Research Article

QoS Evolution in 3GPP Mobile Networks

[1]Firas Ousta, [1]Mohd Zuki Yusoff, [1]Nidal Kamel and [2]Sadek Ali
[1]Department of Electrical and Electronic Engineering, University Teknologi PETRONAS, Center for Intelligent Signal and Imaging Research (CISIR), Bandar Seri Iskandar, 31750, Perak, Malaysia
[2]Department of Electrical and Electronic Engineering, Tishreen University, Lattakia, Syria

Abstract: The objective of this study is threefold: (1) to review the evolution of mobile networks in 3GPP standards; (2) to present the evolution of the Quality of Service (QoS) of the 3GPP mobile family, from GSM to LTE; (3) to present the QoS frameworks, characteristics and attributes of each technology. In the last two decades, 3GPP mobile networks have been evolving from GSM to LTE providing end-users with improved QoS. However, all these networks are still in use up to the present time. Users moving from a coverage area served by one technology to another area covered by a different system would have to perform vertical handovers impacting their established QoS and affecting the performance of their applications. All the QoS mechanisms as well as their theoretical performance as a whole are reviewed. However, in commercial networks, it is proposed that QoS attributes and data measurements be continuously performed in order for operators to set more realistic users' expectations and provide more practical information for application developments.

Keywords: GPRS, GSM, HSDPA, HSPA, HSUPA, LTE, QoS

INTRODUCTION

One of the most important evolutions, over the last three decades, is the tremendous developments, deployments and growths of mobile and wireless networks, particularly, 3GPP mobile networks family. Moreover, this tremendous growth has great impacts on applications developments that have been developed taking into consideration the mobility and location as well as the offered QoS by the latest technology deployed. However, as the users move within the various coverage areas, vertical handoff, between the different technologies, will always occur creating some challenges to the applications on one hand and affecting users' experiences and expectations on the other hand. Additionally, users might be communicating with each other using different technologies and releases, setting some major challenges to migrate these technologies together on one side and within the 4G heterogeneous network on the other side (Stankiewicz and Jajszczyk, 2011; Sarraf and Ousta, 2008; Sarraf *et al*., 2012). QoS attributes set the performance thresholds such as maximum bit rate error, delay variation tolerance, maximum transfer delay, etc. The support of Quality of Service permits different traffic flows to be treated with the appropriate attributes (delay, jitter, bit error rate) required by the application.

In this study, we present the evolution of the QoS of the 3 GPP mobile families from GSM to LTE, presenting as well the QoS frameworks, characteristics and attributes of each technology.

History and evolution of the 3GPP family: Since the establishment of the Global System of Mobile communication (GSM) in 1992, the 3GPP mobile networks family has gone through a tremendous evolution, from GSM to Long Term Evolution (LTE). The history of evolution of 3GPP mobile family is illustrated in Table 1 and 2, respectively.

METHODOLOGY

QoS in 2G mobile networks:
GSM: When 2G mobile networks were introduced in the first half of 1990s, the main focus was on providing voice services. However, data services based on circuit-switched technologies were introduced with phase 2 in 1994. Initially, GSM, which was the 2nd Generation (2G) mobile systems, provided symmetric data services with bandwidth of 9.6 kbps, while 14.4 kbps user data rate was introduced with R96 in 1997. However, as Circuit Switched Data (CSD) services were based on TDMA with circuit-switched technology similar to voice, they were charged based on time, thus they were:

- Quite expensive
- Inefficiently using the radio resources

Table 1: History of 3GPP mobile family

Year	Major features
1982	General System of Mobile communication (GSM) is formed by the Confederation of European Posts and Telecommunications (CEPT) to design a pan-European mobile technology
1988	Release of the GSM phase 1 specifications
1991	Launch of the first network by Radiolinja in Finland
1992	First SMS sent
1993	Telstra Australia becomes the first non-European operator to launch GSM network
1994	GSM phase 2 including data/fax bearer services launched
1997	GSM in the USA using the 1900 MHz band
1999	WAP trials begin in France and Italy
2000	First commercial GPRS services launched
2001	First WCDMA (3GSM) network launched
2002	First MMS go live
2003	First EDGE networks introduced
2005	First HSDPA networks go live
2007	Introduction of HSUPA
2008	More than 190 HSPA networks live
2009	First commercial HSPA+ and LTE networks were introduced
2011	Global mobile connections surpass 6 billion

Table 2: Evolution of 3GPP mobile networks

Release	Year	Major features
GSM Ph1	1988	GSM phase 1: basic GSM features
GSM Ph2	1994	GSM phase 2: EFR codec and fax and data bearer service introduced
R96	1997	14.4 kbps user data rate and HSCSD
R97	1998	GPRS
R98	1999	AMR, EDGE, GPRS for PCS 1900
R99	2000	Introduced UMTS 3G networks incorporating a CDMA air interface
R4	2001	Additional features including all-IP core network
R5	2002	IMS and HSDPA
R6	2004	Integrated operation with WLAN. HSUPA, MBMS, push to talk, GAN
R7	2007	HSPA+, EDGE evolution. Improvements to QoS and real-time applications
R8	2008	LTE; SAE and OFDMA, FDE and MIMO based radio interfaces
R9	2009	WiMAX and LTE/UMTS interoperability. SAE enhancements. Dual-cell HSDPA with MIMO, dual-cell HSUPA
R10	2011	LTE advanced complying with IMT advanced 4G requirements. Multi-cell HSDPA (4 carriers)
R11	2012	Advanced IP interconnection. Heterogeneous Networks (HEtNet) improvements
R12	2014	

Table 3: HSCSD data rates

AIUR (kbps)	TCH/F 4.8	TCH/F 9.6	TCH/F 14.4
4.8	1		
9.6	2	1	
14.4	3		1
19.2	4	2	
28.8		3	2
38.4		4	
43.2			3
57.6			4

High speed circuit switched data-HSCSD: In an attempt to increase the bandwidth, High Speed Circuit Switched Data (HSCSD) services were introduced in release R96 along with the 14.4 kbps user rate. They consist of combining multiple timeslots of the TDMA frame, up to 8, thus using multiple traffic channels for data communications. However, due to system limitations on the A and E interfaces, only up to 4 timeslots of the 14.4 kbps of TCH can be combined, providing up to 57.6 kbps of data communication (3GPP-TS.22.034, 2008).

However, HSCSD is still using circuit switched technology. Due to many limitations including technologies for phone developments that could not support 4 simultaneous timeslots on both the uplink and the downlink on the one hand and the high charges of the service and the inefficient radio resource utilization on the other hand, had resulted in very limited use of this technology. HSCSD was replaced by the General Packet Radio Service (GPRS). HSCSD data rates are presented in Table 3.

General packet radio service-GPRS: In order to resolve the inefficiency with Circuit Switched Data (CSD), General Packet Radio Service (GPRS) was introduced with the release R97 in 1998. By introducing new nodes such as Serving GPRS Support Node (SGSN), Gateway GPRS.

Support Node (GGSN) and Packet Control Unit (PCU) in the BSC, as well as new interfaces, GPRS introduced the packet data service to GSM based networks. Based on R97, GPRS typically provides a bandwidth of 40 kbps in the downlink and 14 kbps in the uplink per one user by combining multiple timeslots of the GSM TDMA frame into one bearer. Enhancements were introduced in releases R98 and R99 to add new coding schemes theoretically providing speeds up to 171.2 kbps. Table 4 shows GPRS data rates.

Enhanced data for GSM evolution-EDGE: To increase the data transmission rate and to improve

Table 4: GPRS data rates (kbps)

Slots	1	2	3	4	5	6	7	8
CS-1	9.05	18.1	27.1	36.2	45.2	54.3	63.3	72.4
CS-2	13.40	26.8	40.2	53.6	67.0	80.4	93.8	107.2
CS-3	15.60	31.2	46.8	62.4	78.0	93.6	109.2	124.8
CS-4	21.40	42.8	64.2	85.6	107	128.4	149.8	171.2

Table 5: EDGE Modulation and Coding Scheme (MCS)

Modulation and Coding Scheme (MCS)	Modulation	Speed (kbps/slot)
MCS-1	GMSK	8.8
MCS-2	GMSK	11.2
MCS-3	GMSK	14.8
MCS-4	GMSK	17.6
MCS-5	8PSK	22.4
MCS-6	8PSK	29.6
MCS-7	8PSK	44.8
MCS-8	8PSK	54.4
MCS-9	8PSK	59.2

Table 6: UMTS QoS classes and parameters

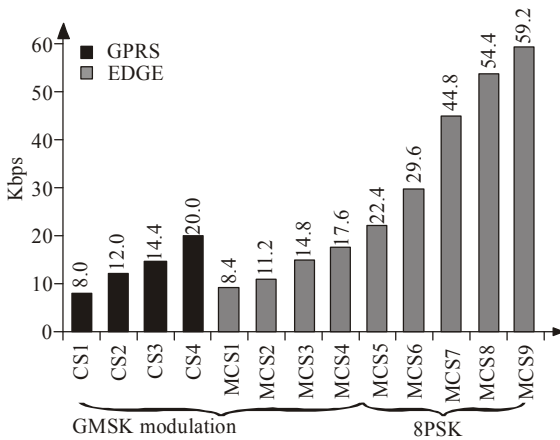| Traffic class	ARP	THP	MBR	GBR
Conversational	Yes	No	Yes	Yes
Streaming	Yes	No	Yes	Yes
Interactive	Yes	Yes	Yes	No
Background	Yes	No	Yes	No

Fig. 1: GPRS and EDGE modulations and coding

network capacity, EDGE (Enhanced Data for GSM Evolution) was introduced in 1999 with R98. With EDGE, a new modulation scheme is applied: 8 PSK (phase shift keying) that utilizes three bits per RF modulated symbol as opposed to the original one bit per symbol in GPRS. This technology change triples the effective data rate for EDGE, resulting in a peak date rate of 59.2 kbit/sec/timeslot. EDGE modulation and coding scheme are illustrated in Table 5. Similar to GPRS, the maximum achievable data rate depends on the supported multi timeslots class of the mobile device and can reach 384 kbps as presented in Fig. 1. It is worth noting that EGPRS is a superset expression comprising EDGE and GPRS.

EDGE Evolution, which has been released in 2007 with R7, contains a set of new features. With the introduction of 16 QAM and 32QAM modulation combined with higher symbol rate (Level B) and turbo coding in the downlink, latency improvements and the use diversity at the mobile station, the data rate would theoretically reach 1.9 Mbps in the downlink. The primary motivation behind EDGE evolution is to ensure the future competitiveness of the dominant second-

generation technology and specifically to provide service continuity across the various radio technologies (GERAN, UTRAN, LTE) supported by core network evolution.

QoS in 3G mobile networks: The specifications of GPRS and EDGE did not include any QoS framework. This has been introduced in 2000 with the introduction of UMTS in R99. Frameworks for QoS including an end-to-end QoS involving GPRS have been introduced in this release (3GPP-TR.23.802, 2007; 3GPP-TS.23.107, 2004). The main purpose in 3GPP-TS.23.107 (2004) is to specify the list of attributes applicable to UMTS Bearer Service and Radio Bearer Service, as well as to describe the Quality of Service architecture to be used in UMTS networks. The (3GPP-TS.23.207, 2004) describes a the interaction between the TE/MT Local Bearer Service, the GPRS Bearer Service and the external Bearer Service and how these together provide Quality of Service for the End-to-End Service. Such architecture is depicted in Fig. 2. However, since the GPRS core architecture is the same for GPRS and UMTS, the QoS frameworks and mechanisms are common to both technologies. Although the architecture has evolved through the different 3GPP releases, this diagram applies to all releases from R99 to R8.

3GPP-TR.23.207 (2004) also defines four QoS classes, which are presented in Table 6, corresponding to different traffic QoS requirements (mainly, delay tolerance).

Conversational class: Audio and video communications with real time constraints.

Streaming class: This class comprises applications for downloading multimedia contents (audio and video) that are reproduced on-line.

Interactive class. Remote access applications, in which a human or a machine sends requests to a distant server and waits for an answer in a "reasonable" time.

Background class: A whole range of data applications for which delay is not a concern.

Some of the most QoS attributes associated with the profile are Traffic Class, Traffic Handling Priority (THP), Allocation/Retention Priority (ARP) and Bitrates such as Maximum Bitrate or Guaranteed Bit rate, Packet Loss, Jitter or Transfer Delay.

QoS in UMTS: With the introduction of new radio characteristics such as WCDMA over a bandwidth of
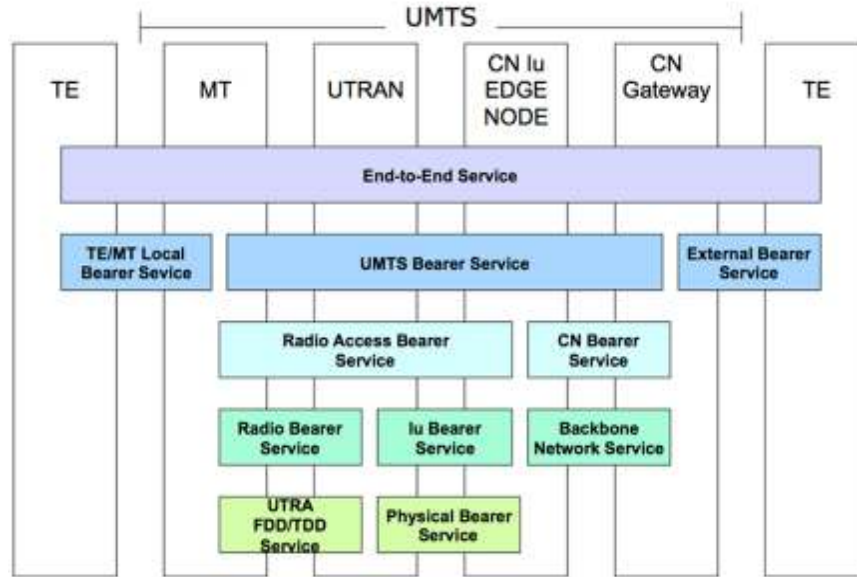
Fig. 2: UMTS end-to-end QoS architecture

Table 7: HSUPA peak data rates

Release	Category	Modulation/dual-cell	Max. No. of codes	Max. data rate (Mbps)
R6	1		1	0.71
R6	2		2	1.45
R6	3		2	1.45
R6	4		2	2.92
R6	5		4	2.00
R6	6		4	5.76
R7	7	16QAM		11.50
R9	8	QPSK, dual-cell		11.50
R9	9	64QAM, dual-cell		22.90

Max.: Maximum

Table 8: HSDPA peak data rates

Release	Category	Modulation/MI/dual cell	Max. number of codecs HS-DSCH	Max. data rates (Mbps)
R5	1	16QAM	5	1.2
R5	2	16QAM	5	1.2
R5	3	16QAM	5	1.8
R5	4	16QAM	5	1.8
R5	5	16QAM	5	3.6
R5	6	16QAM	5	3.6
R5	7	16QAM	10	7.2
R5	8	16QAM	10	7.2
R5	9	16QAM	15	10.1
R5	10	16QAM	15	14.0
R5	11	QPSK	5	0.9
R5	12	QPSK	5	1.8
R7	13	64QAM	15	17.6
R7	14	64QAM	15	21.1
R7	15	16QAM-MIMO	15	23.4
R7	16	16QAM-MIMO	15	28.0
R7	19	64QAM-MIMO	15	35.3
R7	20	64QAM-MIMO	15	42.2
R8	21	16QAM, dual-cell	15	23.4
R8	22	16QAM, dual-cell	15	28.0
R8	23	64QAM, dual-cell	15	35.3
R8	24	64QAM, dual-cell	15	42.2
R9	25	16QAM, MIMO + dual-cell	15	46.7
R9	27	16QAM, MIMO + dual-cell	15	55.9
R9	27	64QAM, MIMO + dual-cell	15	70.6
R9	28	64QAM, MIMO + dual-cell	15	84.4

Max.: Maximum

5 MHz, UMTS provides 0.2 bit/sec/Hz, a maximum data rate of 2 Mbps, RTT at the user plane of 50 msec and call setup time of 2 sec. However, UMTS bearer services have different QoS parameters for maximum transfer delay, delay variation and bit error rate; thus the theoretical offered data rate targets are:

- 144 kbits/sec for satellite and rural outdoor
- 384 kbits/sec for urban outdoor
- 2048 kbits/sec for indoor and low range outdoor

QoS in HSPA: WCDMA networks were further upgraded with R5, R6 and R7 to support High Speed Packet Access (HSPA). High Speed Downlink (DL) Packet Access (HSDPA) was introduced in R6, whiles an Enhanced Uplink (UL), also referred to as High Speed Uplink Packet Access (HSUPA) and was introduced in R6.

With the enhancements of the schedulers, multiple codes, new transport channel called the High-Speed Downlink Shared Channel (HS-DSCH) that uses both QPSK and QAM16 and channelization, data rates have been further increased to reach 14.4 Mbps, with a peak user data rate of 13.4 Mbps (on MAC level). Similarly, HSUPA can also achieve a data rate up to 5.76 Mbps (Siomina and Yuan, 2008; 3GPP-TS.25.306, 2011a). To further increase bitrates, HSPA+, with new functions such as QAM64 on the DL and QAM16 on the UL as well as Multiple Input Multiple Output (MIMO) in the DL only, was introduced with R7. The maximum data rate on the DL is 21.1 Mbps and on the UL is 11.5 Mbps (3GPP-TS.25.306, 2011b).

However, in R7 MIMO cannot be used in combination with QAM64, but it is possible to use it in R8. Additionally, R8 has also introduced the Dual Cell-HSDPA, also referred to as Dual Carrier-HSDPA, DC-HSDPA; where carrier aggregation of two adjacent 5 MHz bands covering the same area. The combination of MIMO and Dual Cell-HSDPA would increase the data rate to a maximum of 28 Mbps with QAM16 and 42 Mbps with QAM64 (3GPP-TS.25.306, 2011a). By combining 64QAM, MIMO-2×2 and Dual-Cell, the data rate has further increased to reach a peak of 84.4 Mbps with R9. Similarly, data rate on the UL has also increased to reach 22.9 Mbps with R9 using 16QAM and dual cell (3GPP-TS.25.306, 2012). Uplink and downlink data rates are presented in Table 7 and 8, respectively.

QoS in LTE: LTE, which was introduced with release R8 is supposed to provide high throughput and low latency in a way to support richer quality of experience for users and the ability to provide sophisticated services and applications such as Video-VoIP, high-definition video streaming, mobile gaming and peer-to-peer file exchange (Yahiya, 2011). In LTE, QoS is provided between UE and PDN Gateway and is applied to the Evolved Packet System (EPS) bearer-Radio bearer, S1 bearer and S5/S8 bearer-as illustrated in Fig. 3.

EPS bearer is further divided into two types of bearers:

- Guaranteed Bit Rate (GBR)
- Non-Guaranteed Bit Rate (non-GBR) referred to as the default bearer (3GPP-TS.36.300, 2010)

A bearer is assigned a value referred to as a QoS Class Identifier (QCI), which refers to a set QoS attributes (3GPP-TS.25.306, 2011b). The mapping of LTE standardized QCI to QoS objectives is presented in Table 9. In addition to QCI, additional QoS attributes are associated with a LTE bearer including:

- Allocation and Retention Priority (ARP)
- Maximum Bit Rate (MBR)
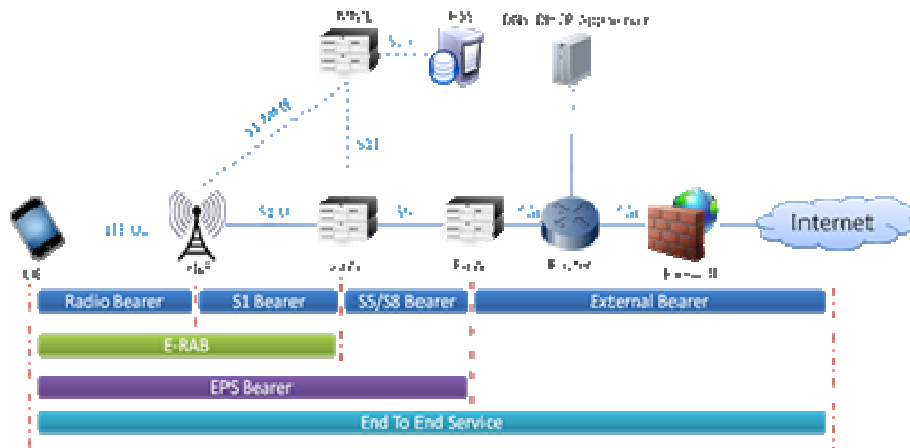- Guaranteed Bit Rate (GBR)
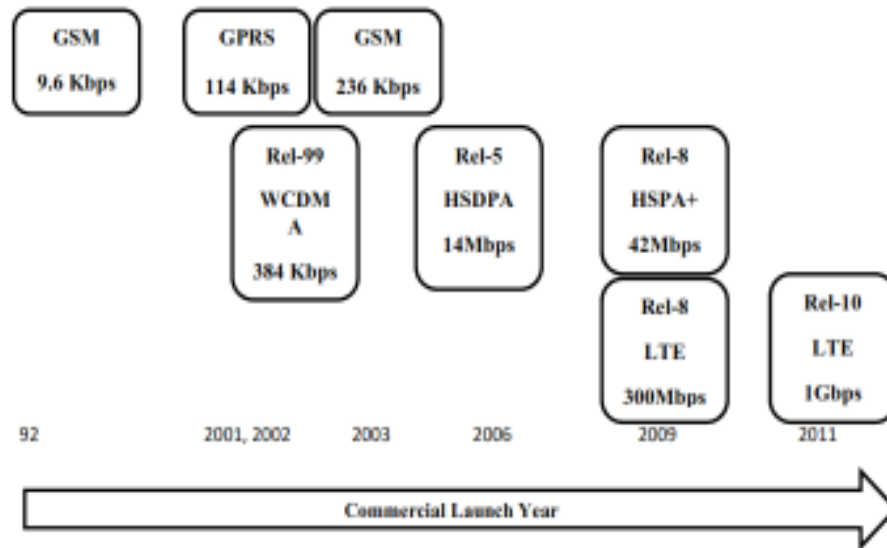- Aggregate MBR (AMBR)

Fig. 3: LTE system architecture

Fig. 4: Evolution of 3GPP peak data rates

Table 9: LTE QoS objectives

QCI	Bearer type	Priority	Packet delay	Packet loss	Applications
1	GBR	2	100 msec	10^{-2}	VoIP
2	GBR	4	150 msec	10^{-3}	Video call
3	GBR	3	50 msec		Online gaming (real time)
4	GBR	5	300 msec	10^{-6}	Video-streaming
5	Non-GBR	1	100 msec		IMS signaling
6	Non-GBR	6	300 msec		Video TCP-based services, FTP
7	Non-GBR	7	100 msec	10^{-3}	Voice, video, interactive gaming
8	Non-GBR	8	300 msec	10^{-6}	Video, email, chat
9	Non-GBR	9			

Table 10: FDD downlink peak data rates

Antenna configuration	SISO	2×2 MIMO	4×4 MIMO
Peak data rate (Mbps)	100	172.8	326.4

Table 11: FDD uplink peak data rates (single antenna)

Modulation	QPSK	16 QAM	64 QAM
Peak data rate	50	57.6	86.4

The traffic generated by a particular application can be differentiated into separate Service Data Flows (SDFs) and mapped to a particular bearer, based on specific parameters provisioned either in the PCRF or defined by the application layer signaling (Alasti *et al.*, 2010). SDFs mapped to the same bearer are treated similarly from the QoS standpoint. LTE is based on new access technique called Orthogonal Frequency Division Multiple Access (OFDMA) on the downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) on the uplink. With a bandwidth consisting of 1.4, 3, 5, 10, 15 and 20 MHz, MIMO up to 4x4 and high modulation (e.g., 64QAM), data rates can be as high as 326.4 Mbps on the downlink and reach 86.4 Mbps in the uplink (3GPP-TS.36.211, 2013; 3GPP-TS.36.212, 2013; 3GPP-TS.36.300, 2013) Peek data rates, for both downlink and uplink, are presented in Table 10 and 11, respectively.

DISCUSSION

Over the past 2 decades, 3 GPP mobile networks have been evolving from GSM in 1992 to LTE Advanced in 2011. Consequently, the QoS frameworks as well as their attributes have also evolved. Peek data rates have increased from 9.6 kbps offered with GSM in 1992 to as high as 1 Gbps with LTE Advanced in 2011. Figure 4 shows the evolution of peak data rates for 3 GPP networks.

However, from our industrial experience, these QoS attributes, including the peek data rates, are theoretical and might not be obtained all the time in commercial networks.

Additionally, as users move within the coverage areas, they might switch to lower data rates, either due to lower radio quality or due to a vertical handover to another technology. Thus, measurements of real QoS attributes, including vertical handovers, in commercial networks should be performed in order to:

- Provide realistic figures for customers
- Improve the QoS performances of the networks

Additionally, mobile applications should take into consideration the real QoS attributes, rather than the

theoretical ones. They also should be designed to properly work with the continuous movements between these different technologies and their associated QoS attributes.

CONCLUSION

In this study we discussed the evolutions of QoS in 3GPP standards showing the various classes and their attributes and frameworks. Furthermore, this study outlined the advantages and drawbacks of each of these technologies and presented the different radio access technologies indicating their digital modulation schemes. Finally, the data rates of the 3GPP standards were theoretically compared.

REFERENCES

3GPP-TS.22.034, 2008. Technical specification group services and system aspects. High Speed Circuit Switched Data (HSCSD): Stage 2. 3GPP Technical Specification, TS 22.034., V8.0.0.

3GPP-TS.23.107, 2004. Technical specification group services and system aspects. Quality of Service concept and architecture, 3GPP Technical Specification, TS 23.107., V6.1.0.

3GPP-TS.23.207, 2004. Technical specification group services and system aspects. End-to-end QoS Concept and Architecture. 3GPP Technical Specification, TS 23.207., V6.4.0.

3GPP-TR.23.802, 2007. Technical specification group services and system aspects. Architectural Enhancements for end-to-end Quality of Service. 3GPP Technical Report, TR 23.802., V7.0.0.

3GPP-TS.25.306, 2011a. Technical specification group services and system aspects. Universal Mobile Telecommunication System; UE Radio Access Capabilities. 3GPP Technical Specification, TS 25.306., V7.12.0.

3GPP-TS.25.306, 2011b. Technical specification group services and system aspects. Universal Mobile Telecommunication System; UE Radio Access capabilities. 3GPP Technical Specification, TS 25.306., V8.12.0.

3GPP-TS.25.306, 2012. Technical specification group services and system aspects. Universal Mobile Telecommunication System; UE Radio Access Capabilities. 3GPP Technical Specification, TS 25.306., V9.1.0.

3GPP-TS.36.211, 2013. Technical specification group services and system aspects. LTE; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation. 3GPP Technical Specification, TS 36.211., V10.7.0.

3GPP-TS.36.212, 2013. Technical specification group services and system aspects. Evolved Universal Terrestrial Radio Access (E-UTRA); Multiplexing and channel coding. 3GPP Technical Specification, TS 36.212., V10.8.0.

3GPP-TS.36.300, 2010. Technical specification group services and system aspects. Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRAN); Overall Description; Stage 2. 3GPP Technical Specification, TS 36.300., V8.11.0.

3GPP-TS.36.300, 2013. Technical specification group services and system aspects. Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access (E-UTRAN); Overall Description; Stage 2. 3GPP Technical Specification, TS 36.300., V10.11.0.

Alasti, M., B. Neekzad, J. Hui and R. Vannithamby, 2010. Quality of service in WiMAX and LTE networks. IEEE. Commun. Mag., 48(5): 104-111.

Sarraf, C. and F. Ousta, 2008. End-to-end quality of services issues in 4G mobile networks. Proceeding of the 12th WSEAS International Conference on Communications, pp: 236-242.

Sarraf, C., F. Ousta, N. Kamel and M. Yusoff, 2012. Quality of service mapping between UMTS, WiMAX and IP-based network in heterogeneous wireless networks. Proceeding of 4th International Conference in Intelligent and Advanced Systems (ICIAS, 2012), pp: 291-295.

Siomina, I. and D. Yuan, 2008. Enhancing HSDPA performance via automated and large-scale optimization of radio base station antenna configuration. Proceeding of Vehicular Technology Conference (VTC, 2008), pp: 2061-2065.

Stankiewicz, Z. and A. Jajszczyk, 2011. A survey of QoE assurance in converged networks. Comput. Netw., 55(7): 1459-1473.

Yahiya, T., 2011. Understanding LTE and its Performance. Springer Science+Business Media, LLC., New York.