Network and Communication Technologies; Vol. 8, No. 1; 2023
ISSN 1927-064X E-ISSN 1927-0658
Published by Canadian Center of Science and Education

Predicting the QoE of Video Streaming in Communication Networks

Giuseppe Iazeolla[1] & Sonia Forconi[2]

[1] ICT and Internet Engineering, Electronics Engineering Department, University of Roma TorVergata, Via del Politenico1, 00133 Rome, Italy

[2] Department of Engineering Science, Guglielmo Marconi University, Via Plinio 44, 00193 Rome, Italy

Correspondence: Giuseppe Iazeolla, ICT and Internet Engineering, Electronics Engineering Department, University of Roma TorVergata, Via del Politenico1, 00133 Roma, Italy. URL: http://www.sel.uniroma2.it/iazeolla. E-mail: iazeolla@uniroma2.it

Received: May 11, 2023 Accepted: May 25, 2023 Online Published: June 1, 2023

doi:10.5539/nct.v8n1p38 URL: https://doi.org/10.5539/nct.v8n1p38

Abstract

The Video streaming QoE (Quality of Experience) index consists of a series of qualitative factors that are difficult to measure. On the other hand, other Video streaming indices, such as the KPIs (Key Performance Indicators) are easily and physically measurable.

This paper introduces a method to predict QoE based on KPIs measures in (wired or wireless) communication networks. Besides the possible academic interest, the method may practically be of interest to the network operator. Indeed, to ensure compliance with the SLA (Service Level Agreement) he would like to predict how the QoE can change as a consequence of a new network management alternative.

To perform prediction, the problem is that the network operator first needs to know how the KPIs would change due to the alternative, and then find a way to derive (say mathematically) the QoE from the new KPIs.

The contribution of this paper is a simulation/mathematical approach to solving the problem. First, a simulation method is introduced to know how the KPIs would change as a consequence of the new alternative, and then a valid KPI/QoE mathematical relationship is introduced to derive the new QoE from the new KPIs.

The paper is organized as follows: in Section 1 an introduction is given to the definition of QoE in Video streaming. In Section 2 the status of the art from the literature on the KPI/QoE mathematical models is dealt with, and a valid model is identified that derives the Video streaming QoE from the network KPIs. In Section 3, a simulated network is introduced to know how the KPIs would change as a consequence of a new network management alternative. Finally, Section 4 uses the identified mathematical relationship to predict the Video streaming QoE from the measured KPIs.

The considered application is an LTE (Long Term Evolution) network, but the approach can be extended to any communication network, wired or wireless from 3G onwards.

Keywords: Extranet, Intranet**,** Key Performance Indicator (KPI), Mean Opinion Score (MOS), Communication network, Network simulation, OPNET Modeler, Quality of experience (QoE), Video streaming

1. Introduction

Video streaming quality is generally assessed with the QoE (Quality of Experience) index. This index is characterized by a series of qualitative factors that are difficult to measure, such as Audio Quality, Image Corruption, Audio/Video Synchronization, Service Setting-up Time, Re-Buffering, etc. Such factors are illustrated at the top level of Figure 1 (3GPP, 2018a), (Vaser & Forconi, 2018). At Figure 1 lower level (called ES QoS (End-to-End Service Quality of Service)), the network factors that are the cause of each of the upper-level factors are indicated (for example, Re-Buffering is determined by Re-Buffering Frequency and Re-Buffering Time). Finally, at Figure 1 lowest level (called S QoS (System Quality of Service)) the network factors are indicated, called KPIs (Key Performance Indicators) which determine those of the ES QoS (for example Packet Loss Ratio determines Re-Buffering Frequency, Re-Buffering Time, Audio Quality, Intraframe Video Quality, and InterFrame Video Quality).

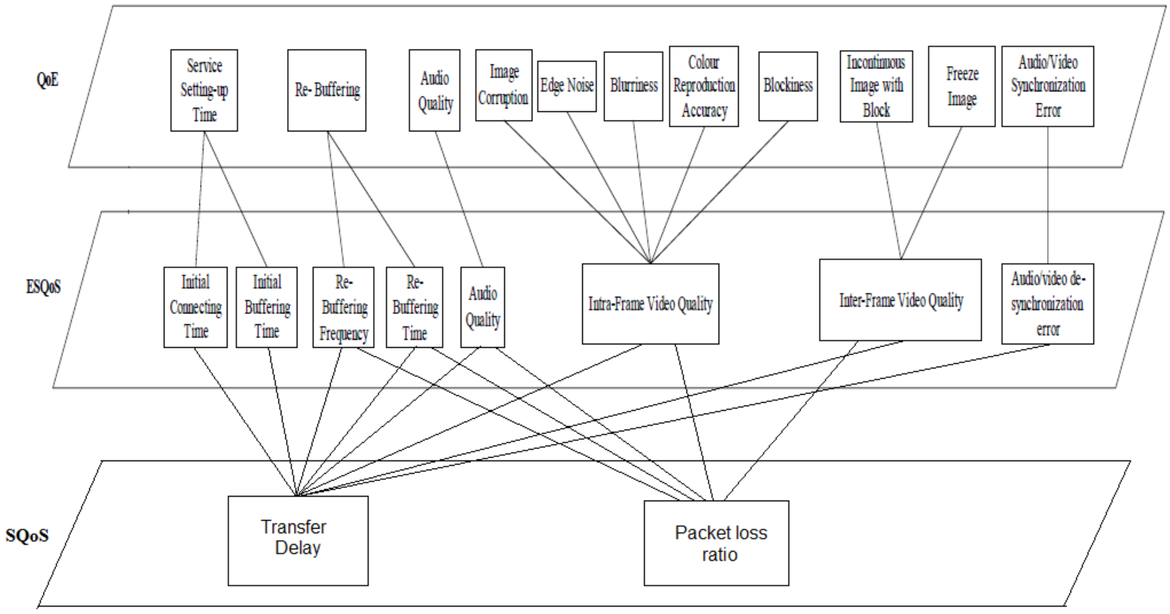

Figure 1. Mapping between KPI and QoE factors for Video Streaming

In summary, Figure 1 shows that at the root of Video streaming QoE, there are two KPIs: Transfer Delay (TD) and the Packet Loss Ratio (PLR) of the communication network.

The KPIs define the network quality, also called QoS, measured by *quantitative* parameters (ITU-T, 2017), (3GPP, 2018 b,c,d). On the other hand, the QoE defines the audio/video quality *subjectively perceived* by the end user and gives information on how well the network meets the user's needs. Examples of video QoE measurements can be found in (Vucic & Skorin, 2020), (Martinez et al., 2021), and (Eb & Fareed, 2022).

The most relevant QoE measurement is the Mean Opinion Score (MOS), an adimensional subjective parameter. The basic element to calculate the MOS is the so-called ACR (Absolute Category Rating), used to perform quality tests (ITU-T, 2022). The levels of the scale are sorted by quality in decreasing order as in Table 1.

Table 1. ACR Rating Scale

Quality level	Assigned value
Excellent	5
Good	4
Fair	3
Poor	2
Bad	1

To arrive at the calculation of the MOS, a series of video sequences, each called PVS (Processed Video Sequence), is presented to the view of a set of participants. Using the ACR scale they express an opinion by an integer in the interval (0,5). The arithmetic mean numeric score over all participants, for each PVS, gives the MOS and is derived by the formula:

$$\mathrm{MOS}_j = (1/I_j)\ \Sigma_i\ o_{ij} \quad i = 1 \ \ldots .\ \mathrm{I}_j$$

where:

o_{ij} is the observed opinion for Participant i and PVS j.

I_j is the number of participants that rated $PVS\ j$

that will result in a decimal in the interval (0-5), a continuous representation of the users' experience.

Below are **Example Mean Opinion Scores** (with accompanied informal evaluations) obtained from a number, say 30, of participants evaluating the QoE of six distinct PVS:

MOS_1 = 1.4450 (nearly all users dissatisfied), MOS_2 = 3.3211 (many users dissatisfied),

MOS_3 = 3.3401 (some users dissatisfied), MOS_4 = 3.6472 (some users satisfied),

MOS_5 = 4.311 (almost all users satisfied), MOS_6 = 4.884 (all users very satisfied).

Unlike QoE, its related KPIs (**PLR** and **TD**) have a physically quantitative evaluation defined as follows:

PLR (Packet Loss Ratio): the % of packets sent that were lost, in a formula:

$$PLR = \left[\frac{(sent - received\ packets)}{sent\ packets}\right] x\ 100 \quad (1)$$

TD (Transfer Delay): time (sec) that a packet takes to go from source to destination, and vice versa, defined into:

- Uplink Transfer Delay: the time it takes for a packet to move from the UE (User Equipment (the source)) to the Video Server (the destination).
- Downlink Transfer Delay: the time it takes for a packet to transfer from the Video Server to the User Equipment.

Figure 2 (Forconi &Vaser, 2018) shows the uplink and downlink along which the packets move in the LTE network, where the E-UTRAN and EPC blocks respectively indicate the Evolved UMTS Terrestrial Radio Access Network (in other words the LTE *Access Network* (3GPP, 2018c)), and the Evolved Packet Core (in other words, the LTE *Core Network* (3GPP, 2018d)).

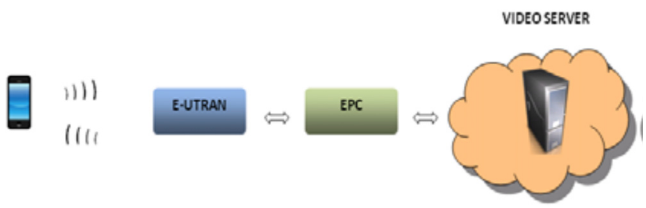

Figure 2. Basic LTE Network scheme for the provision of Video Streaming service

The system of Figure 3 (Aroussi et al., 2012) gives a way to experiment with the effect the PLR and TD play on the QoE of Video streaming. The system includes a VLC Video Client, a Network Emulator (NetEm), and a VLC Video Server (VLC Media Player). NetEm emulates a wide area network by introducing delay (TD) and packet loss (PLR).

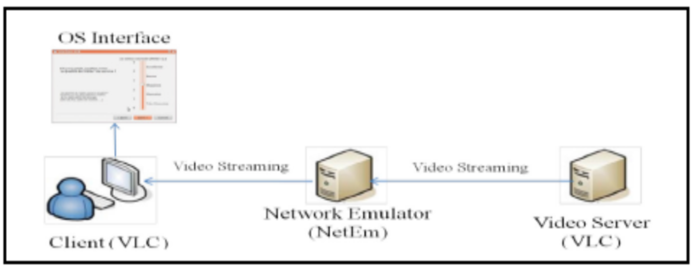

Figure 3. Testbed to study the KPI effects on the Video streaming QoE

The experiment consist in watching a video for 2 minutes, after which the observers express a vote according to the ACR rating scale using the Opinion Score (OS) interface. A given pair (PLR, TD) is chosen and the consequent QoE of the video is evaluated by collecting the votes of 54 observers. As above explained, each observer expresses an opinion by an integer on the interval (0-5). The arithmetical average of opinions is then computed which will result in a decimal on the interval (0-5), that gives the MOS of the QoE for a network with that given (PLR, TD) pair.

In the real world, to ensure compliance with the SLA (Service Level Agreement) the network operator would like to predict how the QoE can change as a consequence of a new network management alternative (see ***Note 1*** at the end).

To perform prediction, the problem is that he first needs to know how the network PLR and TD would change as a consequence of the alternative, and then find out a way to derive the QoE from the new TD and PLR. Such indices are physically measurable. So, to monitor the QoE, the operator might use some KPI/QoE mathematical relationship to derive the QoE from the measured KPIs.

To solve the problem this paper proposes a simulation/mathematical approach. First, a simulation method is introduced to know how the KPIs would change as a consequence of the new alternative, and then a valid KPI/QoE mathematical relationship is introduced to derive the new QoE from the new KPIs.

This work proceeds as follows:

1) In Section 2, the status of the art from the literature on the KPI/QoE existing relationships is dealt with, and a valid relationship is identified, that derives the Video streaming QoE from the network PLR and TD.
2) In Section 3, using a simulated mobile communication network, the pair (PLR, TD) is measured in two different network management alternatives.
3) Section 4, uses the mathematical relationship identified in Section 2 to predict the QoE from the PLR and TD measured in Section 3.

2. Status of the art on the KPI/QoE relationships

This Section deals with the main literature on the KPI/QoE mathematical relationships for communication networks, and the identification of a valid relationship to derive the Video streaming QoE from the network PLR and TD.

The main studies that formally derive the QoE of network services from one or more KPIs can be synthesized as follows.

In (Kovac et al., 2011) an estimation is given of the MOS improvement that can be obtained through Packet Loss modeling.

In (Hossfeld et al., 2008) one of the former hypotheses is given for the exponential interdependency between QoS and QoE of Voice Codecs, known as the IQX Hypothesis.

In (Kim et al., 2008) a measuring method is given to derive the QoE from KPIs such as delay, jitter, packet loss, packet error rate, bandwidth, and call-success-rate, and a KPI/QoE mathematical model is given taking into account the class of service and a coefficient of user satisfaction.

In (Kim & Choi, 2012) a KPI/QoE mathematical model, based on (Kim et al., 2008), is introduced for the IPTV (Internet Protocol Television) services, to evaluate both the IPTV and the IPTV video frame.

In (Truong et al., 2012) a polynomial function, based on (Kim & Choi, 2012), is introduced for the QoE/KPI relationship where only one KPI at a time is considered.

In (Wang et al., 2012) the authors propose a video quality assessment method based on an objective and subjective mapping strategy implemented by considering only one KPI at a time and the related MOS value. The video quality is related to the considered KPI with a correction factor introduced to consider the image complexity and the video transmission speed.

In (Aroussi et al., 2012) a relationship between QoE and several KPIs parameters is introduced. A KPI/QoE exponential model, inherited from (Hossfeld & al., 2008) is proposed, in which the QoE is modeled as a weighted sum of several KPIs (KPI_1, KPI_2, ..., KPIn) as follows:

$$QoE = e^{\alpha_0} e^{-\alpha_1 KPI_1 - \alpha_2 KPI_2 - \ldots - \alpha_n KPI_n} \tag{2}$$

where $\alpha_0, \alpha_1, \ldots, \alpha_n$ are multiple linear regression factors (Rencher & Christensen, 2012).

In the same (Aroussi et al., 2012) the authors apply and validate the model (2) to Video on Demand and specifically to Video streaming using the two KPIs of this paper’s interest, i.e.:

• KPI_1 = Transfer Delay (TD)

• KPI_2 = Packet Loss Ratio (PLR)

Therefore the KPI/QoE exponential model we’ll consider becomes:

$$QoE = e^{\alpha_0} e^{-\alpha_1 TD - \alpha_2 PLR} \tag{3}$$

that shows an exponential decay of QoE for increasing values of TD and PLR.

In Section 4 the testbed of Figure 3 will be used to derive the $\alpha_0, \alpha_1, \alpha_2$ regression factors.

3. Simulation evaluation of the TD and PLR of Video streaming

The above relationship (3) will be used later on in Section 4 to derive the QoE from the given TD and PLR.

In the present Section 3, measures of the PLR and TD are performed, by use of a simulated mobile communication network, in two different network management alternatives.

The network simulator is implemented with the use of the OPNET Simulation System (OPNET Modeler).

Version 17.5 of the Modeler was used (Forconi, 2019). The machine was a Sony Vaio laptop with Intel core I7 2 GHz, 8 GB Ram with Windows Vista 8.1.

Even though the simulated network is an LTE network, this paper's approach can be easily and cheaply applied to any communication network, wired or wireless from 3G onwards and up to 5G and 6G. Indeed, to replicate the approach for a different network, only a few quite cheap tools are needed by the developer. Apart from the OPNET Modeler, he only needs the VLC Media Player and the NetEm emulator of Figure 3. The Modeler is to simulate his communication network. The latter is to estimate the α_0, α_1, and α_2 regression factors (see the way in Section 4). The VLC and the NetEm software can be downloaded for free. The OPNET is the only non-open-source necessary software that can however be obtained at university discounted prices.

This paper's OPNET simulated network is an LTE network assumed to be located in Italy. Figure 4 gives the geographical overview of the simulated scenario.

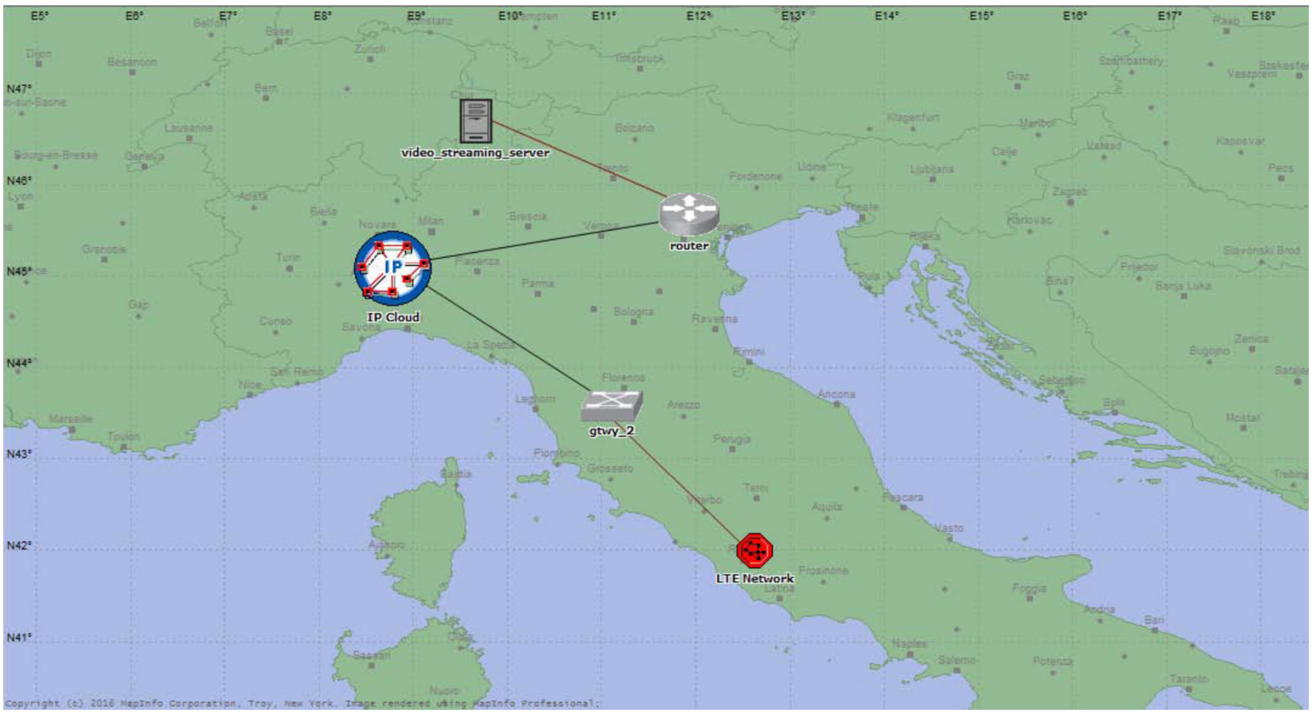

Figure 4. A geographical overview of the OPNET simulation model

There appear the following OPNET nodes:

1) an LTE network node, or Campus Network node, better described below (Figures 5 and 6), physically located in Rome.
2) a Gateway node
3) an IP Cloud node located in the Milan region
4) a Router node located in the Veneto region
5) a Video server CDN node located in the Italy-Switzerland border region.

The Video Server CDN, or Content Delivery Network node (Forconi & Vaser, 2108) is responsible for delivering the traffic by requests coming from the users (Video streaming traffic, FTP traffic, Best effort traffic, etc).

Physical links are as follows:

The Video streaming server is the server that delivers what is requested by users and is linked by a 1000BaseX Ethernet link (Sukhroop et al., 2012) to the Router node, which has 4 Ethernet and 8 IP interfaces. The Router is connected by a 1000BaseX Ethernet link to the IP Cloud node. The Cloud node is in turn linked via the Point-to-Point Protocol T1 link (Lafta et al., 2020) to the Gateway node, simulated by an OPNET Ethernet4_slip8_gtwy, and connected by a 1000BaseX Ethernet link to the Campus Network node.

The work proceeds as follows:

a) **Below, in the current Section 3**, by use of the simulator, the network KPIs (TD and PLR) are measured in two network management alternatives: network with or without call Admission Control (AC). In particular, two simulation studies (Iazeolla & Forconi, 2022) are reported:

Section 3.1: Obtain the TD and PLR for the network without AC (called *Scenario 1*).

Section 3.2: Obtain the TD and PLR for the network with AC (called *Scenario 2*).

[The Admission Control (AC), also called CAC or Call Admission Control (TU-T Y2111, 2009), is the mechanism necessary to guarantee the system an acceptable QoS, in particular for real-time applications such as voice and video traffic. The basic purpose of the AC is to regulate the access of new connection requests by ensuring the integrity of the QoS of already active connections].

b) **In Section 4**: the measured TD and PLR are used to analytically derive the effects of the AC on Video streaming QoE, by use of the KPI/QoE exponential model (3).

3.1 The Scenario 1 Simulation Study

The *Scenario1* model studies the Video streaming KPIs (TD and PLR) arising in the management choice of the network without an AC. Video service requests are assumed to arise in the Campus network, an LTE network described in Figure 5, with a physical dimension of 10x10 km, composed of various OPNET elements, detailed below

The OPNET elements are as follows:

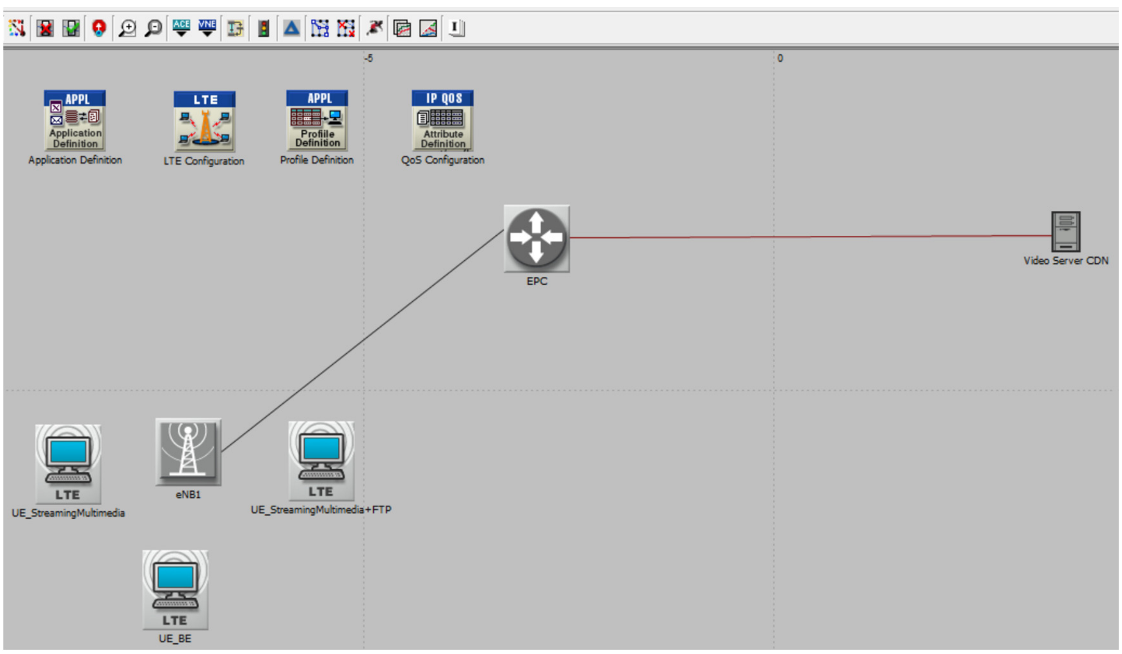

Figure 5. The Scenario 1 (the no AC alternative) Campus network model

1) Three types of User Equipments (UE), which respectively generate:

i) pure Video Streaming traffic (UE_StreamingMultimedia),

ii) Video Streaming + FTP traffic (meaning that the UE generates both Video Streaming traffic and FTP traffic), and

iii) Best Effort traffic (UE_BE).

In other words, to simulate a realistic scenario, in addition to pure Video Streaming traffic, some background traffic is also simulated, which consists of Video Streaming + FTP traffic and Best effort traffic.

2) an eNodeB (the LTE base station) that acts as a radio station for the Ues
3) an Evolved Packet Core (EPC) node (see Figure 2)
4) a video server CDN (Content Delivery Network) node
5) an Application Configuration node, an LTE Configuration node, a Profile Definition node, and a QoS Configuration node.

Physical links are as follows: the eNodeB, at the physical layer, allocates both uplink and downlink shared channel resources. In our OPNET version, the physical channel is set to 10 MHz FDD (see Table 7 in ***Note 2*** at the end). The connection between the eNodeB and the EPC is made with a SONET/OC192, with a speed of 10 Gbps.

The remaining nodes: Application Configuration, LTE Configuration, Profile Definition, and QoS Configuration node are described in ***Note 2*** at the end.

3.1.1 Simulation Output in Scenario 1 (no AC)

The OPNET simulator gives the TD and the PLR measured for the three traffics of *Scenario 1*, i.e. UE_ BE, UE_StreamingMultimedia, and UE_ StreamingMultimedia+FTP. Table 2 reports the measured TD, and Table 3 the PLR.

Table 2. Transfer Delay (TD) in Scenario 1

Scenario 1	End-to-End Delay (sec)
UE_BE	0.00860343187589
UE_StreamingMultimedia	0.00605128523368
UE_StreamingMultimedia+FTP	0.00812700175115

Table 2 shows that the Best effort traffic is the one that suffers the greatest delay, as expected, given the nature of the traffic not subject to any priority treatment (see the OPNET QoS Configuration node *in* ***Note 2*** at the end**).** One can also note that UE_StreamingMultimedia+FTP experiences a greater delay than UE_StreamingMultimedia since its bandwidth availability must be committed to Video traffic and FTP.

Table 3. Packet Loss Ratio (PLR) in Scenario 1

Scenario 1	**Traffic Sent packets/sec**	**Traffic Received (packets/sec)**	**Packet Loss ratio [%]**
UE_BE	34.410228588	34.4092837658	0.002%
UE_StreamingMultimedia	35.3115703195	35.310582409	0.002%
UE_StreamingMultimedia + FTP	34.5856773449	34.5845932695	0.003%

Table 3 shows the value of the traffic sent and received and the packet loss ratio [%] calculated according to formula (1). An almost equal PLR for the three traffics is found, a bit higher for the UE_StreamingMultimedia+FTP, whose transmission consists of a larger number of packets and thus a larger packet discard probabilities.

The Table 2 TD, and the Table 3 PLR of the only traffic of our interest, i.e. only the UE_StreamingMultimedia, will be used in Section 4 to derive the Video streaming QoE of Scenario 1.

3.2 The Scenario 2 Simulation Study

The *Scenario 2* model studies the Video streaming KPIs (TD and PLR) arising in the management choice of the network with an AC. Again as in Scenario 1, the Video service requests arise in the Campus network, an LTE network described in Figure 6, with a physical dimension of 10x10 km, and composed of various OPNET elements, that consist of:

Three types of UEs, two of which generate Video-streaming traffic, and the third generates Best effort traffic, as shown in Figure 6. In more detail :

- a user equipment node, called UE1_StreamingMultimedia, that generates video-streaming traffic.
- a user equipment node, called UE2_StreamingMultimedia, that generates video-streaming traffic with a higher priority (or a lower **ARP** (Allocation Retention Priority, see ***Note2*** at the end) than UE1_StreamingMultimedia)
- a user equipment node, called UE_BE, that generates best-effort traffic.

All remaining nodes are also present in the Figure 5 Campus network of Scenario 1.

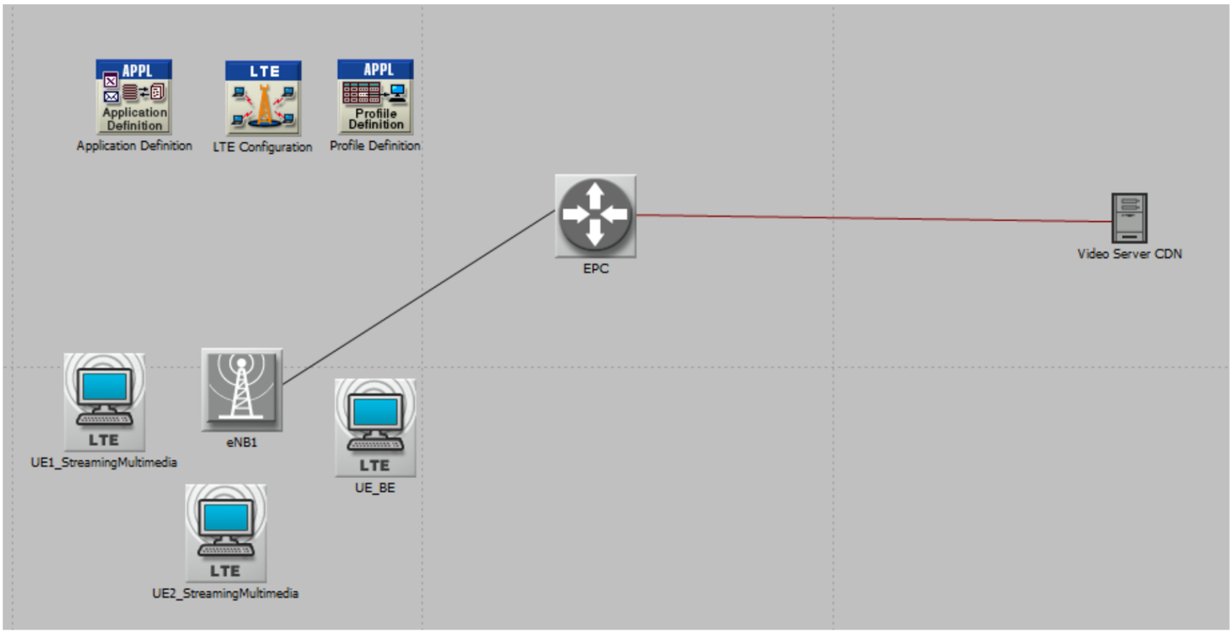

Figure 6. The Scenario 2 (the AC alternative) Campus network model

Physical links between nodes are as in Scenario 1. The remaining nodes: Application Definition, LTE Configuration, and Profile Definition nodes are described in ***Note 2*** at the end.

In the simulation model, the user equipment UE1 was given a lower priority (or a higher ARP) than the UE2 which instead was given a higher priority (or a lower ARP), to better verify how the Admission Control acts on them (so generating a higher TD for the UE1 (whose packets are put longer on hold than the UE2), even though they are both equipped with GBR bearers (see ***Note 3*** at the end), the only non-GBR bearer being the UE_BE. The AC can worsen (Pileggi & al., 2012) in various ways the packet scheduling policies managed by the QoS Configuration node. Indeed, we'll see (Section 4) how small the effect of priorities on the Video streaming QoE is in the presence of AC.

In the OPNET model, the Admission Control is operated by the eNodeB, which manages the **GBR** resources allocated to the UEs based on the **ARP** parameter. In practice, the Admission Control policy will be activated. in case a UE requesting a new connection with a GBR bearer needs insufficient resources (because they are not available at the time of the request).

3.2.1 Simulation Output in Scenario 2

The OPNET simulator gives the TD and the PLR for the three traffics of *Scenario 2*, i.e.: UE_BE, UE1_StreamingMultimedia, and UE2_StreamingMultimedia.

Table 4 reports the TD values, and Table 5 the PLR ones.

Table 4. Transfer Delay (TD) in Scenario 2

Scenario 2	End-to-End Delay (sec)
UE_BE	0.0102129217626
UE1_StreamingMultimedia	1.00564534315
UE2_StreamingMultimedia	0.15145983894

Table 4 shows the resulting TD in Scenario 2, i.e. with the presence of the AC. Comparing Table 4 with Table 2 (case without AC), one can see that the presence of AC significantly increases the TD of both the BE traffic and the Streaming Multimedia traffic. This is what was expected since each new connection is put on hold by the AC, to ensure that the already active connections are completed first. Ad so each new connection gets a higher TD.

However, the comparison with Table 2 also shows the further effect of the AC: that of *altering the priorities between the traffics*. In principle, the BE traffic must be served with lower priority than the Streaming Multimedia (as also guaranteed by the QoS Configuration application, see ***Note 2*** at the end). Therefore BE should be served more *slowly*, and so its TD should be *higher* than the Streaming Multimedia. Now, while Table 2 (without AC) shows that this is true, Table 4 (with AC) shows the opposite, i.e. the TD of BE *is lower* than that of Streaming Multimedia, i.e. the Streaming Multimedia is served more *slowly* than the BE (that is contrary to what the QoS Configuration should guarantee).

Having the QoS Configuration no effect in the presence of AC, the OPNET model of Scenario 2 (Figure 6) does not include the QoS Configuration node, instead, present in the model of Scenario 1 (Figure 5).

A view of the way the AC can alter the priority between the BE and the Streaming Multimedia traffic is reported in ***Note 4*** at the end, where the BE and Streaming Multimedia traffics are considered.

Table 5. Packet Loss Ratio (PLR) in Scenario 2

Scenario 2	Traffic Sent packets/sec	Traffic Received packets/sec	PacketLoss ratio [%]
UE_BE	36.7361771446	36.7107184649	0.07%
UE1_StreamingMultimedia	8.40779962669	4.26751547301	49.24%
UE2_StreamingMultimedia	37.6063524949	24.0950473528	35.92%

Table 5 shows the value of the traffic sent and received and the packet loss ratio [%] calculated according to formula (1). Comparing Table 5 (case with AC) with Table 3 (without AC) one can see how the presence of AC significantly increases the PLR of both the BE and the Streaming Multimedia traffic. This is what was expected since the new connections are sometimes dropped after the AC has put them on hold to complete the active ones.

The Table 4 TD, and the Table 5 PLR of the only traffic of our interest (i.e. only the UE1_StreamingMultimedia and UE2_StreamingMultimedia), will be used in Section 4 to derive the Video streaming QoE of Scenario 2.

4. Analytical derivation of the Video streaming QoE

Once are obtained the End-to-End Delay (TD) and Packet loss ratio (PLR) with the network simulator, one can now proceed to calculate the QoE using a KPI/QoE correlation model (3) introduced above, i.e.:

$$QoE = e^{\alpha_0} e^{-\alpha_1 TD - \alpha_2 PLR}$$

In other words

$$QoE = e^{\alpha_0 - \alpha_1 TD - \alpha_2 PLR}$$

that is easily changed into a multilinear model by writing

$$\log(QoE) = \alpha_0 - \alpha_1 TD - \alpha_2 PLR$$

whose constants $\alpha_o, \alpha_1,$ and α_2 can be estimated by use of a multilinear regression (Rencher & Christensen, 2012). To this scope, the system of Figure 3 was used to vary the TD between 0 and 10000 ms, and the PLR between 0 and 100%. By generating a data sample of 900 pairs [(QoE) and (TD, PLR)], the constants $\alpha_o, \alpha_1,$ and α_2 were estimated by the least squares method and the use of R software (R Project). With the result of:

$$\alpha_o = 1.476,\ \alpha_1 = 0.00004188,\ \alpha_2 = 0.4966$$

Consequently, the QoE/KPIs correlation model we can use becomes:

$$QoE = e^{1.476-(0.00004188)TD-(0.4966)PLR} \tag{4}$$

Reporting in formula (4) the TD and PLR values of Tables 2, 3, 4, and 5, relating to the UE_Streaming Multimedia, the results of Table 6 are obtained, which give the QoE, expressed in MOS (Mean Opinion Score) for the 3 cases:

1) UE Video streaming (UE_StreamingMultimedia) with no Admission Control (Scenario 1).
2) UE1 Video streaming (UE1_StreamingMultimedia) with Admission Control and lower priority than UE2_StreamingMultimedia (Scenario 2).
3) UE2 Video streaming (UE2_StreamingMultimedia) with Admission Control and higher priority than UE1_StreamingMultimedia, and (Scenario 2).

Table 6. Video-streaming QoE with or without AC

Scenario	**TD and PLR**	**QoE (MOS)**
1 UE in the no AC alternative	*0.00605 sec* *0.002 %*	*4.375*
2 UE1 in the AC alternative	*1.00564 sec* *49.24%*	*3.66*
2 UE2 in the AC alternative	*0.15146 sec* *35.92 %*	*3.43*

By using the informal evaluations MOS_1 through MOS_5 of the **Example Mean Opinion Scores** reported in Section 1, one can informally evaluate the MOS results of Table 6 as follows:

UE with no AC (MOS = 4.375) close to "almost all users satisfied" (MOS_5 = 4.311)

UE1 with AC (MOS = 3.66) close to "some users satisfied" (MOS_4 = 3.6472)

UE2 with AC (MOS = 3.43) close to " some users dissatisfied" (MOS_3 = 3.3401)

One can say that the VideoStreaming QoE is affected by the presence of the AC. This is justified considering that the AC produces large increases in the TD and PLR which, according to (4), produce an exponential decay of the QoE. A higher decay for UE1 (whose packets are treated with lower priority (therefore undergo a higher TD, TD = 1 sec)) than for UE2 (whose packets are treated with higher priority (therefore undergo a lower TD, TD = 0.15 sec)).

An operator who had switched from network management with AC to one with no AC without first obtaining a prediction of the possible consequences on the QoE would have greatly damaged the degree of satisfaction of its users. Besides this, going back to the old alternative would not have been easy, or without cost.

It has to be noted however that, in the case of AC, if different priorities are imposed on UE1 and UE2, the resulting difference in their QoE turns out to be quite small (3.43 versus 3.66). This confirms what was announced at the end of Section 3.2: the AC worsens the packet scheduling policies managed by the QoS Configuration node (illustrated in ***Note 2***). In this case, as from Table 6, the effect of priorities on the QoE remains quite small in the presence of the AC.

5. Conclusions

This paper has dealt with the Video Streaming Quality of Experience (QoE) and the Key Performance Indicators (KPI) in communication networks. It is shown that the QoE is hardly measurable. On the other hand, the network KPI indices are physically measurable.

The work has introduced a method to predict QoE based on KPIs measures.

Besides the possible academic interest, the method may practically be of interest to the network operator. Indeed, to ensure compliance with the SLA (Service Level Agreement) he would like to predict how the QoE can change as a consequence of a new network management alternative (e.g. network with or without call Admission Control).

To perform prediction, the problem is that the network operator first needs to know how the KPIs would change due to the alternative, and then find a way to derive (say mathematically) the QoE from the new KPIs.

The contribution of this paper is a simulation/mathematical approach to solving the problem. First, a simulation method is introduced to know how the KPIs would change as a consequence of the new alternative, and then a valid KPI/QoE mathematical relationship is introduced to derive the new QoE from the new KPIs.

The considered application is an LTE (Long Term Evolution) network, but the approach can be extended to any communication network, wired or wireless from 3G onwards.

NOTES

Note 1. The operator this work refers to is not that of a commercial provider operator who, once and for all, has set the KPIs that ensure the optimal QoE that we receive at home via a fixed line (ADSL or Fiber with their 20 or 200 Mbs) or receive wireless at our 90 Mbs mobile phone. Instead, we refer to the operator who, e.g. see an *Internetworked E-Business Enterprise*, Figure 7 (O’Brien, 2006), manages the (wired or wireless) networks that:

a. Connect, via *intranet* links, a thousand employees of his e-commerce services, customer and e-marketing services, accounting and finance services, supply chain management services, and the users of other company locations,

b. Connect, via *extranet* and internet links, a thousand employees of his customers and supply companies,

c. Connect, via *internet* links, the enterprise E-commerce Web Sites.

Such an operator may need to periodically implement new network management alternatives that alter the QoE seen by thousands of users. The method we propose is related to the needs of this kind of operator.

Besides the Internetworked Enterprise, one may think of similar needs of operators that manage the intranet and extranets networks of Research institutions, Banking institutions, State administrative bodies, State military, State hospitals and health bodies, and so on.

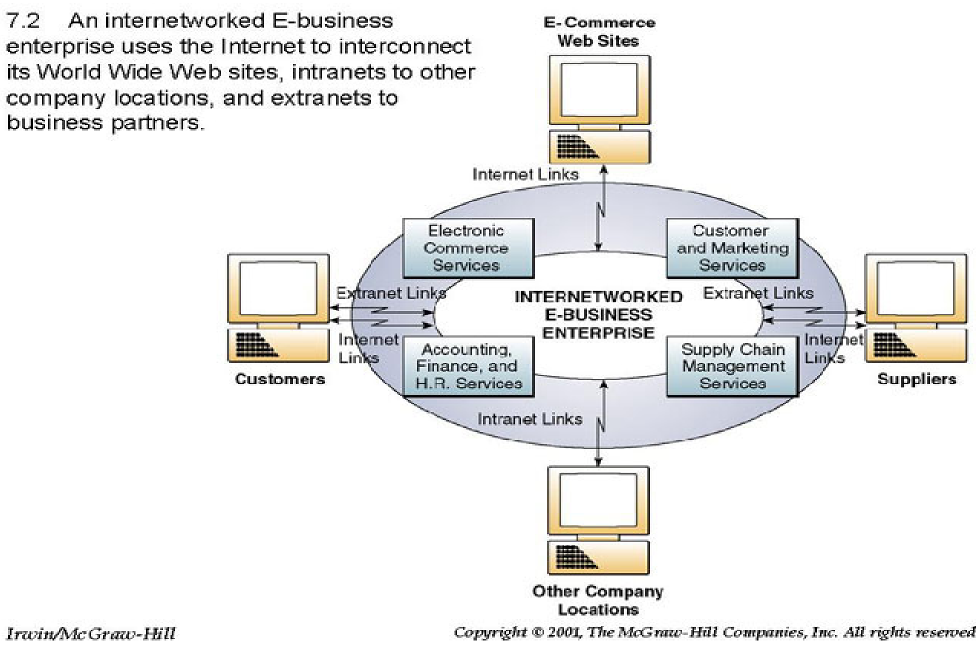

Figure 7. Example context for the operation of this paper method

Note 2. The description of the OPNET nodes appearing in Figures 5 and 6 can be synthesized as follows.

1) ***The OPNET Application Definition node***: a node that generates the applications supported by the LTE network. It is configured to generate pure Video Streaming traffic, Video Streaming + FTP traffic, and Best Effort traffic. OPNET allows you to capture the video streaming traffic with a video streaming client software such as VLC (VLC Media Player) and stores in a file the information necessary for the simulation of the video traffic under examination, such as the size of the packets and the inter-arrival time between them. In this way, OPNET allows the simulation of the transmission of video packets from the video server to the requesting UE.
2) ***The OPNET LTE Configuration node:*** a node that configures the physical profile of the LTE network and the forwarding-packet channels (bearers). Its parameters are shown in Table 7. The bandwidth for both uplink (UL SC-FDMA Channel Configuration) and downlink (DL OFDMA Channel Configuration) tra**nsmission is set at 10 MHz FDD.**

Table 7. Physical profile of the LTE Configuration node

LTE 10 MHz FDD	UL SC-FDMA Channel Configuration	Base Frequency (GHz)	1.92 GHz
		Bandwidth (MHz)	10 MHz
		Cyclic Prefix Type	Normal (7 Symbolsper Slot)
	DL OFDMA Channel Configuration	Base Frequency (GHz)	2.11 GHz
		Bandwidth (MHz)	10 MHz
		Cyclic Prefix Type	Normal (7 Symbolsper Slot)

3) ***The OPNET Profile Definition node***: Traffic generation in the network is not only characterized by the Application Definition node, it is also necessary to define the Profile Definition node, which allows defining how a UE generates traffic through the internet application it is using during the simulation. Basically in the profile, it is defined which application is in use, the instant in time in which the application starts to generate traffic, and for how long during the simulation the traffic generation takes place. In this simulation, the application profiles have been configured in such a way as to start 120 sec after the start of the simulation (Start time) and finish at the end of the same (Duration). Profile repeatability (Repeatability) indicates the repeatability of the profile execution during the simulation. In our case it is set as Once a Start Time, meaning that the profile will start and end with the simulation without repetitions of the application during the profile itself. Each profile is identified by a name, to which one or more applications refer.
4) ***The OPNET QoS Configuration node***: a node that configures the packet scheduling policies. QoS is the different management of various traffic classes to ensure compliance with the SLAs (Service Level Agreements) that the operator undertakes with the user. It is obtained by establishing scheduling operations (that is, more or less privileged treatments to the packets entering the network by users, dividing them into QoS classes). For example, the basic QoS class is the Best Effort in which the network tries to transport packets at its best, without performance guarantees. In the event of congestion and momentary overloads, the excess packet traffic is discarded without particular selection criteria.

Note 3. To better understand what is in Section 3.2 (The Scenario2 Simulation Model), it is good to specify that the QoS in LTE is characterized by three characteristic elements (3GPP, 2017), such as:

- QoS Class Identifier (QCI)
- Allocation Retention Priority (ARP)
- Maximum Bit Rate (MBR/AMBR)

The **QCI** is an integer in the range of 1-9. Three packet treatment quantities are associated with each of its values: a priority level PR, a maximum level of TD, and a maximum acceptable level of PLR. The PR level, the maxTD, and the maxPLR serve to control the forwarding mode of the packet in the network section between the UE and the PDN-GW (one of the components of the core network). The QCI is an important element for QoS as it must be respected for example in the forwarding functions of packets in the network (scheduling), to guarantee specific levels of QoS.

The QCIs divide the forwarding-packet channels (**bearers**) into two categories: Guaranteed Bit Rate (**GBR**) to indicate the bearers that ensure a minimum guaranteed bit rate for the entire duration of the service and Non-Guaranteed Bit Rate (**Non-GBR**) for indicate bearers that do not ensure a guaranteed minimum bit rate. The PR level serves to ensure the required QoS levels for the related services, therefore, for example, in the event of network congestion, the traffic scheduler implemented in the eNodeB must first satisfy the delay requirements of the bearers, and then the flows of higher priority packets, bringing the values relating to delay and loss within the standardized ranges.

The **ARP** (3GPP, 2017) is an integer in the range between 1 and 15 where 1 indicates the highest priority that is used for managing the access procedure, in the case of cell congestion, and affects the priority with which connections are established of the various users. By connections, the establishment of new bearers is meant. For example, when it is necessary to create a new bearer in the LTE network with insufficient resources, the ARP allows deciding whether to remove an existing bearer and create a new one for the new connection that is requesting it, or whether to reuse the existing bearer for the new connection. So the ARP element is only considered when a new bearer is created. Once the bearer has been created, this parameter does not influence how the network manages the information flow associated with it.

The **MBR** allows the definition of a maximum value for the amount of bandwidth available for GBR-type bearers. Instead, an aggregate value specified by the aggregate maximum bit rate (AMBR) is used for Non-GBR. This value allows controlling the amount of bandwidth that can be allocated to all (hence the term aggregate) Non-GBR bearers of a UE.

Note 4. Figure 8 shows the trend of the UE_BE, the UE1, and the UE2 traffic under the effect of the Admission Control.

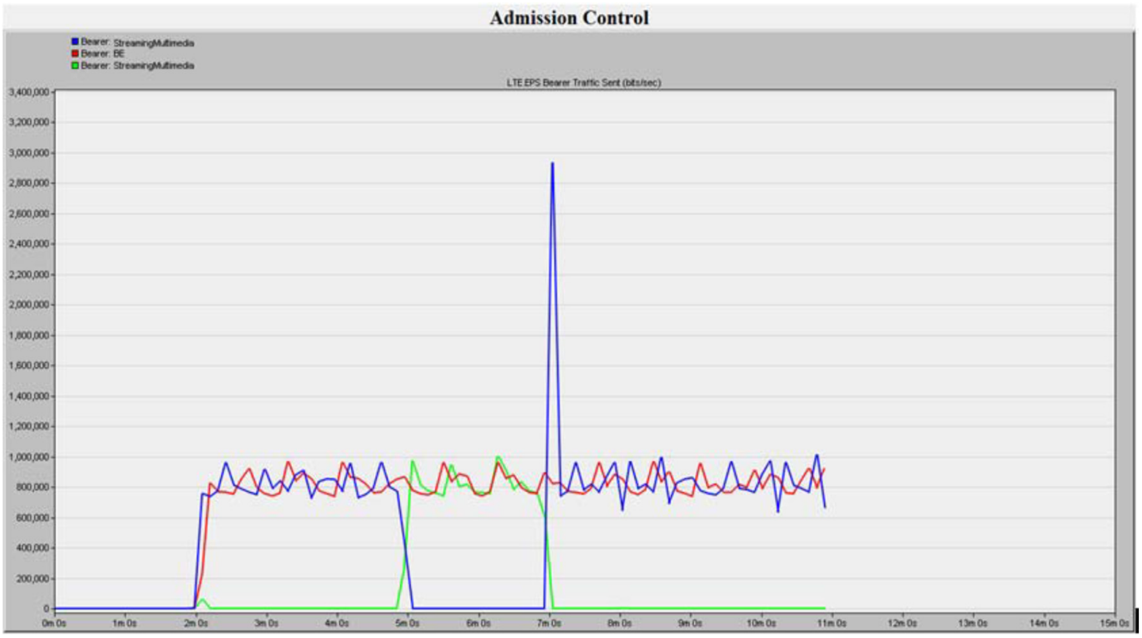

Figure 8. Trend of the UE_BE, the UE1, and the UE2 traffics and Admission Control

One can see that UE1_StreamingMultimedia (blue line) and UE_BE (red line) initially generate traffic but, as soon as (instant 4.9) the UE2_StreamingMultimedia (green line) also begins to generate traffic (i.e. the UE with higher priority than UE1), the EU1 packets (blue line) are traffic blocked due to the action of the AC. The UE1_StreamingMultimedia (blue) throughput is zeroed (instant 5.1) until the UE2_StreamingMultimedia stops sending packets. At instant 6.9, the UE1 (blue) resumes exchanging packets as the exchange of UE2 (green) decreases, completely zeroing at instant 7.1.

Acknowledgments

Funding was from the University of Rome Tor Vergata, Rome Italy, the Strategic Plan on the Performance of Communication Networks, and Next-Generation Networks. The authors are grateful to the anonymous referees

fore their valuable comments.

References

3GPP Tech Rep 26.944 v.10.0.0. (2018a). End-to-end multimedia services performance metrics.

3GPP Technical Specification TS 23.207 V 10.0.0. (2018b). End-to-end Quality of Service (QoS) Concept and Architecture.

3GPP Technical Specification 23.207. (2017). End-to-end Quality of Service (QoS) concept and architecture.

3GPP TS 32.450 version 8.0.0 Release 8. (2018c). Universal Mobile Telecommunications System (UMTS); LTE; Telecommunication management; Key Performance Indicators (KPI) for Evolved Universal Terrestrial Radio Access Network (E-UTRAN): Definitions.

3GPP TS 32.455 version 10.0.0 Release 10. (2018d). LTE; Telecommunication management; Key Performance Indicators (KPJ) for the Evolved Packet Core (EPC).

Aroussi, S., Bouabana-Tebibel, T., & Mellouk, A. (2012). Nat. High Sch. of Comput. Sci., Algiers, Algeria. Empirical QoE/QoS correlation model based on multiple parameters for VoD flows. *IEEE Global Communications Conference (GLOBECOM)*. 2012. https://doi.org/10.1109/GLOCOM.2012.6503403

Eb, R., & Fareed Ghani, R. (2022). Audio-visual quality of experience prediction based on ELM Model. *International Journal of Intelligent Engineering and Systems*, Dec.2022. https://doi.org/10.22266/ijies2022.1031.27

Forconi S., & Vaser M. (2018). 4G LTE Architectural and Functional Models of Video Streaming and VOLTE Services. *The International Conference on Ubiquitous and Future Networks*. Sapporo, Japan, July 2018. https://doi.org/10.1109/ICUFN.2015.7182650

Forconi, S. (2019). Analisi funzionale del servizio Data Streaming in LTE e studio simulativo delle relazioni tra QoE e QoS (Functional analysis of the Data Streaming service in LTE and simulation study of the relationships between QoE and QoS) (PhD Thesis, University of Roma TorVergata), April 2019.

Hossfeld, T., Hock, D., Tran-Gia, P., Tutschku, K., & Fielder, M. (2008). Testing the IQX Hypothesis for Exponential interdependency between QoS and QoE of Voice Codecs and G.711. *18th Seminar on Quality Experience*. Sweden, 2008.

Iazeolla, G., & Forconi, S. (2022). *Evaluating the Video Streaming QoE in LTE networks*. Report RI 03-22, ICT and Internet Engineering, Electronics Engineering Dept., University of Roma Torvergata, March 2022.

ITU-T Recommendation P.10/G.100. (2017). *Vocabulary for performance and quality of service*. 2017.

ITU-T P.910. (2022). *Recommendation. Subjective video quality assessment methods for multimedia applications*.

Kim, H. J., & Choi, S. G. (2012). *A study on a QoS/QoE correlation model for QoE evaluation 011 IPTV service*. Coll. of Electr. & Comput. Eng., Chungbuk Nat. Univ., Cheongju, South Korea 2012.

Kim, H. J., Lee, D. H., Lee, J. M., & Lee, K. H. (2008). Sch. of Electr. &Comput. Eng., Chungbuk Nat. Univ. (CBNU), Cheongju. *The QoE Evaluation Method through the QoS-QoE Correlation Model. Networked Computing and Advanced Information Management*, 2008. https://doi.org/10.1109/NCM.2008.202

Kovac, A., Halas, M., Orgon, M., & Voznak, M. (2011). E-Model MOS Estimate Improvement through Jitter Buffer Packet Loss Modelling. *Information and Communication Technologies and Services, 9*(5), 2011. https://doi.org/10.15598/aeee.v9i5.542

Lafta, S. A., Ali, A. H., Kareem, M. M., Hussein, Y. A., & Ali, A. H. (2020). Performance simulation of broadband multimedia wireless networks simulation based on OPNET. *Indonesian Journal of Electrical Engineering and Computer Science, 17*(1), January 2020. https://doi.org/10.11591/ijeecs.v17.i1.pp1-9

Martinez, H. B., Hines, A. M., & Farias, C. Q. (2021) Perceptual Quality of Audio-Visual Content with Common Video and Audio Degradations. *Applied Sciences, 11*, 5813, 2021. https://doi.org/10.3390/app11135813

NetEm. Retrieved from https://network-emulator-for-windows-toolkit.software.informer.com/

O'Brien, A. J. (2006). Introduction to Information Systems. Essentials for the Internetworked Enterprise McGraw-Hill Irwin 2006.

OPNET Modeler. Retrieved from http://www.riverbed.com/

Pileggi, P., Iazeolla, G., & Kritzinger, P. S. (2012). Demonstrating the Synergy between CAC and Scheduling in

Wireless Networks. *International Journal of Modeling, Simulation, and Scientific Computing IJMSSC*, Nov 2012. https://doi.org/10.1142/S1793962312500274

Rencher, A. C., & Christensen, W. F. (2012). Multivariate regression. *Introduction, Methods of Multivariate Analysis, Wiley Series in Probability and Statistics* (vol. 709, 3rd ed., p. 19). John Wiley & Sons. https://doi.org/10.1002/9781118391686

R Project. The R Project for Statistical Computing. Retrieved from http://www.r-project.org.

Sukhroop P., Singla K., & Singla, A. (2012). Simulate the performance parameters of wired WND wireless networks. *International Journal of Engineering Research and Applications (IJERA), 2*(1).

Truong, T. H., Nguyen, T. H., & Nguyen, H. T. (2012, February). On relationship between quality of experience and quality of service metrics for IMS-Based IPTV networks. In *2012 IEEE RIVF International Conference on Computing & Communication Technologies, Research, Innovation, and Vision for the Future* (pp. 1-6). IEEE. https://doi.org/10.1109/rivf.2012.6169844

Recommendation, I. T. (2009). Resource and Admission Control Functions in Next Generation Networks. *Y. 2111 Revision 1*.

Vaser, M., & Forconi, S. (2018). QoS KPI and QoE KQI Relationship for LTE Video Streaming and VoLTE Services. *The International Conference on Next Generation Mobile Applications, Services, and Technologies. Cambridge*, UK September 2018. https://doi.org/10.1109/NGMAST.2015.34

VLC Media Player, http://www.videolan.org/

Vucic, D., & Skorin-Kapov, L. (2020). *QoE_Assessment_of_Mobile_Multiparty_ AudioVIsual Telemeetings*. IEEE Access. https://doi.org/10.1109/ACCESS.2020.3000467

Wang, W., Jin, Y., Yang, T., & Cui, Y. (2012, October). A video quality assessment method using subjective and objective mapping stategy. In *2012 IEEE 2nd International Conference on Cloud Computing and Intelligence Systems* (Vol. 2, pp. 514-518). IEEE. https://doi.org/10.1109/CCIS.2012.6664227

Copyrights