# Delay Effect on VoLTE End-to-end Performance

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**Abstract**

Smart city is a new paradigm indicating a well performing city in terms of a efficiency and sustainability perceived in different sectors (e.g. mobility, environment, health, space living) by citizens. New cellular technologies as Long Term Evolution (LTE) are crucial for this new approach due to possibility to enable pervasive reception of digital services by users. In order to be able to use all LTE innovative features, Mobile Network Operators (MNO) need to also guarantee acceptable QoS perceived by end user. End-to-end approach for QoS is strongly recommended, especially for IP delay sensitive services like VoIP over LTE (VoLTE). This work presents analysis of delay impact on VoLTE end-to-end performances in multi-user and multi-service (VoLTE and HTTP web browsing) environment. Different LTE network scenarios are simulated using OPNET modeler 17.5. A final comparison of simulation results is provided in order to evaluate delay impact on VoLTE end-to-end performance.

**Keywords**

LTE, VoIP, VoLTE, End-to-end QoS, QoE, LTE network performance, LTE KPIs, OPNET, IP cloud, Smart cities.

## 1. Introduction

Today our cities need to be smarter, especially in terms of efficiency and sustainability perceived by citizen in different sectors of city, e.g. mobility, environment, health, space living [1, 2, 3]. ICT technologies represent the key factor enabling smart city paradigm. Among them cellular technologies, especially Long Term Evolution (LTE) which indicates 4th Generation (4G) standard for wireless systems, gives to citizens the opportunity to make smarter their living conditions due to a pervasive reception of digital services.

This is surely possible also thanks to the incredible capabilities in terms of computing of modern digital systems that allow the efficient implementation of communication systems [4, 5, 6].

In the first quarter of 2014 number of mobile broadband subscribers was characterized by a very strong growth. As mentioned in [7] they will be expected to growth from 6.8 billion in the first quarter of 2014 to 9.2 billion by the end of 2019. Penetration of LTE terminals has grown very quickly: until June 2014 a value of 240 million subscriptions was reached (35 million of subscription added on the first quarter of 2014).

LTE is the first 3GPP cellular standard full IP-based. It is able to offer to end users a download data rate up to 100 Mbps and an upload data rate up to 50 Mbps [8].

LTE is also characterized by several innovative features. Architecture is more flexible and interoperable. It is composed by radio access interface called Evolved UTRAN (E-UTRAN) and a Core Network called Evolved Packet Core (EPC). LTE system also introduces a direct management of QoS policies based on bearers and QoS Class Identifier (QCI) in order to guarantee acceptable servie reception by end user. QoS policies in LTE are mainly focused on available bandwidth, delay, packet loss ratio, data rate, priority.

Actual scenario of ICT technologies is characterized by a strong convergence of different ICT networks (wireless, wireline, cable). LTE is part of this important multi-network, multi-client and multi-service [9, 10] environment where several networks, services and users are operating.

In order to guarantee acceptable QoS to end user using IP transport protocol and best effort type of service (ToS), Mobile Network Operator (MNO) need to integrate LTE native QoS features with other enhanced techniques based on a QoS end-to-end approach. Especially in case of IP delay sensitive services like VoIP over LTE (VoLTE) [11].

## 2. Related works

Since LTE is full IP-based wireless standard it only enables entire wireless transmission over Packet Switching (PS) paths using IP protocol. All major standardization entities already treated issue of QoS in LTE using end-to-end approach. In [12] ETSI provides end-to-end QoS reference architecture for LTE and a description of relative management functions. If these requirements are mandatory to be implemented, all kind of QoS policies and strategies focused on how manage user's traffic flows are left to MNOs. Moreover, devices should be equipped with suitable hardware in order to perform optimal visualization [13].

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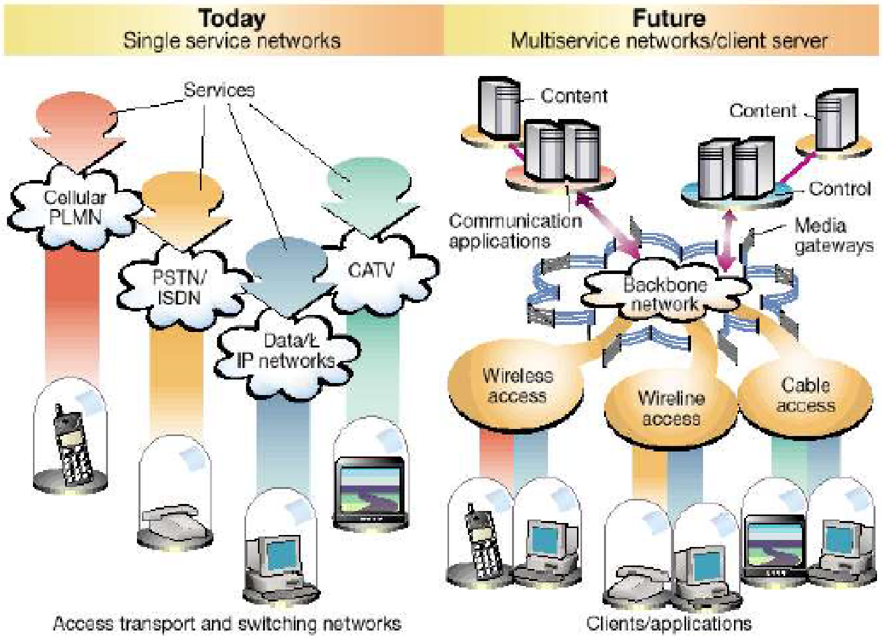



**Figure 1:** LTE network topologies used for simulation

In real scenarios many network impairments can occur (e.g. excessive delay caused by network congestion or faults) and can bring a negative effect for acceptable service transmission/reception [14, 15]. Operators need to adopt opportune network management policies in order to guarantee a good service perception by end user, especially in case of full IP-based network as LTE. In scientific literature several technical papers are focus on it. Vizzarri et al. in [16] presents a review of most important papers focused on end-to-end QoS approach in LTE networks: first studies are only concentrated in E-UTRAN interface, the last ones consider entire transmission chain (both E-UTRAN and EPC).

Network management techniques have also a crucial role for QoS guaranteeing procedures. Horvath in [17] presents a new LTE QoS Signaling (LQSIG) protocol able to guarantee a resource reservation for data path transmission compliant with LTE QCI target values. S. Shen et al. in [18] propose a new LTE performance management framework based on CoS/QoS mapping table: main scope is to identify relationship among QoS informations in LTE and operator transport network. In particular LTE service QCIs are compared with QoS information in case of IP protocol (DSCP value), carrier Ethernet (802.1p value) and MPLS (EXP value). Margoc et al. in [19] analyze QoS in LTE systems that confirms better performances for services with higher priority. Strategies of priority service allocating are left to operators [20]. This is also confirmed by Medbo et al. in [21]. In case of LTE mixed traffic (based on VoIP as first service and real time video or web browsing as second service), service differentiation and prioritization of delay-sensitive traffic (e.g. VoIP) can improve its performance without affecting performances of other delay-insensitive services. Thus is due to small size of VoIP packets.

## 3. VoLTE end-to-end QoS Assessment

Since an efficient end-to-end approach to quality of service needs to analyze both quality of content delivered (voice quality in case of VoLTE) and network performances, a QoS assessment based on the most important Key Performance Indicators (KPIs) is needed [22]. In this work following KPIs are considered in case of VoLTE [23]:

- Mean Opinion Score (MOS)
- End-to-end delay
- Packet loss
- Jitter

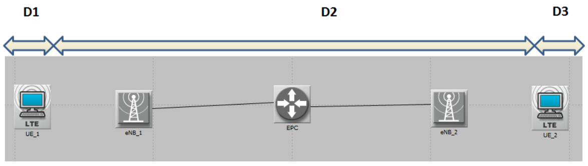



**Figure 2:** End-to-end VoLTE scenario

MOS is a scalar term included in range 1-5. It indicates quality of a voice, VoIP and VoLTE call. Packet loss gives a percentage indication of number of packets lost during transmission. Jitter is variance of packet inter-arrival time. End-to-end delay can be summarized by following formula:

$$D_{e2e-tot} = D_1 + D_2 + D_3 \tag{1}$$

where
$D_1 = D_{Encoding} + D_{Process} + D_{packetization}$
$D_2 = D_{Transmission} + D_{Queing} + D_{Propagation} + D_{Backbone}$
$D_3 = D_{Jitter\_buffer\_delay} + D_{Decoding} + D_{Playback}$

Figure 2 shows a graphic representation.

*D1* is delay affecting VoLTE caller ($UE\_1$). In particular DEncoding is delay due to voice codec utilized, DProcess to hardware processing, Dpacketization due to packetization. *D2* is delay affecting entire LTE network. It is composed by DTransmission due to Uplink and downlink transmission of sender ($UE\_1$) and receiver ($UE\_2$), DQueuing due to queuing and scheduling management of packets, DPropagation due to entire propagation from sender to receiver, DBackbone due to influence of transmission across MNO backbone.

D3 is delay affecting VoLTE callee ($UE\_2$). In particular $D_{Jitter\_buffer\_delay}$ is delay due to buffering capacity, $D_{Dencoding}$ due to decoding phase, $D_{Playback}$ due to terminal software reproducing decoded audio.

Main purpose of this work is to analyze influence of additional impairments on VoLTE KPIs. Impairments are represented by mixed traffic (VoLTE and HTTP web browsing) and delay introduced by presence of IP cloud [24]. D2 is main involved factor. This situation is typical in case of interaction between LTE network and backbone network.

Table 1 shows most KPIs measured in case of VoLTE and HTTP services [25].

# 4. Simulations

Simulation activities of VoLTE services are performed using OPNET Modeler 17.5 PL6 software tool.

**Table 1**
KPIs analyzed for LTE services.

| VoLTE KPIs analyzed | | |
|---|---|---|
| *LTE service* | *Name* | *Measurement Unit* |
| VoLTE | MOS [mean value] | [1..5] |
| | Packet end-to-end delay | seconds |
| | Voice traffic sent | packet/sec |
| | Voice traffic received | packet/sec |
| | Voice Packet Loss ratio | [%] |
| HTTP web browsing | HTTP Web page response time | Seconds |

**Table 2**
simulated scenarios configuration.

| Simulated scenarios configuration | | | | |
|---|---|---|---|---|
| *Scenario* | | *LTE Services* | *IP Cloud* | |
| *Id* | *Name* | *Traffic Flows* | *Packet Discard Ratio [%]* | *Packet Latency [sec]* |
| 1 | 01_VoLTE_no_IPcloud | VoLTE | Not present | Not present |
| 2 | 02_VoLTE_HTTP_no_IPcloud | VoLTE | Not present | Not present |
| 3 | 03_VoLTE_ok_IPcloud | VoLTE<br>HTTP web browsing | 1 | 0.1 |
| 4 | 04_VoLTE_HTTP_ok_IPCloud | VoLTE<br>HTTP web browsing | 1 | 0.1 |

## 4.1. Scenarios

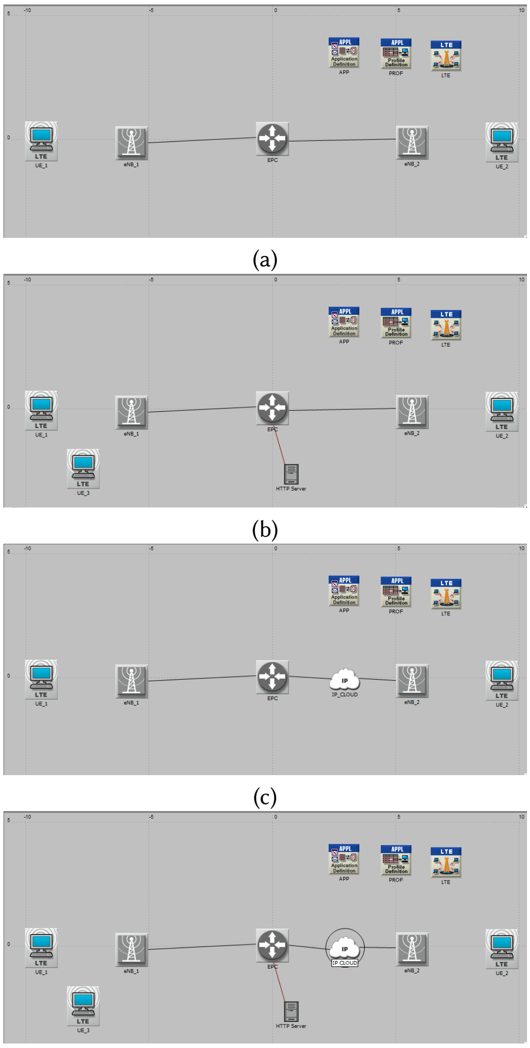
Four different scenarios are simulated changing LTE network topology (with or without IP cloud) and traffic flows (single or mixed).

Scenario n. 1 is characterized by two UEs: $UE\_1$ (caller) is performing a VoLTE call to $UE\_2$ (callee) using a direct link. Traffic flow is single.

Scenario n. 2 is characterized by three UEs and one HTTP web server: $UE\_1$ and $UE\_2$ are performing a VoLTE call while $UE\_3$ is requesting a web service session to HTTP server. Traffic flow is mixed: VoLTE and HTTP web browsing services are performed by UEs.

Scenario n. 3 is similar to scenario n. 1: $UE\_1$ is perfoming a VoLTE call to $UE\_2$, but link among them is interrupted by IP cloud, responsible for addition of packet discard ratio (1%) and delay (01. seconds) to entire transmission chain.

Scenario n. 4 is similar to scenario n. 2: $UE\_1$ and



(a)

(b)

(c)

(d)

**Figure 3:** simulated scenarios.

*UE*_2 are performing a VoLTE call using a direct link interrupted by IP cloud, *UE*_3 is performing HTTP web session.

Table 2 lists the most important features of each simulated scenario.

## 4.2. OPNET Settings

### 4.2.1. Network Topology

Figure 3 shows different LTE network topologies used during simulation activity.

Figure 3a is used in scenario 1, 3b in scenario 2, 3c in scenario 3, 3d in scenario 4.

Simulation area is a typical campus area $10 \times 10$ Km. Models of LTE network nodes are:

- LTE_wkstn: LTE workstation or UE.
- UE_1: VoLTE source (or caller)
- UE_2: VoLTE destination (callee)
- UE_3: requesting HTTP web session
- lte_enodeb_3sector_slip4_adv_1_upgvrade: LTE e-NodeB with 3 sectors. Two different e-NodeBs are considered: eNB_1 serving UE_1 and UE_3, eNB_2 serving UE_2
- lte_epc_atm8_ethernet8_slip8_adv: LTE EPC node
- Ethernet_server: HTTP server
- PPP_DS3: link model for LTE nodes
- 100baseT: link model for HTTP web server

OPNET modeler management nodes are:

- app_config: application configuration node
- profile_config: profile configuration node
- lte_attr_definer_adv: LTE attribute definer node

### 4.2.2. LTE settings

For all simulated scenarios entire LTE network is modeled using parameters listed in Table 3.

### 4.2.3. Application configuration

In this paper voice and HTTP applications are selected among those available in OPNET modeler. New voice application created is named VoLTE. It is launched with a start offset of 20 seconds till the end of simulation period. As requested by 3GPP LTE standard, the same VoLTE application is carried out over EPS bearer with QCI 1 (GBR) and ARP 1.

Table 4 lists the main characteristics of VoLTE application.

New HTTP application is named HTTP. It is launched with a start offset of 40 seconds and it is characterized by:

- N. 1 web page with dimension: 1000 Bytes (constant distribution)
- N. 5 medium images with dimension: uniformly variable from 500 to 2000 bytes
- N. 2 short videos with dimension: uniformly variable from 10000 to 350000 bytes

Table 5 lists the main characteristics of HTTP application.

**Table 3**
LTE Network settings

| LTE Network Settings | | |
|---|---|---|
| *Network Node* | *Parameter Description* | *Parameter Value(s)* |
| User Equipment | Antenna gain | - 1 dBi |
| | Modulation/coding scheme | 9 |
| | Multipath Channel mode (Downlink) | LTE OFDMA ITU Pedestrian B |
| | Multipath Channel mode (Uplink) | 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 buffer size | 8192 bytes |
| Link (PPP DS3) | Traffic load | default |
| Link 100baseT | Traffic load | default |

**Table 4**
VoLTE Application features.

| VoLTE application features | |
|---|---|
| *Attribute* | *Value* |
| Voice codec type | GSM EFR |
| Voice codec transmission bit rate [kbit/sec] | 12.2 |
| Voice codec target MOS | 4.3 |
| Type of Service (ToS) | Best Effort (BE) |
| Voice frames per packet | 1 |
| Compression Delay | 0.02 sec |
| Decompression Delay | 0.02 sec |

### 4.2.4. Profile configuration

In order to simulate VoLTE and HTTP services, two different OPNET profiles are created: VoLTE Profile and HTTP profile. Main settings of profiles are listed in Table 6 and Table 7.

VoLTE Profile uses a unique application, VoLTE application. Since Voice Profile uses also a start offset of 20 seconds, there are two different start offset of 20 seconds: the first one is related to configuration of VoLTE application, the second one is related to configuration of VoLTE profile.

It means that VoLTE packets are going to be sent after 40 seconds from simulation starting. HTTP profile uses a start offset of 40 seconds. Since HTTP application has also a start offset of 40 seconds, IP packets of HTTP session are going to be delivered after 80 seconds after simulation start. Simulation period is 3 minutes for all scenarios.

**Table 5**
HTTP Application features.

| HTTP application features | |
|---|---|
| *Attribute* | *Value* |
| HHTP specification | HTTP 1.1 |
| Page Interrarival Time [sec] | Exponential (60) |
| Object Size (bytes) | constant (1000) |
| Number of objects (Objects per page) | constant (1) |
| Object Size (bytes) | medium image |
| Number of objects (Objects per page) | constant (5) |
| Object Size (bytes) | short video |
| Number of objects (Objects per page) | constant (2) |

**Table 6**
Voice profile settings.

| VoLTE Profile settings | |
|---|---|
| *Attribute* | *Value* |
| Profile name | VoLTE Profile |
| Application name | VoLTE |
| Start time Offset (seconds) | Constant (20) |
| Duration (seconds) | End of profile |
| Repeatability | Unlimited |
| Number of repetitions | Unlimited |
| Operation Mode | Simultaneous |
| Start Time (seconds) | Constant (20) |
| Duration (seconds) | End of simulation |
| Inter-repetition | Constant (300) |
| Repeatability | Unlimited |

## 4.3. Simulation results

In this paragraph main simulation results based on KPIs listed in Table 1 are presented. Figure 4-Figure 8 show

**Table 7**
HTTP profile settings.

| HTTP Profile settings | |
|---|---|
| *Attribute* | *Value* |
| Profile name | HTTP Profile |
| Application name | HTTP |
| Start time Offset (seconds) | Constant (40) |
| Duration (seconds) | End of profile |
| Repeatability | Unlimited |
| Number of repetitions | Unlimited |
| Operation Mode | Simultaneous |
| Start Time (seconds) | Constant (40) |
| Duration (seconds) | End of simulation |
| Inter-repetition | Constant (300) |
| Repeatability | Unlimited |

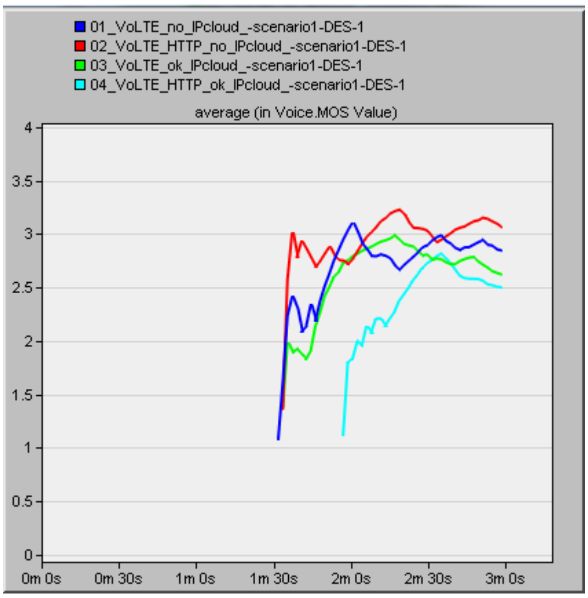



**Figure 4:** Simulation results: MOS mean value.

graphic representation of each scenario in terms of MOS mean value, end-to-end packet delay, VoLTE traffic sent, VoLTE traffic received, HTTP Page response Time.

Table 8 shows comparison of final simulation results for each scenario.

A general comparison among all scenarios underlines better KPIs performance in scenarios 1, 2 (without IP cloud) than ones measured in scenarios 3, 4 (with IP cloud). Simulation results of scenarios 1 and 2 indicate a general behavior of KPIs quite near LTE QoS tar-

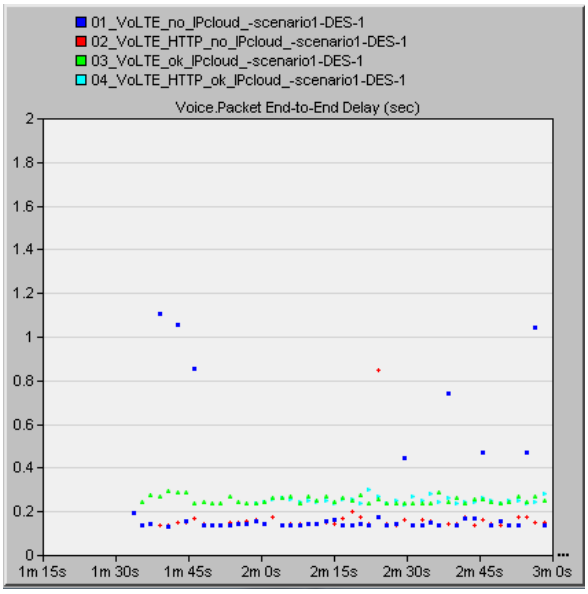



**Figure 5:** Simulation results: end-to-end packet delay.

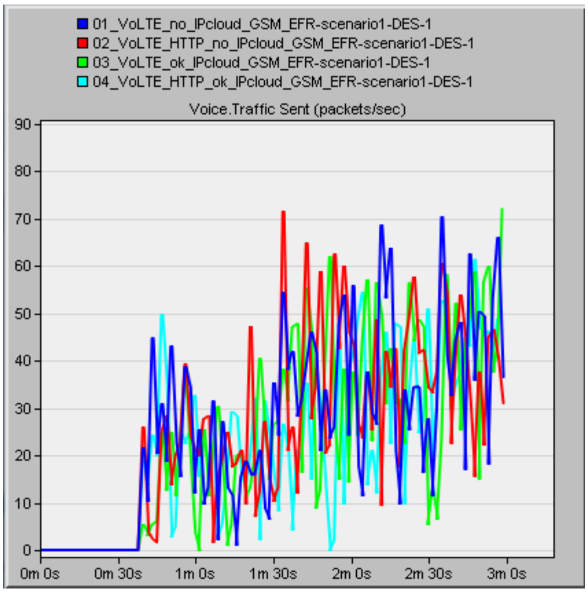



**Figure 6:** Simulation results: VoLTE traffic sent.

get values fixed by QCIs. However MOS mean value is far from target value (see table IV) typical of GSM EFR voice codec. Scenarios 3 and 4 are affected by higher value of end-to-end delay and packet loss than previous scenarios. Worst performance of scenario n. 4 is also evidenced. Combination of mixed traffic together with impairments caused by IP Cloud (1% packet discard ratio and 0.1 second delay) determines KPI end-to-end values around 1.7 in terms of MOS, around 31%

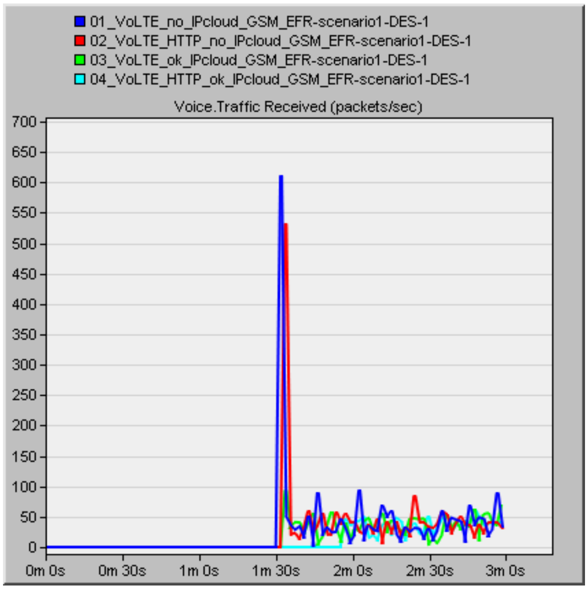



**Figure 7:** Simulation results: VoLTE traffic received.

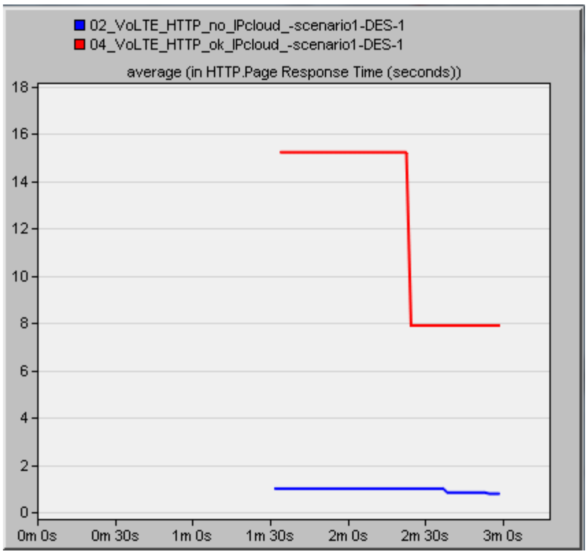



**Figure 8:** Simulation results: HTTP Page response Time.

**Table 8**
Service performance results.

| *Service performance results* | | | | | | |
|---|---|---|---|---|---|---|
| **LTE service** | **KPI** | **Scenario** | | | | |
| Type | Type | 1 | 2 | 3 | 4 |
| *VoLTE* | *MOS mean value [1..5]* | 2.8 | 2.7 | 2.5 | 1.7 |
| | *End-to-end packet delay [sec]* | 0.11 | 0.14 | 0.21 | 0.26 |
| | *Voice Packet Loss ratio [%]* | 6.98 | 8.23 | 27.94 | 31.11 |
| *HTTP web browsing* | *HTTP Web page Response Time [seconds]* | - | 0.94 | - | 11.92 |

in terms of packet loss ratio and 01 seconds in terms of packet delay. These negative performances justify adoption of strong network management techniques by MNO in order to reach maximum value fixed by LTE QCI (10%) using end-to-end QoS approach.

## 5. Conclusion

VoLTE is a crucial service for LTE networks. Purpose of this work is to evaluate end-to-end performance of VoLTE in a multi-user and multi-service environment. Four different scenarios are simulated using OPNET Modeler software tool. Simulation results show a general worsening of all measured KPIs either when HTTP web browsing is added to VoLTE either network impairments due to IP cloud are introduced. Scenario characterized by both of them has the worst performance.

Network impairments due to IP cloud are the heavier factors for a general decrease of VoLTE end-to-end performance. Improvements in LTE network transmission are necessary both in user and control plane in order to improve end-to-service quality perceived by end user and to reach KPI values compliant with requirements fixed by QCIs. Future works are going to investigate network improvements in entire LTE transmission chain and additional techniques able to enhance QoS management (e.g. queue management, user priority).

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