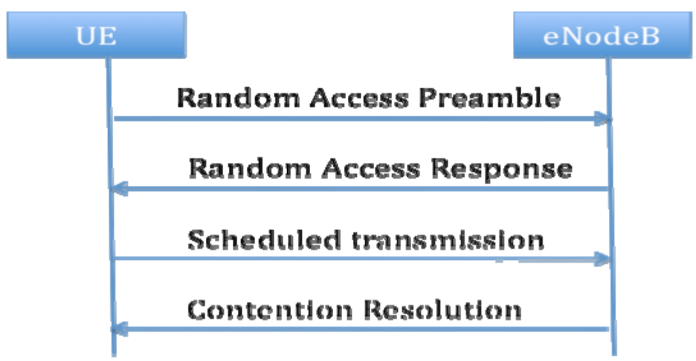

Figure 13: LTE Random Access procedure

- First step consists of UE transmitting a Random Access Preamble allowing the eNB to estimate the transmission timing of the terminal.
- In the next step network transmits a Random Access Response. This consists of timing advance command to adjust the terminal transmit timing, based on timing measurement received in the first step. In addition to establish uplink synchronization this step also assigns uplink resources to be used in next

steps to the terminal. Temporary identity is also assigned to UE for further communication with the network. This response is sent on PDCCH.

- Third step consists of transmission of mobile terminal identity to the network using UL-SCH. The exact content of this signal depends on the state so of terminal whether the network previously knows it or not. (RRC_IDLE)
- 4th step consists of contention resolution message from network to terminal on DL-SCH.

RRC Procedures

There are two RRC states in LTE. RRC_Idle & RRC_Connected.

In RRC_Idle there is no signaling radio bearer established, that is there is no RRC connection.

In RRC_Connected there is a signaling radio bearer established

Signaling Radio Bearers (SRB) are defined as Radio bearers that are used only to transmit RRC and NAS messages. SRB's are classified into

Signaling Radio Bearer 0: SRB0: RRC message using CCCH logical channel.

Signaling Radio Bearer 1: SRB1: is for transmitting NAS messages over DCCH logical channel.

Signaling Radio Bearer 2: SRB2: is for high priority RRC messages. Transmitted over DCCH logical channel.

RRC Procedures:

- Paging
  - To transmit paging info/system info to UE in RRC_IDLE state.
- RRC Connection Establishment
  - The purpose is establishing SRB1.
  - This procedure is initiated by UE when upper layers requests of a signaling connection when UE is in RRC_IDLE mode.
- RRC Connection Reconfiguration
  - The purpose is to establish/modify/release radio bearers.
  - Also to perform handovers
  - Network initiated procedure
- RRC Connection Re-Establishment
  - To re-establish RRC connection which involves SRB1 resumption and reactivation.
- Initial Security Activation
  - Activate security upon RRC establishment.
  - eNB initiated procedure.
- RRC release procedure.

LTE Bearers & QoS

Bearer is the one that carries some information. There are three kinds of bearers in LTE. Radio Bearers, S1 Bearers and EPS Bearers.

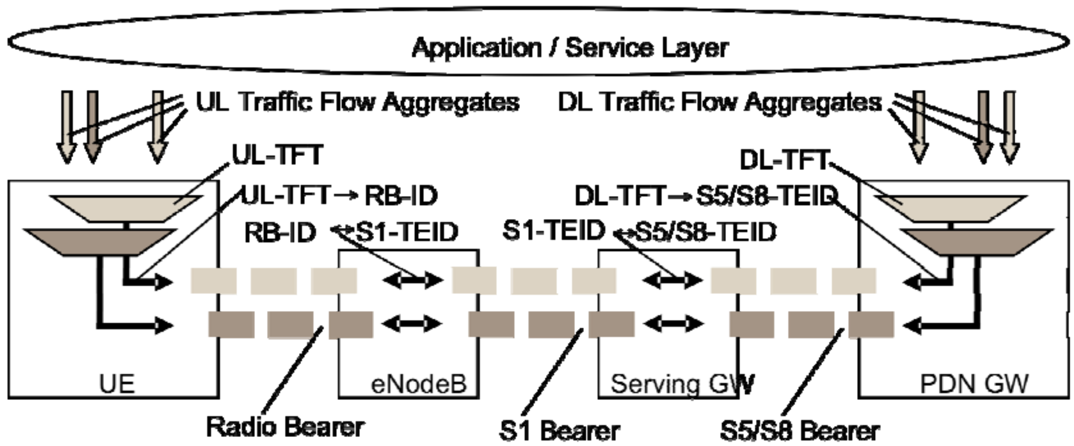

Figure 14: LTE Random Access procedure

Radio bearers carry information on radio interface while S1 bearers exist between eNB and MME/SGW. EPS bearers are between MME and SGW (and between SGW and PGW). The above figure shows the bearers with respect to data plane. There is a one to one mapping between Radio, S1 and EPS bearers.

Radio bearers are established using RRC protocol. The same can be found in above chapters.

For EUTRAN to access EPS, EPS bearers provide the connectivity services.

There is a important concept pertaining to EPS bearers, TFT. Traffic Flow Template (TFT) is used to discriminate between different payloads. A TFT uses IP header, such as IP address or Port numbers etc, to distinguish between payloads. Each TFT is mapped to a QoS and all the data that mapped to this TFT receives the same QoS treatment.

One EPS bearer is established when UE connects to PDN and remains throughout the lifetime of the connection. It is called as default bearer. Default bearer provides always on IP connectivity to the network. Any additional EPS bearer is called a dedicated bearer. Each dedicated bearer is associated with a TFT and each TFT has a QoS tagged to it. So a dedicated bearer is always associated with a particular QoS value. Uplink TFT is used to map uplink traffic to a particular QoS while downlink TFT is used to map downlink traffic to a QoS. Uplink QoS mapping is done at eNB while downlink QoS mapping can be done at SGW or PGW.

An EPS bearer is referred to as a GBR bearer if dedicated network resources related to a Guaranteed Bit Rate (GBR) value that is associated with the EPS bearer are permanently allocated at bearer establishment/modification. Otherwise, an EPS bearer is referred to as a Non-GBR bearer. A dedicated bearer can either be a GBR or

Non GBR bearer but a default bearer is always a Non GBR bearer.

Bearer Level QoS: -

The EPS bearer QoS profile includes the parameters **QCI, ARP, GBR and MBR**, described in this post. Each EPS bearer (GBR and Non-GBR) is associated with the following bearer level QoS parameters:

- **QoS Class Identifier (QCI);**

- **Allocation and Retention Priority (ARP).**

A **QCI** is a scalar that is used as a reference to access node-specific parameters that control bearer level packet forwarding treatment (e.g. scheduling weights, admission thresholds, queue management thresholds, link layer protocol configuration, etc.), and that have been pre-configured by the operator owning the access node (e.g. eNodeB).

The **ARP** shall contain information about the priority level, the pre-emption capability (flag) and the pre-emption vulnerability (flag). The primary purpose of ARP is to decide whether a bearer establishment / modification request can be accepted or needs to be rejected in case of resource limitations (typically available radio capacity in case of GBR bearers).

Each GBR bearer is additionally associated with the following bearer level QoS parameters:

- **Guaranteed Bit Rate (GBR);**

- **Maximum Bit Rate (MBR).**

The **GBR** denotes the bit rate that can be expected to be provided by a GBR bearer. The **MBR** limits the bit rate that can be expected to be provided by a GBR bearer (e.g. excess traffic may get discarded by a rate shaping function).

Each APN access, by a UE, is associated with the following QoS parameter:

- **per APN Aggregate Maximum Bit Rate (APN-AMBR).**

The **APN-AMBR** is a subscription parameter stored per APN in the HSS. It limits the aggregate bit rate that can be expected to be provided across all Non-GBR bearers and across all PDN connections of the same APN (e.g. excess traffic may get discarded by a rate shaping function). Each of those Non-GBR bearers could potentially utilize the entire APN-AMBR, e.g. when the other Non-GBR bearers do not carry any traffic. GBR bearers are outside the scope of APN-AMBR. The P-GW enforces the APN-AMBR in downlink. Enforcement of APN-AMBR in uplink is done in the UE and additionally in the P-GW.

Each UE in state EMM-REGISTERED is associated with the following bearer aggregate level QoS parameter:

- **per UE Aggregate Maximum Bit Rate (UE-AMBR**).

The **UE□AMBR** is limited by a subscription parameter stored in the HSS. The MME shall set the UE□AMBR to the sum of the APN□AMBR of all active APN's up to the value of the subscribed UE□AMBR. The UE□AMBR limits the aggregate bit rate that can be expected to be provided across all Non□GBR bearers of a UE (e.g. excess traffic may get discarded by a rate shaping function). Each of those Non□GBR bearers could potentially utilize the entire UE□AMBR, e.g. when the other Non□GBR bearers do not carry any traffic. GBR bearers are outside the scope of UE AMBR. The E□UTRAN enforces the UE□AMBR in uplink and downlink.

The ARP of the default bearer should be set appropriately to minimize the risk of unnecessary release of the default bearer.

LTE Control Plane and User Plane Procedures

EUTRAN Initial Attach & Default Bearer Establishment: -

When the UE is switched on, it has to be attached to a network. An Uplink and downlink frequency is allocated to the UE so that I can communicate to the network. Along with the frequency allocation UE is also assigned an IP address so that I can communicate to the packet network world. The procedure for the same is described below.

Note: - Security procedures are ignored. PMIP based S5 interface is used.

- The initial procedure, such as cell search, is explained above. Paging message is sent by network to UE to inform about system. UE in RRC_IDLE and RRC_CONNECTED state can understand the paging info.
- If UE wants to communicate to the eNB, it uses a RRC connection. So first a RRC attach procedure takes place. UE in ECM_IDLE State sends out RRC_CONNECTION_REQUEST to eNB. If eNB accepts the request it sends RRC_CONNECTION_ACCEPT to UE. Upon reception of this message the RRC connection is established. Now to complete the procedure UE sends RRC_CONNECTION_COMPLETE message along with a NAS message. NAS is present over in Layer 3 of UE.
- For EUTRAN initial attach the NAS message is **PDN Connectivity request**. This message is used by UE to inform network that it needs a bearer to transmit data.
- Upon reception of RRC_CONNECTION_COMPLETE along with NAS message, eNB extracts the NAS message, places it in S1AP message (**Initial UE message**) and passes it to MME.
- MME reads this NAS message and understands that UE needs a default bearer and an IP address. MME creates a GTP message **Create Session Request** and forwards it to SGW. At this point MME assigns and EPS bearer ID to the bearer.

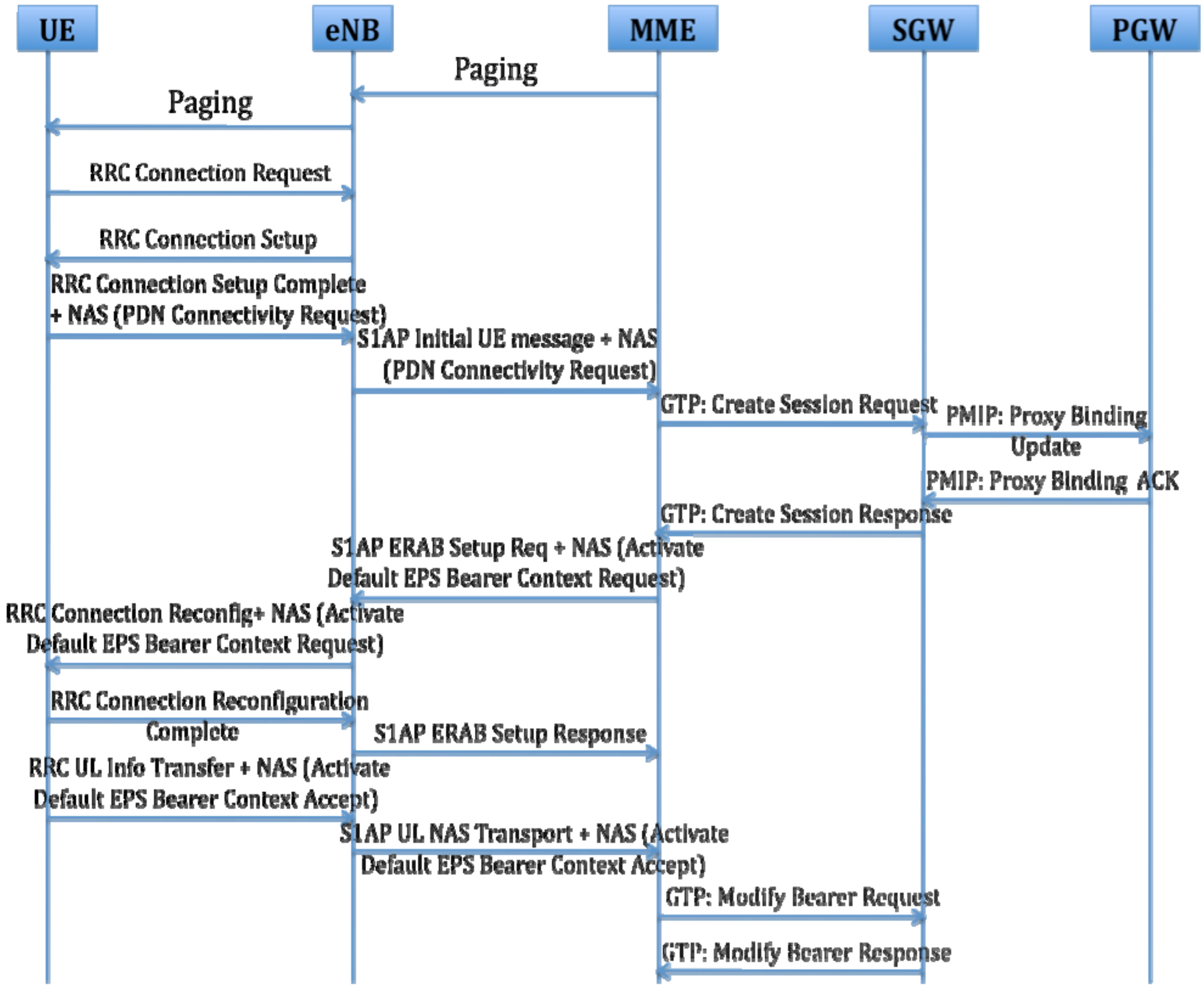

Figure 15: LTE EUTRAN Initial Attach

- Considering PMIP based S5 interface, SGW sends **Proxy binding update** message to PGW. SGW stores the EBI value and maps it to the PMIP based bearer.
- PGW on receiving the message responds with Proxy binding acknowledgment. This message consists an IP address to be sent the UE.
- Once SGW receives the ack, it creates a GTP **Create Session response message** with SGW FTEID for user plane, EBI, and Bearer level QoS values. SGW communicates to PCRF to pull the QOS values.
- MME receives the session response. It takes the SGW FTEID, EBI and QoS values and places it in **Activate Default Bearer Context Request** NAS message and sends it to eNB in **S1AP ERAB setup request message**. At this point EPS bearer is established and a Radio Bearer has to be established so that UE can start transmitting the data.
- ERAB (EUTRAN Radio Access Bearers) Setup Request just does the same. eNB receives the S1AP message, pulls out the NAS message places it in a

RRC_RECONFIGURATION_REQUEST and sends it to UE. Also eNB reads the QoS values and SGW FTEID for uplink data transmission.

- UE responds with **RRC_RECONFIGURATION_COMPLETE** message. It also starts procession the NAS message. Once the NAS layer approves the default bearer establishment the same is informed to eNB in a RRC UL Info Transfer message. NAS message Activate Default Bearer Context Request Accept message is attached to the RRC message. At this point UE knows the Bearer ID, an IP address and corresponding QoS values.
- eNB informs that UE accepted the default bearer to MME in **a S1-AP UL NAS Transport message,** of-course NAS message is also attached to it. Also eNB indicates its FTEID for user plane communication to MME.
- MME now has to indicate the eNB user plane info to SGW. It does the same in GTP message Modify bearer request. SGW learns the eNB user plane info from it. After this the user plane data shall flow on the default bearer.

UE Requested Dedicated Bearer Procedure: -

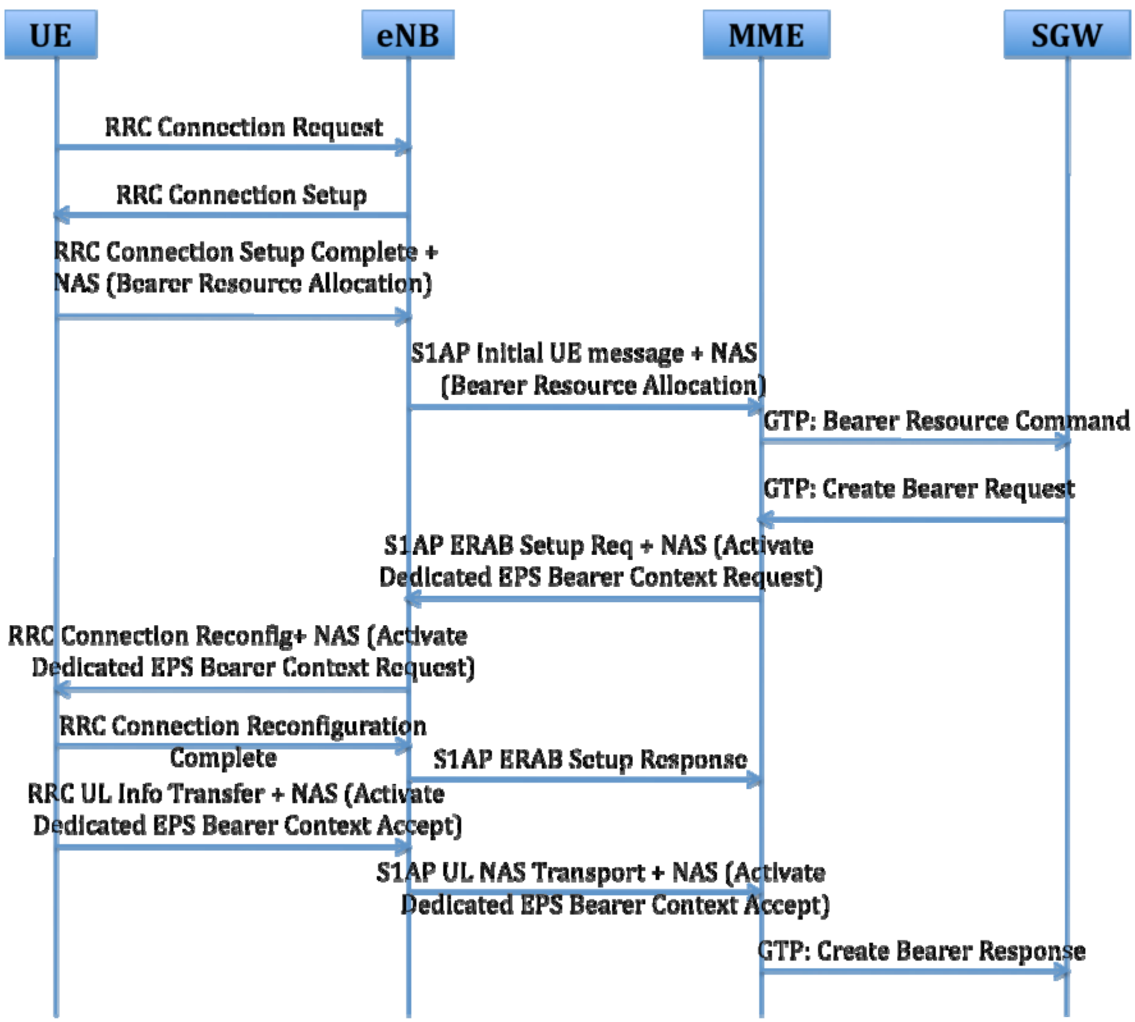

Figure 16: LTE Dedicated Bearer procedure

A dedicated bearer is request by UE to transmit data with a particular QoS. A default bearer is always a non-guaranteed bit rate bearer. If UE wants to have a reliable service for some application it can always request for a dedicated bearer provided network supports it.

- UE requests for dedicated bearer using **Bearer resource allocation** NAS message. It sends Traffic flow template and LBI in the NAS message. Also the NAS message includes a transaction identifier to identify the transaction (Procedure Transaction Identifier). TFT includes the information about the type of traffic. Typically TFT indicates IP header information such as an IP address or TCP/UDP port numbers etc.
- This NAS message is communicated by eNB to MME in S1AP Initial UE message.
- MME upon reception of Bearer resource allocation message creates a GTP Bearer resource command and sends it SGW. Bearer resource command typically consists of PTI, LBI, TFT and QoS values.
- SGW contacts the PCRF and pulls out the QoS values for the TFT. The QoS values can be the one that UE has requested for or they can be different. It depends on the subscription. SGW creates a GTP **Create Bearer Request** message with LBI, new QoS values, PTI and SGW FTEID for user plane and sends it to MME.
- Upon reception of Create bearer request, MME creates a NAS message **Activate Dedicate Bearer Context Request**, places it in S1AP ERAB setup request and sends it eNB. This NAS includes LBI, EBI for dedicated bearer (MME assigns this value), QoS values, PTI and SGW user plane FTEID.
- eNB reads the NAS message, stores the SGW user plane FTEID and QoS values. Later it forwards the NAS message to UE in RRC Re-configuration Request.
- If UE accepts the new QoS values and EBI, it sends **Activate dedicated bearer request accept** NAS message to eNB in RRC UL Info Transfer message.
- eNB forwards the NAS message along with its user plane FTEID to MME.
- MME sends the eNB user plane FTEID and EBI to SGW in **Create Bearer response message.**

LTE Handovers

X2 Based handover

The first handover scenario is X2 based, which we most often see. As mentioned above X2 is the interface between two eNB's and X2-AP is the protocols used for communication over it. Handover takes place when the eNB detects that UE can no longer be served by it because of the power constraints. There are several other reasons for handover which are not mentioned here

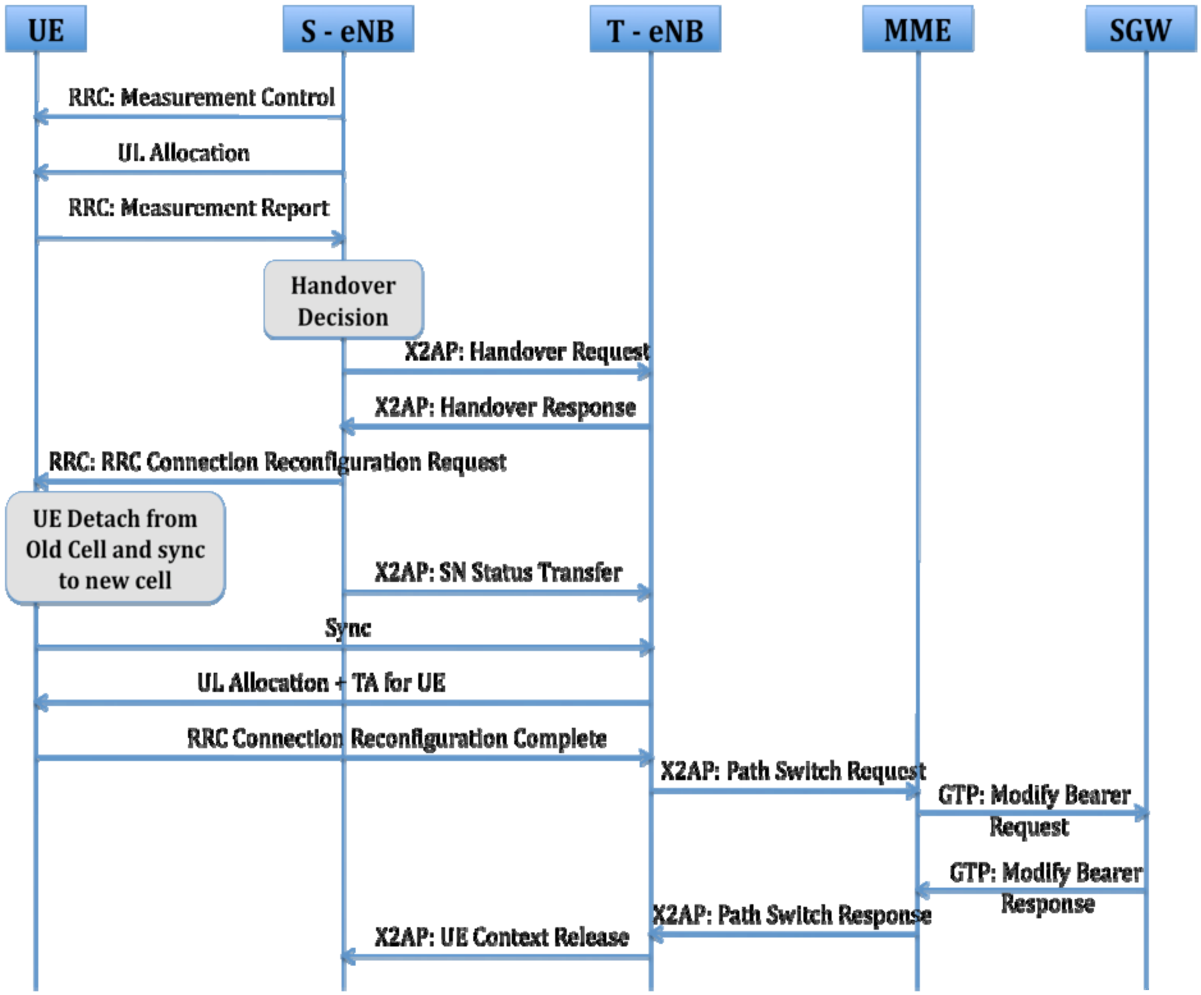

Figure 17: LTE X2 Based Handover

- Source eNB keeps asking UE for the power measurements in a **RRC measurement control** message.
- UE responds with the measurements in **RRC Measurement Report**. The details of these messages can be found RRC protocol specification.
- Based on the measurement report source eNB takes the decision to handover or not. If the source eNB realizes that other eNB can serve better, then it shall start the handover procedure.
- If the handover decision has been taken, then source eNB sends an X2-AP message Handover Request to the target eNB.
- **The Handover Request** may consist of UE Context IE and E-RAB's to be setup. UE context IE typically consists of MME information, UE security capabilities etc. E-RAB's to be setup has ERAB ID, QoS, RRC contexts etc. Multiple E-RAB's pertaining to multiple EPS bearers can be sent in this message.
- If send the **Handover Request Ack** to source eNB. The Ack includes the ERAB's that have been accepted by the target eNB.
- Upon reception of Handover Request Ack from target eNB, source eNB sends **RRC Connection Reconfiguration** message to UE, to indicate that handover

should take place. Source eNB sends **SN Status Transfer message** to target eNB to indicate PDCP and HFN status. At this moment, UE detaches from source eNB and syncs with target eNB.

- UE completes the RRC reconfiguration by sending RRC Connection **Reconfiguration Complete message** to target eNB. And also UE starts transmitting the data towards target eNB. This data is buffered at target eNB until the EPS Bearers have been modified.
- Next, target eNB sends an **S1-AP patch Switch Request** message to MME indicating that handover has taken place. This message includes the ERAB's that have been accepted by the eNB.
- MME now has to modify the EPS bearers, corresponding to ERAB's accepted. MME sends **Modify bearer request** to SGW, which includes all EPS bearers that are to be modified and also the target eNB's FTEID.
- SGW, if request is accepted, sends the response along with the S1-U SGW FTEID, if they are modified.
- MME upon reception of Modify Bearer Response sends Path Switch Request Ack to target eNB indicating the successful modification of EPS bearers. Target eNB now asks the source eNB to release all contexts related to the UE.
- If PMIP based S5/S8 interface is considered, then there will be no message over that same interface for this handover scenario.

S1 Based Handover

This type of handover takes place when there is no X2 connectivity between source eNB and target eNB. Considering the way networks are deployed if there is no X2 connection between eNB's, it means that both eNB's are served by different MME's. Just to make the scenario complete, even SGW's are separated. So now we have a UE moving from source eNB to target eNB. Source eNB is served by source MME and source SGW while target eNB is served by target MME and target SGW. In this scenario we assume that source and target MME's can communicate over S10 interface. Since all the handover decisions are taking place on S1 interface, its called as S1 based handover.

- Source eNB takes a decision to handover the UE to target eNB. I realizes that it doesn't have a connectivity with the target eNB, so S1 based handover is chosen for this purpose.
- Source eNB sends **S1AP message Handover Required** to source MME, indicated S1 based handover and the cause for the handover. This message includes MME UE S1 AP and eNB UE S1 AP ID. These ID's are used to identify the UE uniquely in a given eNB and MME.
- Source MME sends **GTP message Forward Relocation Request** to target MME over S10 interface indicating S1 based handover. This message includes all the details that were sent when the UE was attached to the EUTRAN. This message also includes all the EPS bearer contexts that were established for UE.

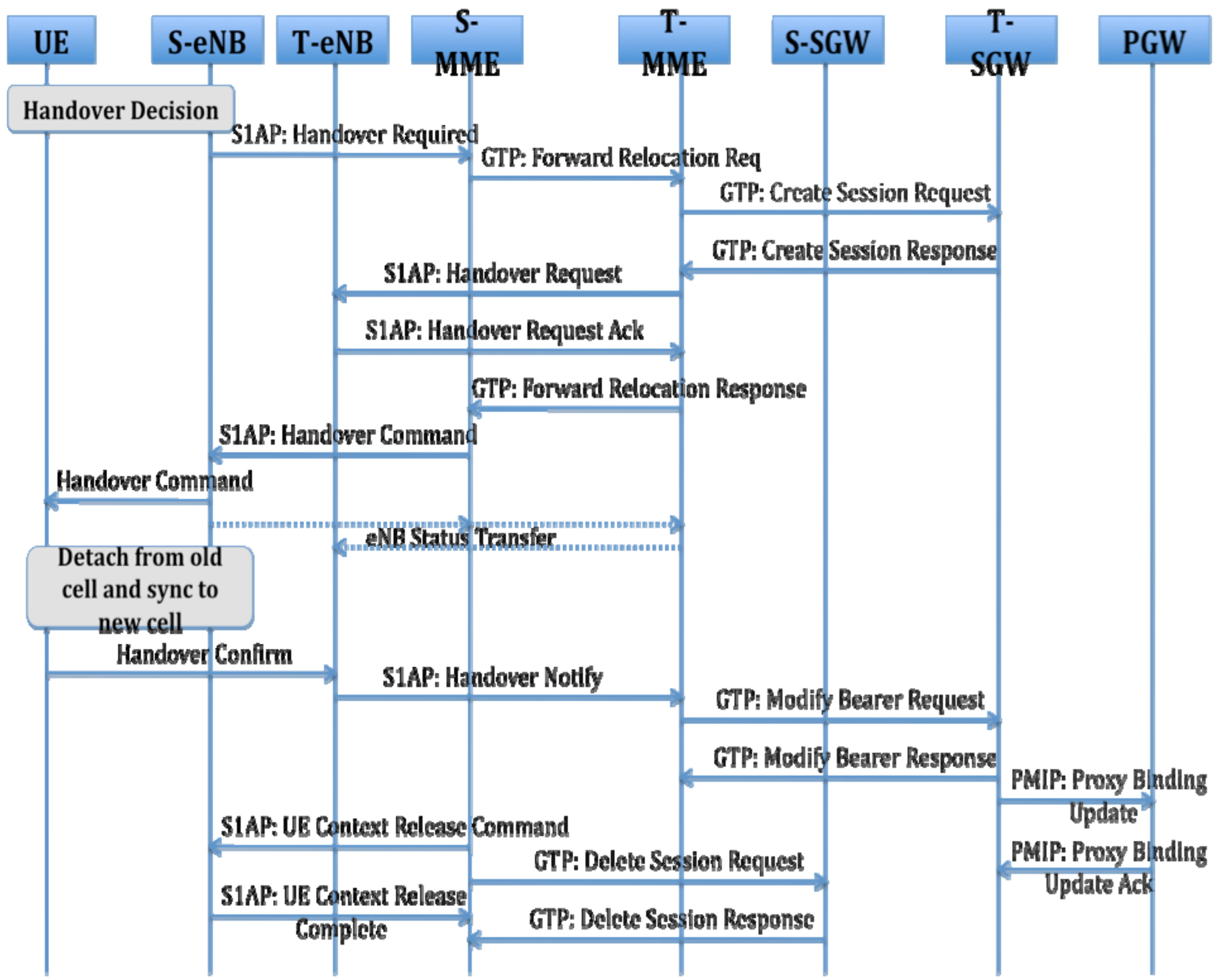

Figure 18: LTE S1 Based Handover

- As the same SGW is not serving both source and target MME's, target MME sends a **GTP message Create Session Request** to target SGW. This message includes all the EPS bearer contexts established and also all the information that was send during initial attach. (QoS, APN, PDN type etc). Target SGW, if accepted, sends a **Create Session Response** to target MME indicating success.
- Target MME then sends **S1AP message Handover Request** to target eNB. This message includes the E-RAB contexts that are to be established along with new MME UE S1AP ID. The handover type is set to S1 based handover. Target MME responds to this message **Handover Request Ack.** This ack includes the ERAB contexts admitted.
- In the next step, target MME sends **GTP message Forward Relocation Response** to source MME indicating that handover request has been accepted. This response also includes all the EPS bearers that have been admitted.
- Once the above response is received by source MME, it sends **S1AP message Handover Command** to source eNB asking it to handover the UE to target

eNB. Source eNB forwards the same to UE. After this UE breaks from old cell and attaches to new cell.

- Target eNB informs that UE has attached to it by sending **Handover Notify** to target MME over S1 interface.
- Target MME sends **GTP message Modify Bearer Request** to target SGW indicating the new eNB FTEID. Target accepts the same.
- Source MME asks source eNB to delete all the UE contexts. Also it sends delete session request to source SGW asking it to delete all the EPS bearers for that UE.

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