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4G System: Network Architecture and Performance

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Abstract—* 4G is new wireless technology developed by the third Generation Partnership Project (3GPP) with objectives of high-data-rates, low latency and flexible bandwidth deployments. Named as LTE « Long term evolution », the 4G system architecture is made up of an EPC (Evolved Packet Core) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN).This paper provides an overview of the 3GPP releases relevant to 4G. We present an overview of the E-UTRAN Radio Interface characteristics and 4G network architecture elements. We next provide a high-level description of 4G interfaces. An outlook of QoS in 4G network is presented and finally we present the conclusion of our work.

Keywords— 4G; Architecture; Interfaces; E-UTRAN; EPC; QoS

I. INTRODUCTION

In recent years ,rapid development in wireless communication, high demands for broadband mobile wireless communications and the emergence of new wireless multimedia applications have constituted the motivation to the development of broadband wireless access technologies. The mobile communication systems and the wireless communication technologies have been improving very fast day by day, new types of services and applications as VoIP, video conferencing, video-on-demand and media streaming have strict requirements that must be guaranteed.

Long-Term Evolution/System Architecture Evolution (LTE/SAE) marketed as 4G specified by 3rd Generation Partnership Project (3GPP) is new mobile generation supersedes the 3.75 G (HSPA+), 3.5 G (HSPA) and 3G(UMTS) families of standards to achieve a high system capacity and coverage, high peak data rates, low latency, reduced operating costs, multi-antenna support and flexible bandwidth operations.

4G system include several specifications categorized in Releases. For example, In 2008, 3GPP published and introduced the Release 8 that represent the original LTE standard and the basis for 4G system. This effort is continued in Release 9 to provide enhancements to LTE. In 2011, Release 10 was brought as LTE-Advanced, to expand the limits and features of Release 8 and to meet the requirements of the International Mobile Telecommunications Advanced (IMT-Advanced) for the fourth generation (4G) of mobile technologies[3-12].

The LTE-A system specified by the 3GPP LTE Release 10 enhances the existing LTE systems to support much higher data usage, lower latencies and better spectral efficiency [2]. LTE-Advanced is therefore not a new technology; it is an evolutionary step in the continuing development of LTE.

However, predictions based on the wireless traffic explosion in recent years indicate a need for more advanced technologies and higher performance. Hence, 3GPP's efforts have continued through Rel-11 and now Rel-12.

In addition to the features introduced in Release 10, Release 11 includes basic functionality for coordinated multipoint (CoMP) transmission and reception.

In June 2012, 3GPP RAN held a workshop on Release 12 in order to prepare the next evolution step of LTE. Further enhancements and new technologies are proposed at this meeting including Interference coordination and management, Dynamic TDD, Frequency separation between macro and small cells, Inter-site carrier aggregation and macrocell-assisted small cells and Wireless backhaul for small cells.

Depending on the progress in Rel-12, future releases will start earlier or later in 2015. Rel-13 is expected to further enhance LTE-Advanced technologies and it include Licensed-Assisted Aggregation (LAA), LTE enhancements for Machine-Type Communications (MTC) , Full-Dimension MIMO and Indoor positioning projects, while Rel-14 and Rel-15 could potentially define a new access technology [13].

TABLE 1 - BASIC DIFFERENCES BETWEEN 4G RELEASES

Generation	4G			
3GPP Releases	Rel-8/9	Rel-10	Rel-11/12	Rel-13 and beyond
Technology	LTE	LTE-Advanced		B4G
Peak data rate (DL)	100 Mbps	1Gps	1Gbps	>=1Gbps
Peak data rate (UL)	50 Mbps	500 Mbps	500 Mbps	>=500 ms
Latency round trip time	10 ms			=< 10 ms
Access technology	OFDMA(downlink) /SC-FDMA (Uplink)			
Modulation Types	QPSK, 16QAM,64QAM (Uplink and downlink)			
Frequency Band	2-8 GHz			
Start from	2010			

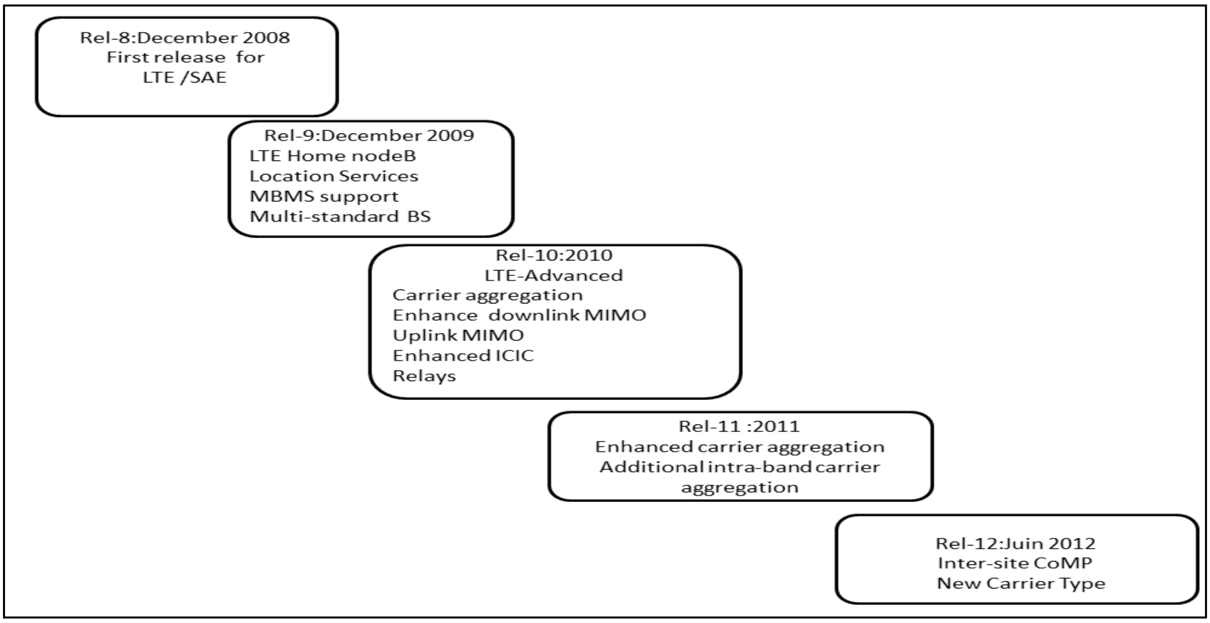

Fig. 1. 4G Releases technologies

II. 4G ARCHITECTURE AND CHARACTERISTICS

The 4G Architecture is new architecture developed to provide a higher level of performance in line with the requirements of LTE .Known as SAE-System Architecture Evolution ,The 4G Architecture offers many advantages compared to 2G and 3G architectures such as new routing techniques , efficient solutions for sharing dedicated frequency band, increases mobility and bandwidth capacity. This requirement are achieved by means of several EPS network elements that have different roles .3GPP identified in Release 8 the architecture of LTE system that serving as a basis architecture network of 4G Network. The LTE architecture includes the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) network.

The 4G network architecture consists of the following elements:

- eNodeB
- Mobility Management Entity (MME)
- Serving Gateway (S-GW)
- Packet Data Network Gateway (P-GW)
- Home Subscriber Server (HSS)
- Policy and Charging Rules Function (PCRF)

A. E-UTRAN: Evolution and Architecture

E-UTRAN is a radio access network of 3GPP's Long-Term Evolution (LTE) .It is new air interface system, which provides High speed data-rate, lower latency and is optimized for packet data. It uses OFDMA radio access for the downlink and SC-FDMA for the uplink.

In LTE, Two duplexing schemes are used, time division duplexing (TDD) and frequency division duplexing (FDD).Using LTE-TDD, a single frequency channel is assigned to both the transmitter and the receiver .LTE-FDD requires paired spectrum with sufficient frequency separation to allow simultaneous transmission and reception.

The E-UTRAN Network require high speed data-rate and reliable transmissions with bandwidth efficiency as given in Table 1.To meet these requirements Multiple input multiple-output(MIMO)system have been implemented in which multiple antennas are used in both transmitter and receiver and up to four antennas can be used by a single LTE cell .

The radio access network E-UTRAN achieves many functionalities including:

- Radio resource management (RRM)
- Provides initial access to the network, registration, and attach/detach to the network
- Mobility Management Functions
- Security Functions
- Terminal state transition
- Flexibility in spectrum usage
- Selection of an MME at UE attachment when no MME information is provided by the UE
- Handover Management—Intra-eNode

TABLE 2
E-UTRAN RADIO INTERFACE CHARACTERISTICS

PARAMETERS	VALUES
Radio interface peak data rates	100 Mbps downlink (20 MHz spectrum) 50Mbps uplink (20 MHz spectrum)
Spectrum efficiency	5bits/Hz(downlink) and 2.5 bits/Hz(Uplink)
Modulation Types	QPSK,16QAM,64QAM (Uplink and downlink)
Transmission BW(MHz)	1.25 2.5 5 10 15 20 MHz
Access technology	OFDMA(downlink)/SC-FDMA(Up-link)
Advanced MIMO spatial multiplexing	(2 or 4) x (2 or 4) downlink and uplink

B. E-UTRAN architecture

The E-UTRAN architecture consists of eNodeBs that interfaces with the user equipment (UE) and provide user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations toward the user equipment (UE). eNodeB is a logical element that serving one or more E-UTRAN cells and eNodeBs are normally interconnected with each other by means of an interface known as X2, and are also connected by means of the S1 interface to the Evolved Packet Core (EPC), specifically to the Mobility Management Entity (MME) by means of the S1-MME interface and to the Serving Gateway (SGW) by means of the S1-U interface as illustrated in Fig.1 [15]

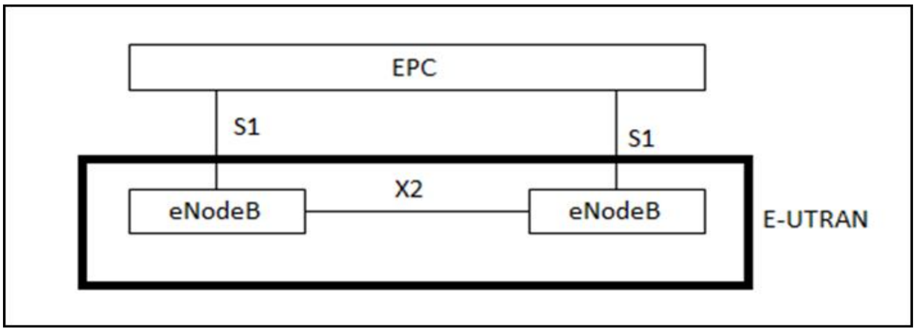

Fig .2 . E-UTRAN Architecture

The E-UTRAN in LTE architecture consists of a single node, i.e., the eNodeB that interfaces with the user equipment (UE). The aim of this simplification is to reduce the latency of all radio interface operations. eNodeBs are connected to each other via the X2 interface, and they connect to the PS core network (EPC) by means of the S1 interface. The eNodeBs are normally interconnected with each other by means of an interface known as “X2” and to the EPC by means of the S1 interface. The eNBs are also connected by means of the S1 interface to the Evolved Packet Core (EPC).

C. Key technologies of LTE-A

In order to increase the peak rate ,peak spectral efficiency ,average rate and improve the network efficiency ,LTE-Advanced has introduced by 3GPP.The goals of LTE-Advanced are to support a bandwidth of up 100 MHz, a downlink peak rate of 1 Gbps with an increased spectral efficiency of 30 bps/Hz, a uplink peak rate of 500 Mbps with an increased spectral efficiency of 15 bps/Hz . To achieve those goals and requirements, various promising technologies for LTE-A wireless communications are required. These technologies include the Carrier Aggregation technology (CA) and Coordinated Multipoint technology. The CA technology has been introduced by 3GPP to aggregate two or more carriers up to five carriers, each carrier have a bandwidth up to 20 MHz, this implies a maximum bandwidth of 100 MHz [19-x4].The CA technologies propose three carrier aggregation deployments scenarios in order to provide sufficient coverage and to achieve best system performance in terms of spectral efficiency and mobility.CA technology support both Frequency Division Access (FDD) and Time Division Access (TDD) .The CA benefits include :

- Improved average user throughput.
- Increased peak data rate
- Inter-cell interference mitigation
- Load balancing
- Handover Improvement

The task of high data delivery cannot accomplish just by boosting the signal power of the transmission [20-c1]. The LTE-A requires more and advanced wireless communications techniques to mitige inter-cell. This problem has attracted much intention in recent years .To resolve this problem and in order to improve cell edge performance ,3GPP has initiated the work item on Coordinated Multiple Point transmission and reception (CoMP) in September 2011 .CoMP is considered by 3GPP. As a key tool to improve system efficiency ,cell edge throughput and coverage of LTE-advanced .In CoMP cooperation ,multiple points geographically separated coordinate with each other to transmit to /or receive from user equipment signals with the aim of improving the system performance .

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D. EPC: Components and Functions

Presented as the latest evolution of the 3GPP core network architecture the Evolved Packet core EPC is a new, all-IP mobile core network developed by 3GPP to allow handover between different technologies .The Evolved packet Core EPC is specified by 3GPP Release 8 standards to improve network performance by the separation of control and data planes and through a IP architecture. The EPC network elements are described in more detail in Fig.2..

The EPC Functions include:

- Network Access Control Functions.
- Packet Routing and Transfer Functions.
- Mobility Management Functions.
- Security Functions.
- Radio Resource Management Functions.
- Network Management Functions.
- Charging Functions.

The EPC is composed of several function entities:

- Mobility Management Entity (MME): The MME is the key control node for the LTE access network. It is responsible for idle mode UE tracking and paging procedure including retransmissions. The MME also terminates the S6a interface toward the home HSS for roaming UEs.
- PDN Gateway (P-GW): The P-GW is the anchor point for sessions towards the external Packet Data Networks .The P-GW is responsible for IP management, connection to external data networks; focus on highly scalable data connectivity, QoS enforcement and support online charging using IETF based techniques [14].
- Serving Gateway (S-GW): Serving a large number of eNodeBs, focus on scalability and security .The S-GW routes and forwards user data packets, . It manages and stores UE contexts, e.g.,parameters of the IP bearer service and network internal routing information .The S-GW represent the termination point of the user packet data interface towards E-UTRAN .

The EPC also contains other types of nodes such as Policy and Charging Rules Function (PCRF) responsible for quality-of-service (QoS) handling and charging, and the Home Subscriber Service (HSS) node that represent a database containing subscriber information. In more details ,Home subscriber server (HSS) is the master database that contains the UE profiles and authentication data used by the MME for authenticating and authorizing UEs. It also stores the location information of the UE which is used for user mobility and inter-technology handovers. The HSS communicates with the MME using diameter protocol

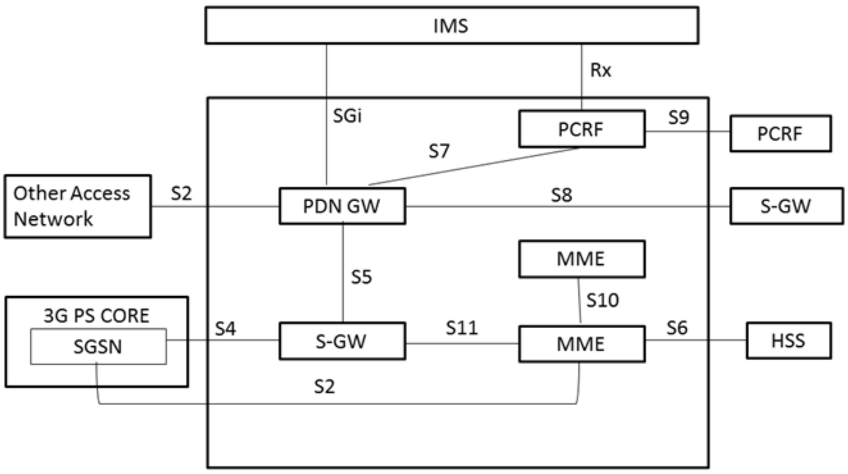

Fig. 2. EPC elements and interfaces

Table 3 - EPC Interfaces

Interface	Description
S2	Is Locating between P-GW and other wireless Access Networks and support control and Mobility procedures for non-3GPP networks.
S3	Links The MME to 2G/3G SGSN. It supports user and bearer information exchange for inter-3GPP access network mobility in idle and/or active state and it's derived from 2G/3G Gn interface using GPRS tunnelling protocol (GTP)

S5	Is located between S-GW and P-GW and supports bearer management and user plan data tunneling between this 2 entities and it derived from Gn interface using GTP protocol
S6	Interconnected the EPC with the HSS through MME .It enables transfer of subscription , authentication data and location update procedures for authenticating and authorizing user access between MME and HSS. The S6 Interface is based on Diameter protocol as used in IP multimedia system (IMS).
S7	It is used between the P-GW and PCRF and supports policy and charging roles functions transfer from the PCRF to EPC .it's based on 3GPP Release 7 Gx interface.
S8	Interconnected the visited S-GW and the home P-GW ,it supports user plan transfer between this 2 gateways when the mobile is roaming ,it's also derived from S5 interface using GTP
S9	It provides transfer of (QoS) policy and charging control information between the Home PCRF and the Visited PCRF in order to support local breakout function. It's derived and had characteristics from Gx 3G interface
S10	Links several MME nodes ,it's used for MME relocation and MME to MME information transfer to exchange session and user context .It is based on GTP control plan GTP-C .
S11	Reference point between MME and Serving GW ,it's support bearer management at user attachment or service request and it's based also on GTP-C
S12	Can be found between E-UTRAN (eNB) and Serving GW For user plane tunneling when direct tunnel is established. It's based on the Gn-U using GTP user plan protocol GTP-U as defined between RNC and SGSN .
Rx	The Rx reference point resides between the IMS and the PCRF, it is used to provide service dynamic information to the PCRF and it is based on the IETF Diameter protocol evolution
Gx	It provides transfer of QoS policy and charging rules to Policy and Charging Enforcement Function (PCEF) in the PDN-GW.
SGi	Is used between the P-GW and IMS and it's based on 2G/3G Gi interface for provision of IMS services

III. QOS IN 4G NETWORK

New types of services and applications supported by the 4G system as VoIP and Streaming video are characterized by guarantees of QoS requirements, These Expectations and requirements continue to grow and evolved with variation of 4G service demand.

3GPP has defined the QoS framework for 4G network, In the QoS concept [16][17][18],the 4G Bearer or Bearer is a logical entity that includes all the packet flows that receive a common QoS treatment between UE and EPC Gateway and it present the basic level of granularity for QoS control.

4G bearer is classified into two; Guaranteed Bit Rate (GBR) and Non- Guaranteed Bit-Rate (n-GBR) Bearer [15][16].Each bearer has a set of QoS parameters that describes the properties of the transporting channel, such as bit rates, packet delay, packet loss, bit error rate and Jitter. GBR has dedicated network resources and is needed for real-time voice and video applications. A non-GBR bearer does not have dedicated bandwidth and is used for best effort traffic such as file downloads, www, IMS signaling and email.

For 4G network, each bearer assigned only one QoS class and each class is identified with a single scalar called QCI (QoS Class Identifier). QCI specifies the forwarding treatment that the user-plane traffic gets between UE and gateway such as resource type, packet delay budget and packet error lost rate.

3GPP has standardized nine QCI values from 1 to 9 , QCI specification parameters and common applications as presented in Table 3 .The QCI characteristics ensures that services using the same QCI class will receive a minimum level of QoS.

The bearer parameters associated with a QCI are:

- The bearer parameters associated with a QCI are:
- Packet Delay Budget (PDB)
- Packet Loss Rate (PLR)
- Priority
- Resource Type (GBR or Non-GBR)

- Table 3 - E-UTRAN Radio Interface characteristics

QCI	Resource Type	Priority Level	Packet Delay Budget	Packet Loss Rate	Example Services
1		2	100 ms	10-2	Conversational Voice
2		4	150 ms	10-3	Conversational Video (Live Streaming)
3		3	50 ms	10-3	Real Time Gaming
4	GBR	5	300 ms	10-6	Non-Conversational Video (Buffered Streaming)
5		1	100 ms	10-6	IMS Signalling
6		6	300 ms	10-6	Video (Buffered Streaming)
7		7	100 ms	10-3	Voice,Video (Live Streaming) Interactive Gaming
8		8	300 ms	10-6	TCP-based (e.g., www, e-mail, chat, ftp, p2p file
9	Non-GBR	9			sharing, progressive video,

IV. Conclusions

This article provides an overview of the evolution of 4G system, some of the key components: key characteristics of E-UTRAN, E-UTRAN and EPC functions, 4G elements and interfaces are described here. Also it provides an outlook of QoS in 4G network. In our future work, we will present and configure the traffic model of 4G network using NS-2 simulator, more traffic models will be considered by analysis and approximation in order to study and evaluate QoS parameters.

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