Analysis of VoLTE End-To-End Quality of Service using OPNET

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***Abstract*— Long Term Evolution (LTE) is a 3GPP standard for wireless transmission systems. It is also the first 3GPP wireless standard full IP-based. Due to its possibility to reach very high throughput (e.g. 100 Mbps in downlink), an efficient end-to-end QoS treatment is needed in order to guarantee a good QoS perceived by end user (QoE). Voice service delivered by LTE systems is Voice over IP (VoIP) service, with no QoS-aware mechanism. LTE provides a unique and native QoS-aware mechanism for end-to-end service delivering based on EPS bearer and QCI. Since efficient end-to-end QoS management of VOLTE should treat different aspects, this paper analyze the influence of voice codecs on end-to-end VoLTE performance. Different voice codecs are considered in different scenarios simulated using OPNET Modeler software tool. Final comparison among them is provided.**

Keywords: LTE; VoIP; VoLTE; end-to-end QoS; LTE network performance; LTE KPIs; OPNET;

I. INTRODUCTION

Long Term Evolution (LTE) is a Third Generation Partnership Project (3GPP) standard for wireless transmission systems. It is also used to indicate 4 Generation (4G) of wireless systems. It is characterized by several innovative features, like [1]:

- Download data rate: up to 100 Mbps
- Upload data rate: up to 50 Mbps
- Bandwidth: 1,4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz, 20 MHz
- Radio access techniques: Ortogonal Frequency Division Multiplexing Access (OFDMA) in downlink, Single Carrier Ortogonal Frequency Division Multiplexing (SC-OFDM) in uplink
- Spectral efficiency (transmitted bit/s Hz): 3 times higher than HSPA
- Low latencies: < 100 ms from idle to active state, < 5 ms for small IP packets
- Support for at least 200 users per cell in case of frequency bands > 5 MHz
- Optimal mobility support

Due to these important features LTE is able to provide good performances, especially for those bandwidth-consuming services like video streaming or data downloading services. On the other hand voice service (VoIP over LTE) also remains one of the most important services delivered by LTE network.

LTE is first 3GPP full IP-based wireless standard. It means every end-to-end connection between LTE network and end user IP protocol as communication transport protocol. For this reason Circuit Switching (CS) data paths are not present in LTE system but only Packet Switching (PS) data paths.

In order to guarantee minimum Quality of Service (QoS) requirements for its service delivered to the end user and then to improve his perception, LTE standard provides a unique and native QoS-aware mechanism for end-to-end service delivering. Type Style and Fonts

II. EASE OF USE

A. *Reference architecture*

LTE reference architecture is structured into two main parts:

- Evolved UMTS Terrestrial Radio Access Network (E-UTRAN)
- Evolved Packet Core (EPC)

From a protocol stack point of view, LTE is based on data plane (DP) and user plane (UP) as others 3GPP wireless standard.
Fig. 1 presents LTE reference architecture. [2]

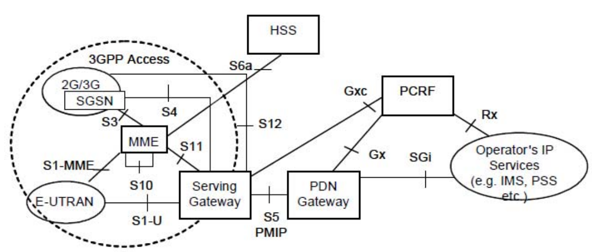

Figure 1: LTE network architecture. [Font: 3GPP]

B. *QoS management*

LTE system foresees a QoS management [3] based on two main elements:

- Evolved Packet System (EPS) bearers
- Quality of Service Class Identifiers (QCI).

EPS bearers are connection-oriented virtual transmission channels carried out on a single Packet Data Network [PDN] connection among two or more end-points. When User Equipment (UE) is going to be attached to LTE networks a

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default bearer is created. It provides a simple connectivity with no QoS policies. If a particular service needs for a QoS guaranteeing, a dedicated bearer can be activated by LTE network. Figure 2 shows relationship between PDN connection and EPS bearer.

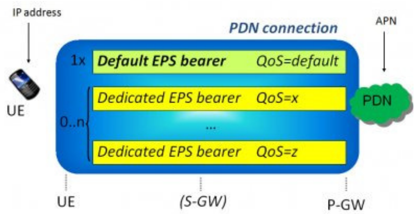


Figure 2: PDN connection and EPS bearer. [Font: 3GPP MCC]

Second ones, QCIs, are scalar parameters used to differentiate digital services delivered by LTE network. They can be:

- Guaranteed Bit Rate (GBR): QoS constraints to be observed
- Non Guaranteed Bit Rate (Non-GBR): no QoS constraints to be observed

Table I shows list of different LTE QCIs. [4]

TABLE I. LTE QCI LIST

QCI	***Resource Type***	***Priority***	***Packet Delay Budget***	***Packet Error Loss Rate***	***Example Services***
1	GBR	2	100 ms	0,01	Conversational Voice
2		4	150 ms	0,001	Conversational Video (live streaming)
3		3	50 ms	0,001	Real-Time Gaming
4		5	300 ms	0,000001	Non-Conversational Video (buffered streaming)
5	Non-GBR	1	100 ms	0,000001	IMS Signaling
6		6	300 ms	0,000001	Video (Buffered Streaming) TCP-based (e.g., web, e-mail, chat, FTP, point-to-point file sharing, progressive video, etc.)
7		7	100 ms	0,000001	Voice, Video (Live Streaming), Interactive Gaming
8		8	300 ms	0,001	Video (Buffered Streaming), TCP-based (e.g., web, e-mail, chat, FTP, point-to-point file sharing, progressive video, etc.)
9		9		0,000001	

Table II explains LTE QCI attributes giving a brief description.

TABLE II. DESCRIPTION OF QCI ATTRIBUTES

QCI Attribute	***Description***
Resource	Type Guaranteed Bit Rate vs. Non-Guaranteed Bit Rate
Packet Delay Budget	Maximum acceptable end-to-end delay between the UE and the PDN-GW
Packet Error Loss Rate	Maximum acceptable rate of IP packets that are not successfully received by the PDCP layer
Allocation Retention Priority	Value assigned for scheduling when capacity is reached, with "1" being highest level

III. VOIP OVER LTE (VOLTE)

VoIP over LTE (VoLTE) is voice service delivered by LTE network using IP transport protocol integrated with SIP signaling protocol. For this reason VoLTE service need IMS subsystem and its node elements. [5]

Figure 3shows VoLTE service architecture based on LTE network and IMS nodes.

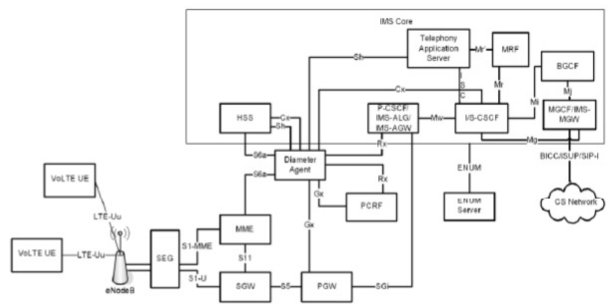


Figure 3: VoLTE intra-PMN scenario. [Font: GSMA]

IV. VOLTE QOS ASSESSMENT

An efficient QoS assessment of VoLTE service is a crucial item for LTE networks operators for several reasons. [6]

In wireless systems quality of service perceived by end-users, also named Quality of Experience (QoE), is essential. Since in case of a VoIP service like VOLTE QoE is strictly related to the quality of speech, QoS-oriented techniques are to be implemented in order to reduce transmission delays or latencies.

Another aspect is that LTE network uses end-to-end IP connection to/from UE: an end-to-end approach to delay reduction is recommended. [7] [8]

Finally VoLTE is service voice for LTE networks. It is characterized by QoS requirements quite different from other services mixed with, like HTTP web browsing or FTP downloading.

An efficient QoS assessment for VoLTE is structured in three main areas to be analyzed and managed:

- Voice codec
- LTE QoS features: Bearer & QCI
- IP network routing enhancement (DSCP mapping)
- Network impairments (network congestions or faults)

Coding and decoding techniques are very important in order to prepare a good digital signal to be transmitted or received. In case of LTE these techniques should be integrated with its QoS management features implemented at network level (EPS bearer and QCI), Type of Service (ToS) and DSCP mapping criteria, network congestion avoidance. [9]

This paper is only focused on the first area: voice codec. Since for 3GPP in case of VoLTE it is mandatory to use at least voice codecs of Adaptive Multi-Rate Narrow Band (AMR-NB) family, this work makes analysis of VOLTE Key Performance Indicators (KPIs) in different scenarios with different voice codecs.

MOS parameter is the most important KPI used to evaluate VoIP service QoS (VoLTE included). [9] Table III shows MOS values and their relationship with QoS perception of a call by end users.

TABLE III. MOS VALUES AND QOS PERCEPTION BY END USER

MOS Values and QoS perception by end user	
MOS value	***QoS perception***
5	Imperceptible
4	Perceptible, not annoying
3	Slightly annoying
2	Annoying
1	Very annoying

Table IV lists all voice codecs considered and relative MOS target value. [10]

TABLE IV. VOICE CODEC CONSIDERED FOR SIMULATION

Simulation scenarios			
Voice Codec	***Sampling frequency [KHz]***	***Transmission rate [kbit/s]***	***Target MOS***
G.711	8	64	> 4.1
GSM EFR	8	12.2	4.3
AMR 12.2 k	8	12.2	4.3
IS 641	8	7.4	4
G.729A	8	8	3.92

In order to evaluate end-to-end VoLTE performances in this work any network transport factors are managed (e.g. SIP signaling, DSCP and other QoS IP-based features, etc) but only voice codecs. [11] [12]

Since an efficient end-to-end approach to quality of service needs to analyze both quality of content delivered (voice in case of VOLTE) and network performances, following main network KPIs are investigated together with MOS:

- End-to-end packet delay
- Voice traffic sent (packets/seconds)
- Voice traffic received (packets/seconds)
- Voice packet delay variation
- LTE downlink delay (seconds)
- LTE uplink delay (seconds)

V. SIMULATIONS

Simulation activities of VoLTE services are performed using OPNET Modeler 17.5 PL6 software tool, based on Discrete Event Simulation (DES) approach. Since purpose of this work is to analyze only influence of different voice coded on end-to-end performance of VoLTE, Type of Service (ToS) considered is only Best Effort (BE).

A. Scenarios

Five different VoLTE scenarios are considered. Each of them uses a different voice codec: G.711, GSM EFR, AMR 12.2K, IS 641, G.729A. Table V lists relationship between scenario and voice codec used during simulation. [13]

TABLE V. SIMULATION SCENARIOS

Simulation scenarios			
Id	***Voice Service***	***Voice Codec***	***Type of Service (ToS)***
1	PCM Quality Speech	G.711	Best Effort (BE)
2	GSM Quality Speech	GSM EFR	Best Effort (BE)
3	GSM Quality Speech	AMR 12.2k	Best Effort (BE)
4	GSM Quality Speech	IS 641	Best Effort (BE)
5	IP Telephony	G.729A	Best Effort (BE)

B. OPNET Settings

1) Network Topology

Figure 2 shows topology of simulated LTE network in a typical campus area 10 x 10 Km.

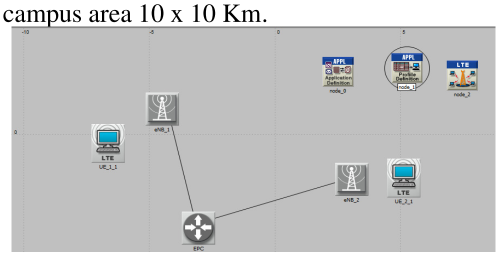


Figure 4: simulated LTE network topology.

Models of LTE network nodes are:

- *LTE_wkstn:* LTE workstation or UE. Entire network topology is composed by two UEs:
  - ✓ UE_1_1: VoLTE source (or caller)
  - ✓ UE_2_1: VoLTE destination (callee).
- *lte_enodeb_3sector_slip4_adv_1_upgvrade:* LTE e-NodeB with 3 sectors. Two different e-NodeBs are considered, one for each UE
- *lte_epc_atm8_ethernet8_slip8_adv:* LTE EPC node
- *PPP_DS3:* link model

OPNET modeler management nodes are:

- *app_config:* application configuration node
- *profile_config:* profile configuration node

- *lte_attr_definer_adv:* LTE attribute definer node

2) LTE settings

Entire LTE network is modeled following parameters listed in Table VI.

TABLE VI. LTE NETWORK SETTINGS

LTE Network Settings		
Network Node	***Parameter Description***	***Parameter Value(s)***
User Equipment	Antenna gain	- 1 dBi
	Modulation and coding scheme	9
	Multipath Channel mode (Downlink)	LTE OFDMA ITU Pedestrian B
	Multipath Channel mode (Downlink)	LTE SC-OFDM ITU Pedestrian B
	Pathloss	Free space
	Receiver sensitivity	-200 dBm
eNodeB	Sectors	3
	LTE bandwidths	10 MHz
	Duplex mode	FDD
	eNodeB antenna gain	15 dBi
	Receive antennas	2
	Transmit antennas	2
	Operating power	20
	Receiver sensitivity	-200 dBm
EPC	DRX for idle mode	256
	N3 bufer size	8192 bytes
Link (PPP DS3)	Traffic load	default

3) Application configuration

In OPNET modeler several applications are predefined and suitable. In this paper voice application is selected.

A new application is created and named *Voice*. Voice application is launched with a start offset of 40 seconds till the end of simulation period. The same application is used for all scenarios but each scenario uses a different voice codec.

4) Profile configuration

A unique profile is created. It is named *Voice Profile*.
Main profile settings are listed in the following table.
In table VII settings of Voice Profile are described.

TABLE VII. VOICE PROFILE SETTINGS

Voice Profile settings	
Attribute	***Value***
Profile name	Voice Profile
Application name	Voice
Start time Offset (seconds)	Constant (40)
Duration (seconds)	End of profile
Inter-repetition	Exponential (300)
Number of repetitions	Unlimited
Repetition Pattern	Serial
Operation Mode	Simultaneous
Start Time (seconds)	Constant (40)
Duration (seconds)	End of simulation
Inter-repetition	Constant (300)
Number of repetitions	Constant (60)
Repetition Pattern	Serial

Voice Profile uses a unique application, *voice* application. Voice Profile uses also a start offset of 40 seconds. So there are two different start offset of 40 seconds: the first one is related to configuration of Voice application, the second one is related to configuration of Voice profile. It means that packets are going to be sent after 80 seconds from simulation starting.

In case of VoLTE simulation, in OPNET modeler a gold bearer is chosen. It provide a 96 Kbps link bitrate both in downlink and uplink.

5) Statistics

DES statistics selected for VoLTE simulation are:

- *Global statistics:*
- *Node statistics:*

In VoLTE simulation the following statistics are selected:

- *Global statistics* (simulation results are provided at entire network level)*:* IP, LTE, Voice
- *Node statistics* (simulation results are provided at network single node)*:* IP, LTE, LTE PHY, UDP, Voice

6) DES settings

For all scenarios simulation period is 3 minutes. Main DES settings are listed in Table VIII.

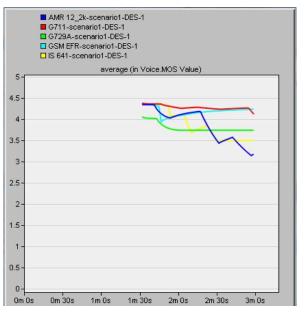
TABLE VIII. DES SIMULATION SETTINGS

DES Simulation setting	
Attribute	***Value***
Duration	3 minutes
Seed	128
Value per statistic	120
Update interval	5000.000 events
Number of runs	1

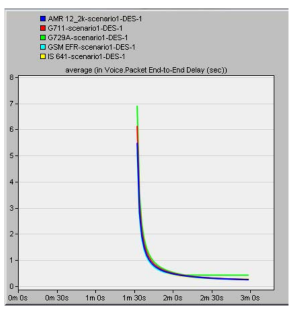
C. *Simulation results*

In this paragraph main simulation results based on KPIs cited in paragraph V are discussed.

Figure 5 shows for each scenario their grafic representation in terms of MOS (a), end-to-end packet delay (b), voice traffic sent (c), voice traffic received (d), voice packet delay variation (e), LTE downlink delay (f), LTE uplink delay (g) .



(a)



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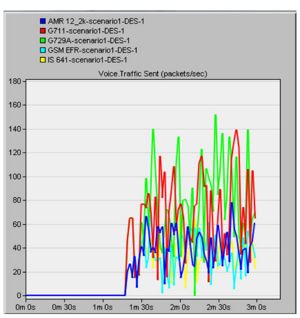

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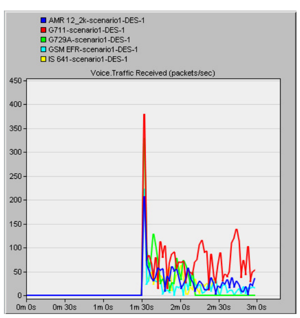

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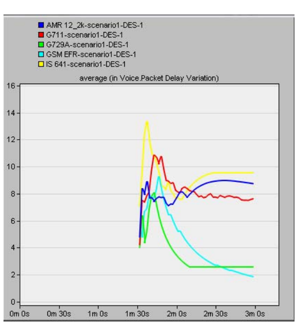

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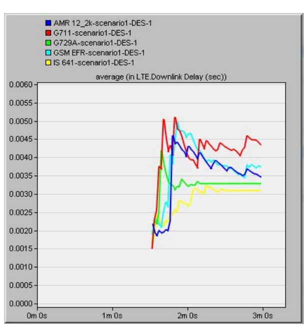
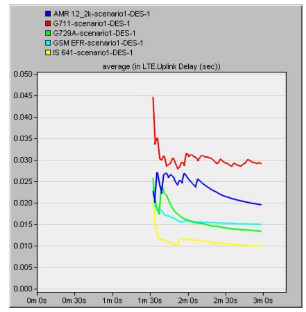


(f)



(g)

Figure 5: Graphic representation of simulation results.

G.711 and GSM EFR codecs can guarantee better performance in terms of MOS, while AMR 12.2k only in terms of end-to-end packet delay.

IS 641codec provides a good performance in terms of LTE delay both in downlink and in uplink.

G.729A and GSM G711 provide a good performance in terms of sent/received voice traffic, while G.729A and GSM EFR in terms of packet delay variation. G.729A provides lowest value of end-to-end packet delay.

Regarding MOS performances, table IX compare measured MOS values with relative target values for each scenario.

TABLE IX. VOLTE PERFORMANCE COMPARISON

VoLTE performance comparison				
Scenario ID	***Voice Codec***	***Target MOS***	***Measured MOS [min value]***	***Measured MOS [max value]***
1	G.711	> 4	4.1	4.3
2	GSM EFR	4.3	3.9	4.3
3	AMR 12.2k	4.3	3.1	4.3
4	IS 641	4.1	3.3	4.1
5	G.729 A	3.92	3.7	3.9

G.711 provides a best performance in terms of MOS because it uses higher transmission bit rate (64 kbps). It can reach target value during entire simulation and its behavior is sufficiently continuous. [12] GSM EFR codec can reach its MOS target for a good part of simulation with a behavior less continuous than G.711. [15]

AMR 12.2k provides only a MOS value near its target in the first part of transmission. After that very low values of MOS are measured. The same behavior is noticed for MOS values provided by IS 641.

G.729A provides a MOS value quite near its target during entire simulation with a behavior more continuous than IS 641 and AMR 12.2k.

VI. CONCLUSIONS

Purpose of this work is to evaluate end-to-end QoS of VoLTE focusing on influence of voice codec. Different voice codecs are considered and used in five different scenarios.

Any network transmission factor is considered. An efficient analysis of end-to-end QoS KPIs is presented. It based on MOS, end-to-delay, voice traffic sent and received, voice packet delay variation, LTE downlink /uplink delay.

From a voice codec point of view, analysis of MOS values measured in each scenario underlines better performances reached by G.711 and GSM EFR codecs.

Other voice codecs (AMR 12.2k, IS 641, G.729A) present a very discontinuous behavior because they are more affected by network transmission factors like transmission delays.

GSM EFR belongs to AMR-NB codec family and it is mandatory to use in LTE.

Future works are going to investigate usage of LTE QoS features and efficient network management techniques in order to improve VoLTE end-to-end QoS perception by end user.

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