

LTE Network Architecture: Basic

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This document provides a brief overview of the LTE network architecture as the first technical document of “LTE” area. First, the LTE network reference model is defined and its basic Evolved Packet System (EPS) entities and the functions of each entity are described. Next, the interfaces between the EPS entities and the protocol stack across the interfaces are described. Finally, how user traffic is delivered across the LTE network is explained for Internet service.

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Abbreviations

AS	Access Stratum
BSS	Business Support System
CDR	Charging Data Record
DL	Downlink
DRB	Data Radio Bearer
E2E	End to End
ECM	EPS Connection Management
EMM	EPS Mobility Management
eNB	Evolved Node B
EPC	Evolved Packet Core
EPS	Evolved Packet System
ESM	EPS Session Management
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
GTP	GPRS Tunneling Protocol
GTP-C	GTP Control
GTP-U	GTP User
HSS	Home Subscriber Server
IP	Internet Protocol
LTE	Long Term Evolution
MAC	Medium Access Control
MME	Mobility Management Entity
NAS	Non Access Stratum
NRM	Network Reference Model
OCS	Online Charging System
OFCS	Offline Charging System
OSS	Operations Support System
PCC	Policy and Charging Control
PCEF	Policy and Charging Enforcement Function
PCRF	Policy and Charging Rules Function
PDCP	Packet Data Convergence Protocol
PDN	Packet Data Network
QoS	Quality of Service
RLC	Radio Link Control
RRC	Radio Resource Control
RRM	Radio Resource Management
S1-AP	S1 Application Protocol
SCTP	Stream Control Transmission Protocol
SDF	Service Data Flow
SN	Sequence Number
SPR	Subscriber Profile Repository
TEID	Tunnel Endpoint Identifier
UE	User Equipment
UDP	User Datagram Protocol
UL	Uplink
X2-AP	X2 Application Protocol

I. Introduction

This document presents the LTE network architecture as the first technical document of “LTE” area. The LTE network called Evolved Packet System (EPS) is an end-to-end (E2E) all IP network; EPS is divided into two parts - LTE part which deals with the technology related to a radio access network (E-UTRAN) and EPC part which deals with the technology related to a core network. An E2E all IP network means that all traffic flows – from a UE all the way to a PDN which connects to a service entity – are transferred based on IP protocol within EPS.

In order for LTE services to be provided to a user over the LTE network, an E2E LTE network reference model (NRM) is generally comprised of three additional domains - BSS/OSS domain for subscriber, application domain for providing services, and IP transport network domain for sending IP packets – in addition to basic EPS domain. The scope of this document is focused on the basic EPS domain. Other EPS domain features, such as the architectures for LTE interworking with 3GPP/non-3GPP and roaming, are out of the scope of this document and will be described in other technical documents later.

The remainder of this document is organized as follows. In Chapter II, the LTE network reference model is defined and the EPS entities and interfaces are explained. Chapter III will describe the protocol stacks and then Chapter IV will explain traffic flows over the LTE network.

II. LTE Network Reference Model

Figure 1 shows an LTE network reference model, consisting of LTE entities (UE and eNB) and EPC entities (S-GW, P-GW, MME, HSS, PCRF, SPR, OCS and OFCS). A PDN is an internal or external IP domain of the operator that a UE wants to communicate with, and provides the UE with services such as the Internet or IP Multimedia Subsystem (IMS). In the following, Table 1 and Table 2 show the functions of the LTE and EPC entities. Table 3 lists the reference points of the LTE network reference model and gives a description of interfaces between EPS entities.

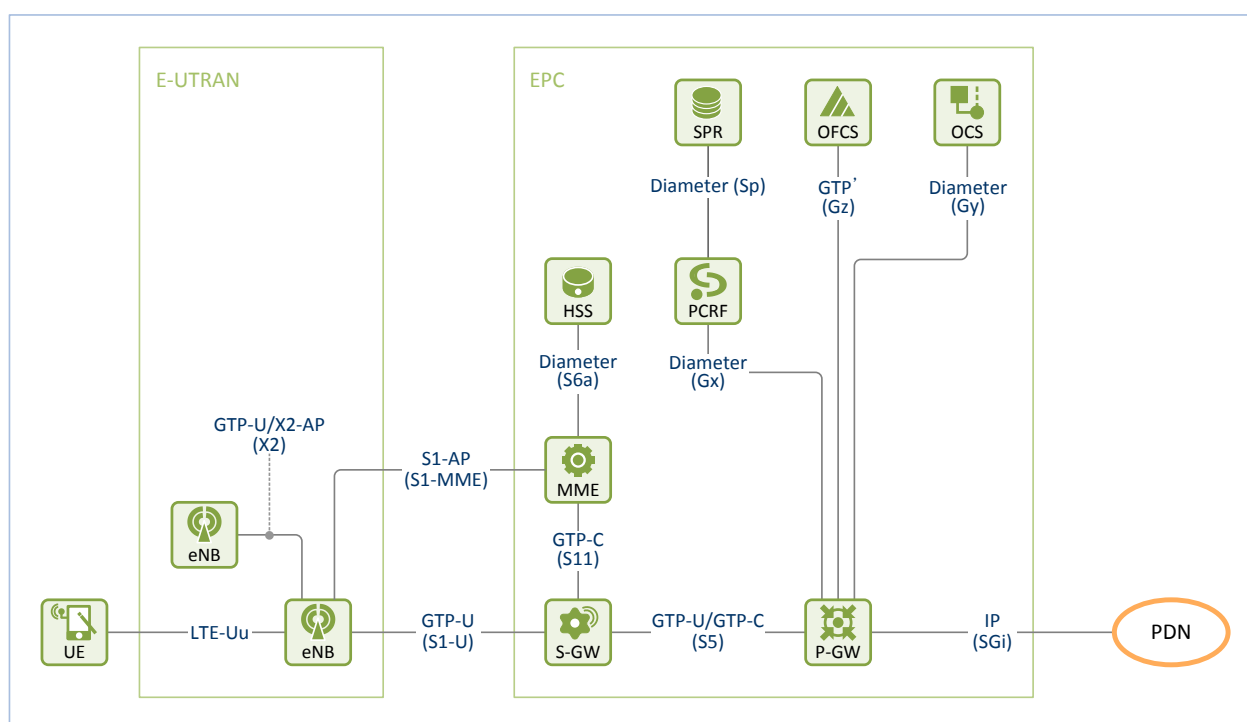


Figure 1. LTE network reference model

Table 1. LTE entities

Entity	Description
UE	A UE connects to an eNB over the LTE-Uu interface.
eNB	An eNB provides users with the radio interfaces and performs Radio Resource Management (RRM) functions such as dynamic resource allocation (scheduler), eNB measurement configuration and provision, radio admission control, connection mobility control and Radio Bearer (RB) control and Inter-Cell Interference Coordination (ICIC).

Table 2. EPC entities

Entity	Description
MME	<p>An MME is the main control entity for the E-UTRAN. It communicates with an HSS for user authentication and user profile download, and provides UEs with EPS Mobility Management (EMM) and EPS Session Management (ESM) functions using NAS signaling. The main functions supported by a MME are as follows:</p> <ul style="list-style-type: none"> • NAS signaling (EMM, ESM and NAS Security) • User authentication and roaming with HSS over the S6a interface • Mobility management (paging, Tracking Area List (TAI) management and handover management) • EPS bearer management
S-GW	An S-GW terminates the interface towards an E-UTRAN. It serves as the local mobility anchor point of data connections for inter-eNB handover and inter-3GPP handover.

P-GW	<p>A P-GW provides a UE with access to a PDN by assigning an IP address from the address space of the PDN. The P-GW serves as the mobility anchor point for handover between 3GPP and non-3GPP. It also performs policy enforcement, packet filtering and charging based on the PCC rules provided by a PCRF. The main functions supported by a P-GW are as follows:</p> <ul style="list-style-type: none"> • IP routing and forwarding • Per-SDF/Per-User based packet filtering • UE IP address allocation • Mobility anchoring between 3GPP and non-3GPP • PCEF functions • Charging per-SDF/per-User
HSS	An HSS is the central DB where user profiles are stored. It provides user authentication information and user profiles to the MME.
PCRF	A PCRF is the policy and charging control entity. It makes policy decisions for SDFs and provides the PCC rules (QoS and charging rules) to the PCEF (P-GW).
SPR	A SPR provides subscription information (access profile per subscriber) to the PCRF. Receiving the information, the PCRF performs subscriber-based policy and creates PCC rules.
OCS	An OCS provides (i) real-time credit control and (ii) charging functions based on volume, time and event.
OFCS	An OFCS provides CDR-based charging information.

Table 3. LTE interfaces

Reference point	Protocol	Description
LTE-Uu	E-UTRA (control plane and user plane)	An interface for the control and user planes between a UE and an E-UTRAN (eNB). The signaling connection over the LTE-Uu is the RRC connections represented by Signaling Radio Bearers (SRBs), and the user plane connection is the logical channels represented by Data Radio Bearers (DRBs).
X2	X2-AP (control plane) GTP-U (user plane)	An interface for the control and user planes between two eNBs. It is used during X2 handover and/or for Self Organizing Network (SON)-related functions. X2-AP protocol is used in the control plane and a GTP-U tunnel per bearer is provided for data forwarding in the use plane.
S1-U	GTP-U	An interface for the user plane between an E-UTRAN (eNB) and an S-GW. It provides a GTP tunnel per bearer.
S1-MME	S1-AP	An interface for the control plane between an E-UTRAN (eNB) and an MME.
S11	GTP-C	An interface for the control plane between an MME and an S-GW. It provides a GTP tunnel per user.
S5	GTP-C (control plane) GTP-U (user plane)	An interface defined between an S-GW and a P-GW for the control plane and user plane. The S5 interface provides a GTP tunnel per bearer for the user plane and GTP tunnel management (creation, modification and deletion) per user for the control plane. For inter-PLMN, however, an S8 interface is used instead. The S8 interface is out of the scope of this document and will be described in other LTE interworking document to follow.
S6a	Diameter	An interface for the control plane between an HSS and an MME. It exchanges user subscription and authentication information.
Sp	Diameter	An interface for the control plane between an SPR and a PCRF.
Gx	Diameter	An interface for the control plane between a PCRF and a P-GW. It transfers policy control and charging rules from the PCRF to the P-GW to support QoS policy and charging control.
Gy	Diameter	An interface for the control plane between an OCS and a P-GW.
Gz	GTP'	An interface for the control plane between an OFCS and a P-GW.
SGi	IP	An interface for the control and user planes between a P-GW and a PDN. The IETF-based IP packet forwarding protocols are used in the user plane while DHCP and RADIUS/Diameter protocols are used in the control plane.

III. LTE Protocol Stacks

Based on the EPS entities and interfaces defined in Chapter II, the LTE protocol stacks for the user plane and control plane are described in Chapter III.

3.1 User plane protocol stacks

Figure 2 shows the user plane protocol stacks for the LTE network reference model shown in Figure 1. The functions of the key layers of the protocol stacks are briefly described below.

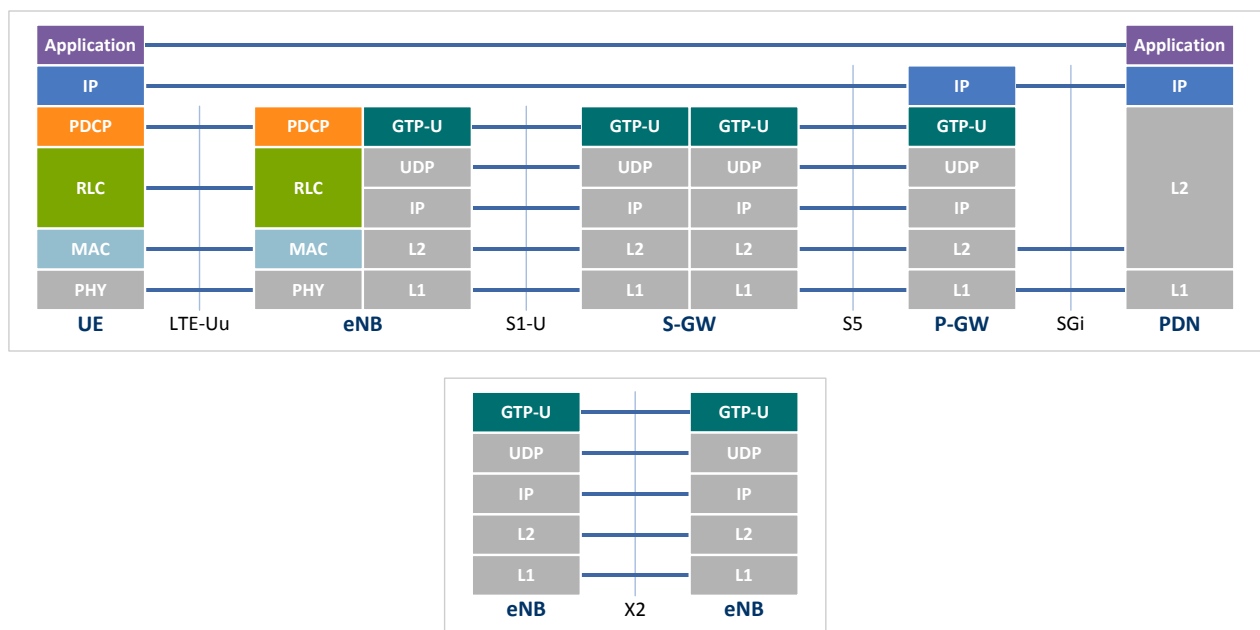


Figure 2. LTE user plane protocol stacks

1) LTE-Uu interface

- **PDCP:** The PDCP protocol supports efficient transport of IP packets over the radio link. It performs header compression, Access Stratum (AS) security (ciphering and integrity protection) and packet re-ordering/retransmission during handover.
- **RLC:** In the transmitting side, the RLC protocol constructs RLC PDU and provides the RLC PDU to the MAC layer. The RLC protocol performs segmentation/concatenation of PDCP PDUs during construction of the RLC PDU. In the receiving side, the RLC protocol performs reassembly of the RLC PDU to reconstruct the PDCP PDU. The RLC protocol has three operational modes (i.e. transparent mode, acknowledged mode and unacknowledged mode), and each offers different reliability levels. It also performs packet (the RLC PDU) re-ordering and retransmission.
- **MAC:** The MAC layer lies between the RLC layer and PHY layer. It is connected to the RLC layer through logical channels, and to the PHY layer through transport channels. Therefore, the MAC protocol supports multiplexing and de-multiplexing between logical channels and transport channels. Higher layers use different logical channels for different QoS metrics. **The MAC protocol supports QoS by scheduling and prioritizing data from logical channels.** The eNB scheduler makes sure radio resources are dynamically allocated to UEs and performs QoS control

to ensure each bearer is allocated the negotiated QoS.

2) S1-U/S5/X2 interface

- **GTP-U:** GTP-U protocol¹ is used to forward user IP packets over S1-U, S5 and X2 interfaces. When a GTP tunnel is established for data forwarding during LTE handover, an End Marker packet is transferred as the last packet over the GTP tunnel.

3.2 Control plane protocol stacks

Figure 3 shows the control plane protocol stacks for the LTE network reference model. The functions of the key layers of the protocol stacks are briefly described below.

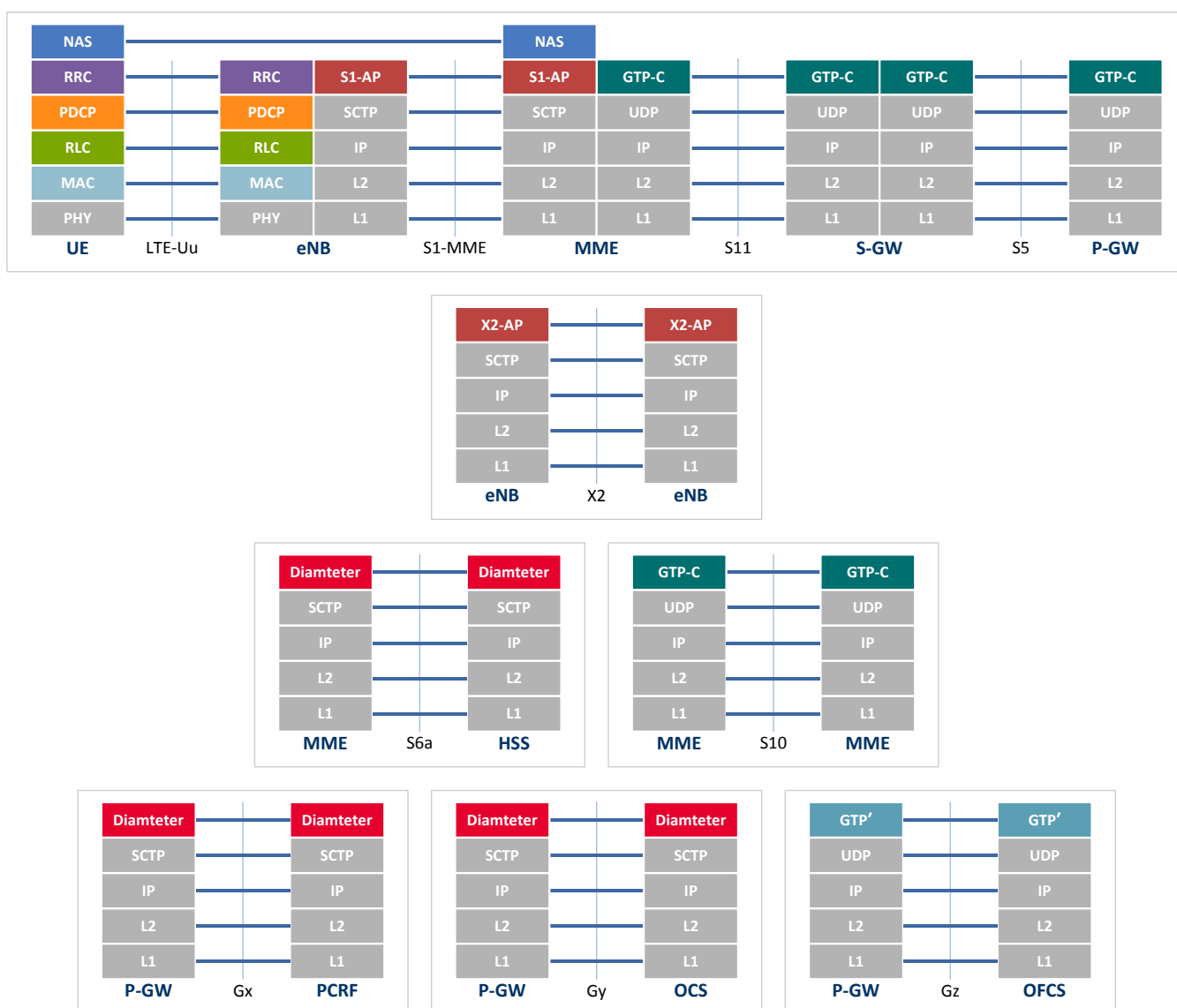


Figure 3. LTE control plane protocol stacks

¹ A simple example for packet forwarding over GTP tunnel is described in Section IV.

1) LTE-Uu Interface

- **NAS²**: NAS protocol performs mobility management and bearer management functions.
- **RRC**: RRC protocol supports the transfer of the NAS signaling. It also performs functions required for efficient management of the radio resources. The main functions are as follows:
 - Broadcasting of system information
 - Setup, reconfiguration, reestablishment and release of the RRC connection
 - Setup, modification and release of the radio bearer

2) X2 interface

- **X2AP**: X2AP protocol supports UE mobility and SON functions within the E-UTRAN. To support UE mobility, the X2AP protocol provides functions such as user data forwarding, transfer of SN status and UE context release. For SON functions, eNBs exchange resource status information, traffic load information and eNB configuration update information, and coordinate each other to adjust mobility parameters using the X2AP protocol.

3) S1-MME interface

- **S1AP**: S1AP protocol supports functions such as S1 interface management, E-RAB management, NAS signaling transport and UE context management. It delivers the initial UE context to the eNB to setup E-RAB(s) and manages modification or release of the UE context thereafter.

4) S11/S5/S10 interfaces

- **GTP-C**: GTP-C protocol supports exchange of control information for creation, modification and termination for GTP tunnels. It creates data forwarding tunnels in case of LTE handover.

5) S6a interface

- **Diameter**: Diameter protocol supports exchange of subscription and subscriber authentication information between the HSS and MME.

6) Gx interface

- **Diameter**: Diameter protocol supports delivery of PCC rules from the PCRF to the PCEF (P-GW).

7) Gy interface

- **Diameter**: Diameter protocol supports exchange of real-time credit control information between the P-GW and OCS.

8) Gz interface

- **GTP'**: GTP' protocol supports CDR transfer from the P-GW to the OFCS.

² It, although not one of the protocol layers that form the LTE-Uu interface, is described here for the sake of convenience. The NAS layer of a UE communicates with its counterpart of an MME through the radio link and over the LTE-Uu interface.

IV. Traffic Flow on the LTE Network

Figure 4 shows the flow of user plane traffic accessing the Internet in the LTE network reference architecture. Figure 4 (a) shows the traffic flow from a UE to the Internet and Figure 4 (b) shows one from the Internet to a UE. IP packets are forwarded through the GTP tunnel over S1-U and S5 interfaces. These GTP tunnels are established per EPS bearer when a user is attached to the LTE network.

More than one EPS bearer is established on each of the S1-U and S5 interfaces. So, in order to identify these bearers, a Tunnel Endpoint Identifier (TEID) is assigned to the end points (UL and DL) of each GTP tunnel (When identifying a GTP tunnel, a TEID, IP address and UDP port number are used in general. Here, however, for convenience of description, only a TEID is used for this purpose). The receiving end side of the GTP tunnel locally assigns the TEID value the transmitting side has to use. The TEID values are exchanged between tunnel endpoints using control plane protocols

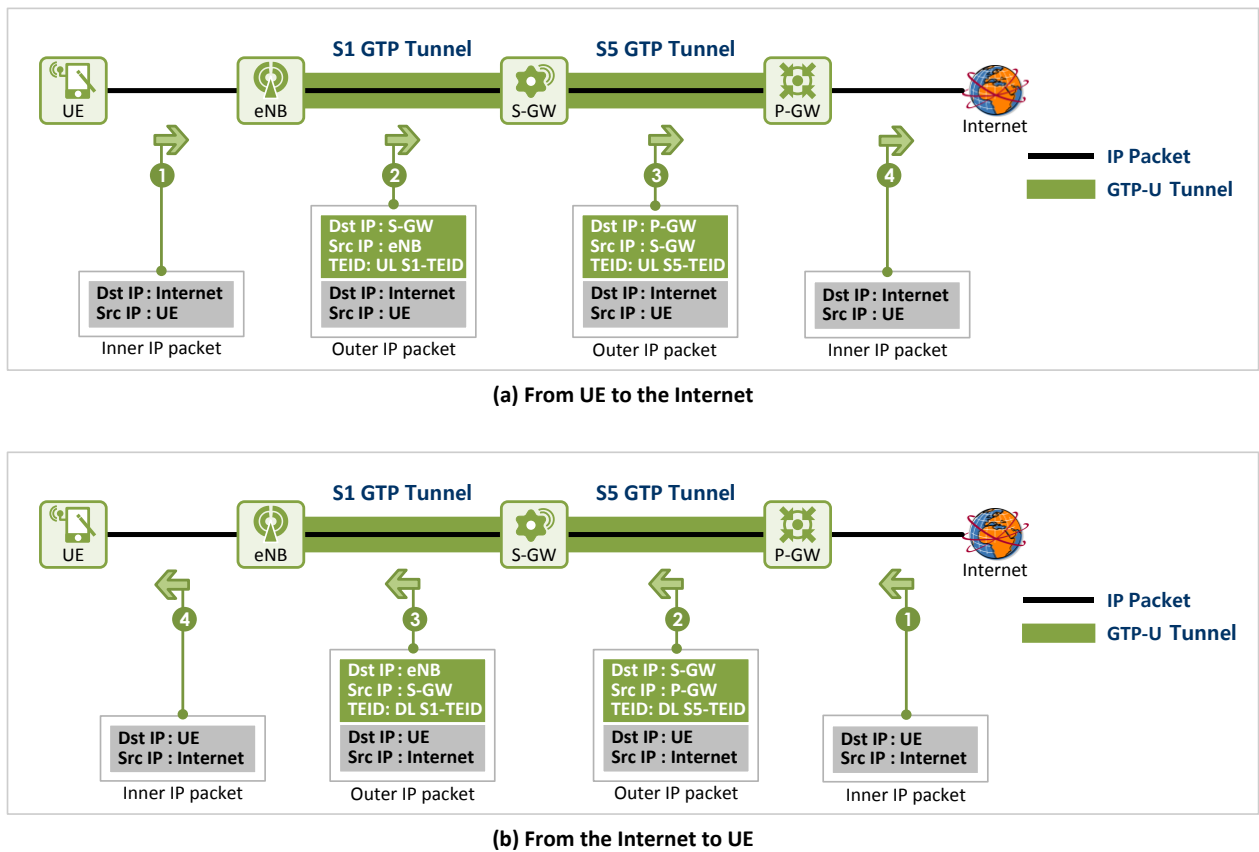


Figure 4. Traffic flow on the LTE network

When a GTP tunnel is established on the S1-U interface, the S-GW assigns a TEID (UL S1-TEID in Figure 4(a)) for uplink traffic and the eNB assigns a TEID (DL S1-TEID in Figure 4(b)) for downlink traffic. The TEID values of the S1 GTP tunnel are exchanged between the eNB and the S-GW using S1AP and GTP-C messages. Likewise when a GTP tunnel is established on the S5 interface, the P-GW assigns a TEID (UL S5-TEID in Figure 4(a)) for uplink traffic and the S-GW assigns a TEID (DL S5-TEID in Figure 4(b)) for downlink traffic. The TEID values of the S5 GTP tunnel are exchanged between the S-GW and the P-GW using GTP-C protocol.

When a user IP packet is delivered through a GTP tunnel on the S1-U and S5 interfaces, the eNB, S-GW and P-GW forward the user IP packet by encapsulating with the TEID assigned by the receiving peer GTP entity. In uplink direction, the S-GW builds a one-to-one mapping between an S1 GTP tunnel (UL S1-TEID) and an S5 GTP tunnel (UL S5-TEID) to terminate the S1 GTP tunnel and forward the user IP packet into the S5 GTP tunnel. Likewise in downlink direction, the S-GW builds a one-to-one mapping between a S5 GTP tunnel (DL S5-TEID) and a S1 GTP tunnel (DL S1-TEID) to terminate the S5 GTP tunnel and forward the user IP packet into the S1 GTP tunnel. In figure 4, the procedure through which each EPS entity forwards Internet traffic flow is as follows:

a) Traffic flow in uplink direction: from UE to the Internet

- ① A UE transfers user IP packets to an eNB over LTE-Uu interface.
- ② The eNB encapsulates the user IP packets with the S1 GTP tunnel header and forwards the resulting outer IP packets to the S-GW. Here, the eNB selected a “TEID” value (i.e. UL S1-TEID), “Destination IP Address” (i.e. S-GW IP address), and “Source IP Address” (i.e. eNB IP address) to make the S1 GTP tunnel header.
- ③ After receiving the outer IP packets, the S-GW strips off the S1 GTP tunnel header, encapsulates the user IP packets (the inner IP packets) with the S5 GTP tunnel header and forwards the resulting outer IP packets to the P-GW. Here the S-GW selected a “TEID” value (i.e. UL S5-TEID), “Destination IP Address” (i.e. P-GW IP address), and “Source IP Address” (i.e. S-GW IP address) to make the S5 GTP tunnel header.
- ④ After receiving the outer IP packets, the P-GW gets the user IP packets by stripping off the S5 GTP tunnel header and transfers them to the Internet through IP routing.

b) Traffic flow in downlink direction: from the Internet to UE

- ① A P-GW receives IP packets destined for a UE over the Internet.
- ② The P-GW encapsulates the user IP packets with the S5 GTP tunnel header and forwards the resulting outer IP packets to the S-GW. Here, the P-GW selected a “TEID” value (i.e. DL S5-TEID), “Destination IP Address” (i.e. S-GW IP address), and “Source IP Address” (i.e. P-GW IP address) to make the S5 GTP tunnel header.
- ③ After receiving the outer IP packets, the S-GW strips off the S5 GTP tunnel header, encapsulates the user IP packets (the inner IP packets) with the S1 GTP tunnel header and forwards the resulting outer IP packets to the eNB. Here, the S-GW selected a “TEID” value (i.e. DL S1-TEID), “Destination IP Address” (i.e. eNB IP address), and “Source IP Address” (i.e. S-GW IP address) to make the S1 GTP tunnel header.
- ④ After receiving the outer IP packets, the eNB gets the user IP packets by stripping off the S1 GTP tunnel header and transfers them to the UE through the Data Radio Bearer (DRB) over the radio link³.

³ For DRB, refer to the technical document, “LTE Identification III: EPS Session/Bearer Identifiers”

V. Closing

The LTE network architecture has been presented as the first document of the “LTE” technical document series. The LTE network architecture explained in this document applies to a LTE only network provided by a single operator and thus has covered the most basic components of the EPS system. To be able to move on to other LTE technical documents that follow, fundamental understanding of the entities and interfaces of the EPS system is required. The next technical document, consisting of three companion documents, is another basic LTE document and will discuss the LTE identification applied to the LTE network reference model. These basic documents would be helpful in better understanding of subsequent documents, which will discuss more advanced functions of the LTE architecture including LTE interworking and roaming.

References

- [1] 3GPP TS 36.300, “Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2”.
- [2] 3GPP TS 23.401, “General Packet Radio Service (GPRS) enhancements for Evolved Universal Terrestrial Radio Access Network (E-UTRAN) access”.
- [3] Magnus Olsson, et. al., SAE and the Evolved Packet Core – Driving the Mobile Broadband Revolution, AP, 2009.
- [4] NMC Consulting Group Confidential Internal Report, “E2E LTE Network Design”, August 2010.

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