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Research Article

Study of Long Term Evolution Network, its Architecture along with its Interfaces

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Abstract

In the field of mobile communication, Long Term Evolution Network is the emerging network. The main features of LTE are high peak data transmission rate, spectrum usage flexibility, low latency times and capacity per cell is higher. Its architecture is designed in such a way that it deliver the services according to the need of the customers, like higher internet data rate (upto 100 mbps downlink and upto 75 mbps uplink), video conferencing, etc. For providing services, the network should satisfy the following criterion - open interfaces as against closed technologies of the past, reduced cost per bit, increased service provisioning by lowering the cost and increasing efficiency and experience, higher spectral efficiency, power consumption efficiency, scalable and flexible usage of frequency bands. The aim of this paper is to give an overview of the LTE Network Architecture along with its interfaces.

Keywords: *The User Equipment (UE), The E-UTRAN, The Evolved Packet Core (EPC), Packet Data Network (PDN) Gateway, Serving Gateway (S-GW), Mobility Management Entity (MME)*

1. Long Term Evolution Network Architecture

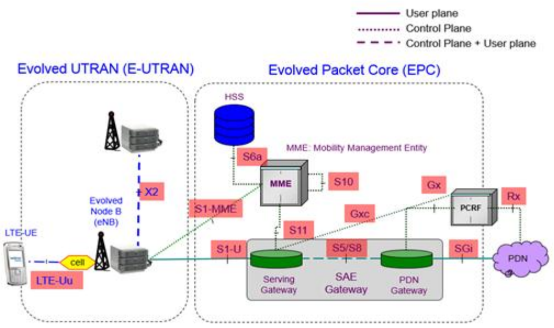

Fig.1 LTE Network Architecture

The network architecture of LTE is comprised of following three main components:

- The User Equipment (UE).
- The Evolved UMTS Terrestrial Radio Access Network (E-UTRAN).
- The Evolved Packet Core (EPC).

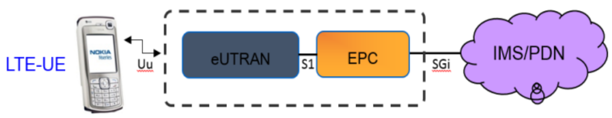

Fig. 2 LTE Network Components

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The evolved packet core communicates with packet data networks in the outside world such as the internet, private corporate networks or the IP multimedia subsystem. The interfaces between the different parts of the system are denoted Uu, S1 and SGi as shown above.

A. The User Equipment (UE)

The internal architecture of the user equipment for LTE is identical to the one used by UMTS and GSM which is actually a Mobile Equipment (ME). The mobile equipment comprised of the following important modules:

- Mobile Termination (MT): This handles all the communication functions.
- Terminal Equipment (TE): This terminates the data streams.
- Universal Integrated Circuit Card (UICC): This is also known as the SIM card for LTE equipments. It runs an application known as the Universal Subscriber Identity Module (USIM).

A USIM stores user-specific data very similar to 3G SIM card. This keeps information about the user's phone number, home network identity and security keys etc.

B. The E-UTRAN

The architecture of evolved UMTS Terrestrial Radio Access Network (E-UTRAN) has been illustrated below.

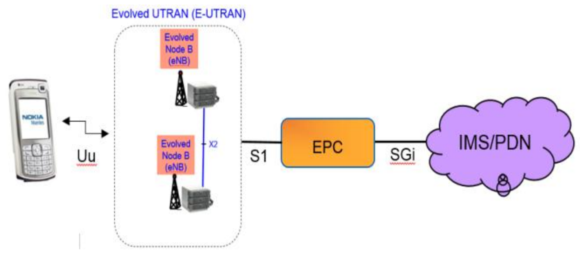

Fig. 3 E-UTRAN

The E-UTRAN handles the radio communications between the mobile and the evolved packet core and just has one component, the evolved base stations, called eNodeB or eNB. Each eNB is a base station that controls the mobiles in one or more cells. The base station that is communicating with a mobile is known as its serving eNB.

LTE Mobile communicates with just one base station and one cell at a time and there are following two main functions supported by eNB:

- The eBN sends and receives radio transmissions to all the mobiles using the analogue and digital signal processing functions of the LTE air interface.
- The eNB controls the low-level operation of all its mobiles, by sending them signalling messages such as handover commands.

Each eNB connects with the EPC by means of the S1 interface and it can also be connected to nearby base stations by the X2 interface, which is mainly used for signalling and packet forwarding during handover.

A home eNB (HeNB) is a base station that has been purchased by a user to provide femtocell coverage within the home. A home eNB belongs to a closed subscriber group (CSG) and can only be accessed by mobiles with a USIM that also belongs to the closed subscriber group.

C. The Evolved Packet Core (EPC) (The core network)

The architecture of Evolved Packet Core (EPC) has been illustrated below. There are few more components which have not been shown in the diagram to keep it simple. These components are like the Earthquake and Tsunami Warning System (ETWS), the Equipment Identity Register (EIR) and Policy Control and Charging Rules Function (PCRF).

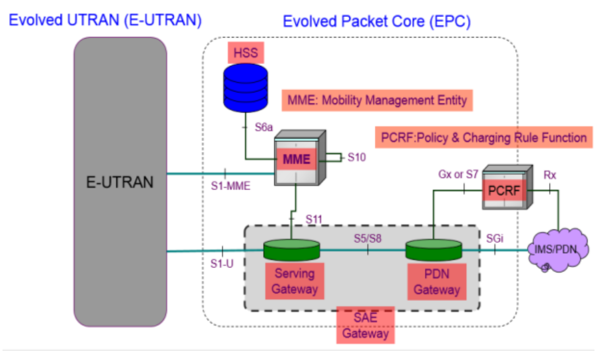

Fig. 4 EPC

Below is a brief description of each of the components shown in the above architecture.

1. Home Subscriber Server (HSS)

HSS component has been carried forward from UMTS and GSM and is a central database that contains information about all the network operator's subscribers.

2. Packet Data Network (PDN) Gateway

It communicates with the outside world ie. packet data networks PDN, using SGi interface. Each packet data network is identified by an access point name (APN). The PDN gateway has the same role as the GPRS support node (GGSN) and the serving GPRS support node (SGSN) with UMTS and GSM.

3. Serving Gateway (S-GW)

The SGW terminates the downlink data path for UEs in LTE Idle state and initiates paging (to MME) when downlink data arrive for the UE. It manages and stores UE contexts (user IP-address, EPC bearer QoS, eNB/PGW IP-addresses and TEIDs). The SGW connects to E-UTRAN (eNB) via the S1-U interface using the GTP-U protocol.

During, and after, a handover to GERAN/UTRAN the SGW acts as User Plane anchor, forwarding downlink user IP-packets to the SGSN via the S4-interface (GTP-U). In case the UTRAN system has a ‘Direct Tunnel’ architecture (SGSN eliminated from the User Plane) this forwarding takes place over the S12-interface (GTP-U).

4. Mobility Management Entity (MME)

It controls the high-level operation of the mobile by means of signalling messages and Home Subscriber Server (HSS). The MME manages and stores contexts (i.e. information lists) relating to UEs in both LTE Idle and LTE Active state. The UE context contains parameters such as: IMSI, S-TMSI, current Tracking Area, security keys, UE capabilities and currently assigned EPC bearer QoS. The MME is responsible for handling mobility management procedures such as Paging, Attach/Detach and Tracking Area updates. It handles security procedures such as Authentication and allocation of temporary identities (S-TMSI).

5. Policy Control and Charging Rules Function (PCRF)

It is a component which is not shown in the above diagram but it is responsible for policy control decision-making, as well as for controlling the flow-based charging functionalities in the Policy Control Enforcement Function (PCEF), which resides in the P-GW.

2. LTE Interfaces

a) LTE Radio Interface and the X2 Interface

The radio protocol architecture for LTE can be separated into control plane architecture and user plane. At user plane side, the application creates data packets that are processed by protocols such as TCP, UDP and IP, while in the control plane, the radio resource control (RRC) protocol writes the signalling messages that are exchanged between the base station and the mobile. In both cases, the information is processed by the packet data convergence protocol (PDCP), the radio link control (RLC) protocol and the medium access control (MAC) protocol, before being passed to the physical layer for transmission.

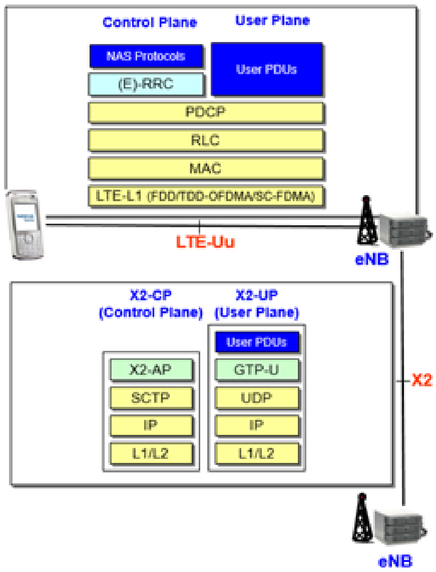

Fig. 5 LTE Radio Interface and the X2 Interface

User Plane

The user plane protocol stack between the e-Node B and UE consists of the following sub-layers.

- Medium Access Control (MAC).
- RLC (radio Link Control)
- PDCP (Packet Data Convergence Protocol)

Medium Access Layer (MAC)

MAC layer is responsible for Mapping between logical channels and transport channels, Multiplexing of MAC SDUs from one or different logical channels onto transport blocks (TB) to be delivered to the physical layer on transport channels, de multiplexing of MAC SDUs from one or different logical channels from transport blocks (TB) delivered from the physical layer on transport channels, Scheduling information reporting, Error correction through HARQ, Priority handling between UEs by means of dynamic scheduling, Priority handling between logical channels of one UE, Logical Channel prioritization.

Radio Link Control (RLC)

RLC operates in 3 modes of operation: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM).

RLC Layer is responsible for transfer of upper layer PDUs, error correction through ARQ (Only for AM data transfer), Concatenation, segmentation and reassembly of RLC SDUs (Only for UM and AM data transfer).

RLC is also responsible for re-segmentation of RLC data PDUs (Only for AM data transfer), reordering of RLC data PDUs (Only for UM and AM data transfer), duplicate detection (Only for UM and AM data transfer), RLC SDU discard (Only for UM and AM data transfer), RLC re-establishment, and protocol error detection (Only for AM data transfer).

Radio Resource Control (RRC)

The main services and functions of the RRC sublayer include broadcast of System Information related to the non-access stratum (NAS), broadcast of System Information related to the access stratum (AS), Paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN, Security functions including key management, establishment, configuration, maintenance and release of point to point Radio Bearers.

Packet Data Convergence Control (PDCP)

PDCP Layer is responsible for Header compression and decompression of IP data, Transfer of data (user plane or control plane), Maintenance of PDCP Sequence Numbers (SNs), In-sequence delivery of upper layer PDUs at reestablishment of lower layers, Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on RLC AM, Ciphering and deciphering of user plane data and control plane data, Integrity protection and integrity verification of control plane data, Timer based discard, duplicate discarding, PDCP is used for SRBs and DRBs mapped on DCCH and DTCH type of logical channels.

Non Access Stratum (NAS) Protocols

The non-access stratum (NAS) protocols form the highest stratum of the control plane between the user equipment (UE) and MME.

NAS protocols support the mobility of the UE and the session management procedures to establish and maintain IP connectivity between the UE and a PDN GW.

X2 Interface

The X2-interface connects the eNBs within E-UTRAN together. The X2interface is an IP-based interface and can therefore be seen as a point to multi-point interface (the eNB may communicate with every other eNB). The Control Plane (CP) instance of the X2-interface (X2-C) uses the *X2 Application Protocol* (X2AP) for control signalling purposes between eNBs. The User Plane (UP) instance of the X2-interface (X2-U) uses the *GPRS Tunnelling Protocol- User plane* (GTP-U) for user data tunnelling between eNBs.

X2 Application Protocol (X2AP)

The X2AP protocol is used for control signalling exchange between eNBs. It supports Common and Dedicated procedures. Common procedures are signalling procedures that do not relate to a specific UE. An example of a Common procedure is Load Indication. Dedicated procedures are signalling procedures that *do* relate to a specific UE. An example of this is Handover. Currently specified X2AP procedures include:

- **Handover -** Initiated by the source eNB by sending a Handover Request message to the target eNB. The target eNB reserves the necessary radio resources and sends a Handover Request Acknowledge message back to the source eNB. The ACK message contains a complete radio interface Handover Command message, to be sent to the UE, and the preferred Target eNB IP-address for data forwarding over X2 during the handover execution phase.
- **Release resource** - After a successful handover, the Target eNB initiates this procedure to inform the Source eNB that it can now stop data forwarding over X2 and release all resources for this UE.
- **Load Indication** - The purpose of the Load Indication procedure is to transfer an uplink 'Interference Overload Indication' between intra-frequency neighboring eNBs for interference coordination purposes. The Overload Indication is sent when the eNB experiences too high interference level on some resource blocks. This procedure is linked to the E-UTRAN Inter-Cell Interference Cancellation (ICIC) function, that allows eNBs to 'agree' on what set of OFDM sub-carriers to use at overlapping cell borders.

Stream Control Transmission Protocol (SCTP)

The Stream Control Transmission Protocol (SCTP) is used to support the exchange of X2 Application Protocol (X2AP) signaling messages between two eNBs. SCTP is a session-oriented protocol providing connection-oriented, error-free, flow-controlled, in-sequence transfer of signaling messages over IP. It is in many respects similar to TCP, but there are some differences. One such difference is that SCTP is *message oriented* while TCP is *byte oriented*. Another difference is that the insequence delivery is optional for SCTP (i.e. it can be 'turned off') while it is always mandatory for TCP.

SCTP makes use of so-called Stream Identifiers to identify a logical signaling connection ('stream') between two network nodes. A single SCTP association per X2-C interface instance is used, with different pairs of Stream Identifiers for X2-C common and dedicated procedures.

A UE specific Context Identity is assigned by the Source eNB (i.e. the one sending a message) and the Target eNB (the one receiving a message) for signaling related to dedicated X2-C procedures. The purpose of the UE Context Identity is to distinguish UE specific X2-C signalling transport bearers from each other. The UE Context Identity is conveyed in all X2AP messages pertaining to the specific UE.

GPRS Tunneling Protocol- User Plane (GTP-U)

This is the same protocol as used in GPRS and UMTS (release 8). The main task of the GTP-U protocol is encapsulation and tunneling of user data packets between network nodes. It is used on the X2-interface for forwarding of packets during handover execution, on the S1-interface (between eNB and SGW) and on a number of additional EPC interfaces. Each user data IP-packet is encapsulated by adding a GTP header. The header contains, among other things, a Tunnel Endpoint Identifier (TEID). The TEID is a locally allocated reference number that uniquely identifies a GTP tunnel in the node that allocated it. Thus, a GTP tunnel has two TEIDs associated with it (one in each 'end').

Transport Layer Protocols

The transport layer uses standard Internet Engineering Task Force (IETF) defined protocols, i.e. UDP/IP running over the selected data link and physical layer protocols. These transport layer protocols are not discussed further in this document.

b) S1-MME & S1-U Interfaces

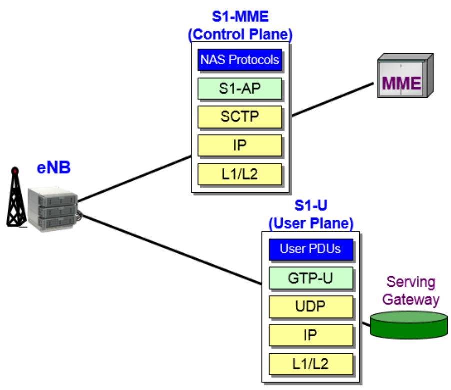

Fig. 6 S1-MME & S1-U Interfaces

The S1-interface connects the Evolved UTRAN with the Evolved Packet Core (EPC). The termination point for the S1-interface on the E-UTRAN side is the eNB, and on the EPC side the Mobility Management Entity (MME) and the Serving Gateway (SGW). The S1-interface is, like the X2interface, an IP-based point to multi-point interface. The CP instance of the S1-interface (S1-MME) uses the *S1 Application Protocol* (S1AP) for control signalling purposes between eNB and MME. The UP instance of the S1-interface (S1-U) uses GTP-U for user data tunnelling between eNB and SGW. The S1AP protocol is described here.

S1 Application Protocol (S1AP)

The S1AP protocol is used for control signalling exchange between eNB and MME. All S1 procedures relate to a specific UE and are in that sense 'dedicated', even though the S1 specification does not use the term. Currently specified S1AP procedures include:

- **Paging** - Enables the MME to page the UE in a specific eNB. The MME initiates the paging procedure by sending a Paging message to each eNB with cells belonging to the Tracking Area(s) in which the UE is registered. The paging response back to the MME is initiated on the NAS layer and is forwarded to MME by the eNB as part of the NAS Signalling Transport procedure.
- **NAS Signalling Transport** - This procedure provides means to transport NAS messages to/from a given UE over the S1-interface. (This procedure is in all respects the same as the UTRAN Direct Transfer procedure).
- **Initial Context Setup** - This procedure supports the establishment of the necessary overall initial UE Context in the eNB to enable fast Idle-to-Active transition. The UE Context includes: SAE Bearer context, security context, roaming restriction, UE capability info, "subscriber type" info etc. The procedure is always initiated from the MME, typically in combination with network registration (Attach or Tracking area update).
- **SAE Bearer Management** - The SAE Bearer management function is responsible for establishing, modifying and releasing E-UTRAN resources for user data transport with a given QoS (once an initial UE context is available in the eNB). The procedure is always initiated from the MME, with the exception of SAE Bearer Release that may be initiated from the eNB.
- **Handover** - Handover preparation and execution signalling over the S1-interface is only needed during inter-RAT handover or when there is no X2-interface present between the Source eNB and the Target eNB. For a normal X2-interface initiated inter-eNB handover a S1AP Handover Notification message is sent from the Target eNB to the MME after the UE has been successfully transferred to the new cell.

c) S10 & S6a Interfaces

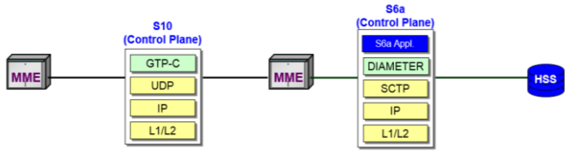

Fig. 7 S10 & S6a Interfaces

Interface between different MMEs

d) S5/S8 Interface (3GPP Candidate based on GTP)

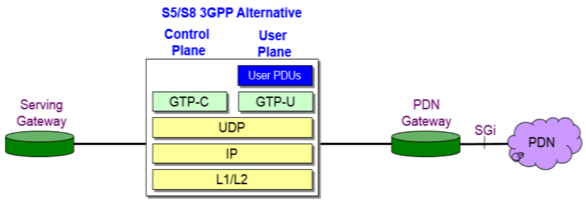

Fig. 8 S5/S8 Interface

Interface between Serving GW and PDN GW

e) S11 Interface Functions

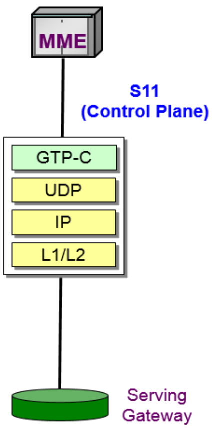

Fig. 9 S11 Interface

Interface between MME and a Serving GW

f) Gx (or S7) & Gxc Intefaces

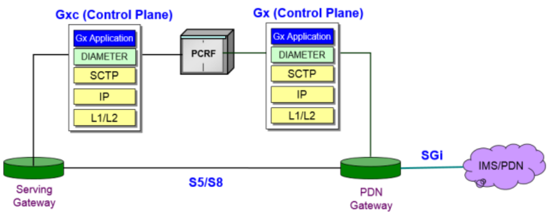

Fig. 10 Gx (or S7) & Gxc Intefaces

- Interface between Serving GW (S-GW) and PCRF (Policy and Charging Rule Function)

Gx (Also referred as S7) Functions

- Interface between PDN GW and PCRF (Policy and Charging Rule Function) It allows:

g) Rx & SGi Interfaces

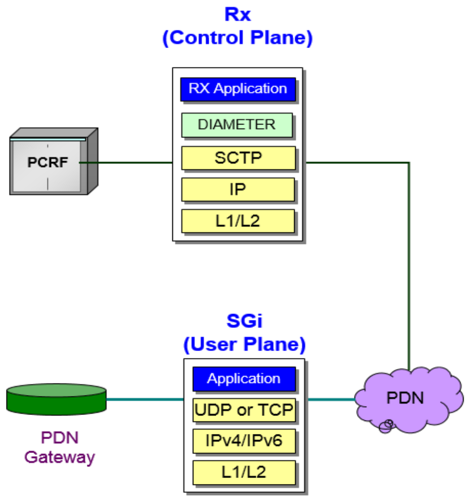

Fig. 11 Rx & SGi Interfaces

- Interface between PCRF (Policy & Charging Rules Function) and the external PDN network/operators IMS (in general, towards the Service Domain)
- Interface used by the PDN GW to send and receive data to and from the external data network or Service Platform

Conclusion

LTE Network is a future oriented radio access network designed to serve user requirements like high speed internet, Multimedia online gaming, Mobile TV etc. The IP-based flat multi-core network architecture is called EPC. While LTE is designed for high data-rate, spectral flexibility, low latency, improved coverage and battery lifetime, EPC supports robust IP-based services with seamless mobility and advanced QoS mechanism. The paper is focused on the technical overview of LTE, their architecture, features and services.

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