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Quality of Service Experience for Cellular Data Network in Residential Clutter

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ABSTRACT

The current network usage is data-oriented, and this has also become a major concern to service providers to ensure that subscribers are satisfied in this regard. In this research, an approach for objective quality of experience (QoE) measurements of three quality of service parameters was implemented in an indoor setting. The quality of service (QoS) parameters include packet loss, latency, and jitter, measured through packet capture of LTE data services transmitted by three mobile network providers in Nigeria. Regression coefficients of the exponential mapping functions were obtained by using lower end and upper end benchmark values, and the resulting model was used to map the QoS onto the mean opinion score (MOS). By the valued MOS from the mapping function for packet loss, we obtained quality of experience (QoE) rated 'very good' for all the networks, with MNO2 as the best. For latency, we obtained a poor QoE for MNO1 and MNO3 and a fair QoE for MNO2. In terms of jitter, MNO1 and MNO2 were rated poor, while MNO3 was rated very bad QoE. MNO2 was seen to be the best in overall performance.

Keywords: Experience; Jitter; Latency; Packet loss; Quality; Service.

1. Introduction

The demand for data services in the cellular network has become even higher than the demand for voice services in recent years. According to Ivo et al. (2020), data traffic will reach a 7-fold increase between 2017 and 2022, representing a 46% annual growth rate. In their work, Saeid et al. (2015) stated that the popularity and expansion of public switch telephone networks (PSTN) will be diminishing with the emergence of high-speed public switch data networks (PSDN), which include the 3G, HSPA, HSPA+, WiMAX, fourth-generation long-term evolution network (4GLTE), emerging 5G, and so on. Today there are so many avenues through which cellular data is put to use. These include the social networks (WhatsApp, Facebook, Instagram, Twitter, etc.), YouTube, email services, online shopping, multi-level marketing, video calls, virtual meetings, etcetera. According to the National Communication Commission (NCC), a total of 112,055,872 mobile internet subscriptions were recorded in Nigeria in 2018, and data-only mobile broadband subscriptions (dongles) recorded 733,933 subscriptions during the same period (NCC, 2018). There is also a global report of 2015-2020 by Ericsson that monthly global traffic will exceed 30.5 exabytes by 2020, with 40% on mobile LTE subscriptions within the same period (Giuliana et al., 2016). This shift in network traffic has come with a lot of challenges, which some researchers noted should require good management of the network, not just by providing additional bandwidth but also by the quality of service QoS offered by the operators (Sumit et al. 2013). In their work, Fiedler et al. (2010) stated that in usability engineering, the reaction time threshold of the user is as follows: 100ms as when the user perceives the network is responding instantaneously; at less than 1s, delay is perceived but not enough to generate reactions; less than 10s can spur anxiety, while at above 10s comes the risk of the user abandoning the activity on the web. This has opened the research front for this work to investigate the quality of data service offered by the operators as it affects the end user quality of experience (QoE) in a broadband network here in Nigeria. According to Edy et al. (2017), quality of service refers to the overall quality of applications experienced by the end users of the network. Though many of the times, good QoS results in better QoE, fulfilling all traffic requirements may not guarantee user satisfaction, meaning that QoS may not translate directly into QoE Stankiewicz and Jajszczyk (2011). The author of Vera (2017) had shown that QoE can reliably be judged by the quality of service metrics and radio frequency channel measurements of signals offered by the service provider. And QoE is the user perception about the quality of particular service offered by the network (Nokia, 2020; Vera, 2017).

In measurement of QoS, six parameters can be used, namely: upload speed, download speed (or throughput), latency or round trip time (RTT), jitter, packet loss, and availability (Mizuta et al., 2009; Edy & Umul, 2017). Ghassan et al. (2011) defined throughput as the total amount of data exchanged per second between source and destination in a network. And round-trip time, as defined by Guang-Qian (2018), is the time interval from which a data packet is sent until it is acknowledged. Latency is the time it takes a subscriber to make a service request and for the request to reach the destination host/server. Latency can either be one-way or round-trip, but the latter is the commonly used measure. Motorola (2009). Round trip time (RTT), as defined in Guang-Qian (2018), is the time interval from which a data packet is sent until it is acknowledged. RTT covers the time from the initiation of a service request on the subscriber's device (e.g., a mobile phone) through the network and back down the network until the result displays on the subscriber’s device. Jitter is defined in Edy et al. (2017) as the end-to-end delay from one packet to the next within the same packet stream/connection/flow, or simply the variation of latency as in Edy and Umul (2017). While packet loss is the amount of packet that fails to reach its destination host or server over the network, The negative impact of packet loss is mostly noticed on video streaming or VOIP traffic. Our QoS parameter measurements shall be carried out over 4GLTE networks. “Long Term Evolution (LTE) is a type of 4G wireless broadband technology developed by the Third Generation Partnership Project (3GPP) release 8 and represents the competitiveness of Universal Mobile Telecommunications System (UMTS)” (Ghassan et al., 2011). LTE network standard was first published in March 2009, with the objective of high-data-rate, low-latency, and packet-optimized radio access technology (Ghassan et al., 2011). It was intended to enhance the Universal Terrestrial Radio Access Network (UTRAN). The major parts of the LTE network include evolved NodeB (eNodeB), serving gateway, packet data gateway, user equipment, and routing unit (Ghassan et al., 2011). The LTE wireless access technology user-throughput in the uplink and downlink is targeted at 100Mbps and 50Mbps, respectively, far higher than preceding 3G networks, with improved user-plan latency of less than 5ms, Motorola (2009). Therefore, the use of LTE should improve the end-user quality of experience (QoE).

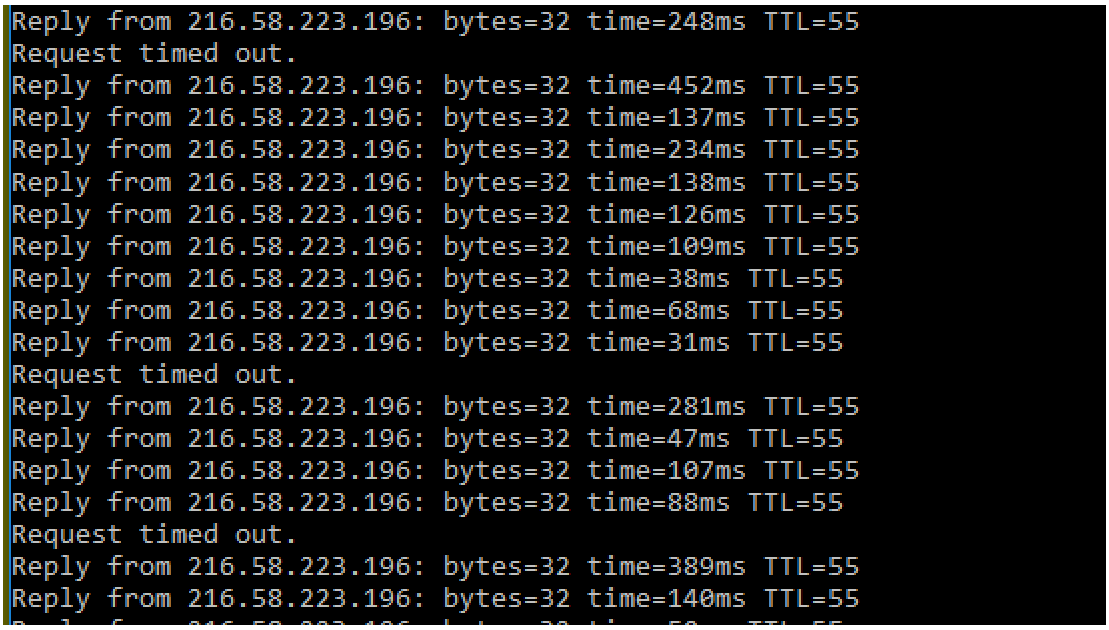
Tchao et al. (2018), in their work conducted in Ghana, used some key network parameters at 2600 MHz of the LTE network under varying MIMO antenna configurations in their performance check. The metrics included average sector throughput, peak downlink throughput, peak uplink throughput, and reference signal received power (RSRP) up to a distance of 2.5 km from the foot of the tower on the drive test. The bulk of the work on 2x2, 4x4, and 8x8 MIMO antennas was simulation-based, and afterwards we were only able to conduct field measurements on 2x2 due to constraints. Simulation results showed the 8x8 to outperform the 4x4 and 2x2. A related study was carried out by Imoize and Adegbite (2018) in Lagos State, Nigeria. They worked on a measurement-based performance analysis of a 4G network using five key performance parameters, namely signal-to-noise plus interference ratio (SINR), reference signal received power (RSRP), packet data convergence protocol (PDCP) downlink throughput, and packet component career downlink throughput, as well as reference signal received quality (RSRQ). Their measurement was carried out at 1876.6MHz through a drive test using a Genex probe installed in a computer and connected to the network through a 4G modem. They affirmed that their results compared favorably with the Nigerian Communication Commission’s benchmark. One of such works is also documented in Oghogho et al., 2014; 2018). The team carried out an empirical investigation on TCP upstream-throughput dependence on signal-to-noise ratio (SNR). In this paper, the TCP upstream, defined by the authors as “data speed in Mbps sent from client to WLAN radio,” was measured at the transport layer at every SNR in the physical layer measured at various receiver positions in IEEE 802.11b WLAN. In the end, a model was generated that is capable of predicting the TCP with lower root mean square (RMS) values compared to others. But the work was carried out on wireless LAN, and it has been noted in Yin et al. (2014) that WiFi networks maintain a vastly different profile from cellular networks due to link differences. So the result obtained here cannot be used to judge subscriber’s quality of experience (QoE) in cellular data networks. In Mika et al. (2004), the authors proposed a framework for realizing ‘lightweight’ measurement of TCP throughput by using TCP modeling. Their frame work was divided into two parts, which they christened estimating parameters and TCP modeling. At the estimating parameters stage, data obtained from active measurements were used to estimate the input parameters of TCP modeling. While at the TCP modeling stage, TCP throughput was calculated through an analytical model of TCP using the input parameters obtained at the first stage, the estimating-parameters stage. In Ghassan et al. (2011) on performance evaluation of different versions of TCP over a model of LTE network using NS-2 network simulator (NS-2 version 2.32), three metrics were used, which are: throughput, queue size, and packet loss. Their TCP performance over LTE simulation showed a similar throughput for all TCP’s considered, but the best performance goes to Vegas with maximum bandwidth and minimum loss packet. Though a good effort towards showing the possibility of measuring the performance metrics of the cellular data network on LTE, the work was simulation-based. Anamonye and Nnebedum (2015) have carried path loss prediction models on the 3G signal.Yin et al. (2014) also carried out a measurement study of cellular data networks on three service providers in Singapore. The work was aimed at understanding the characteristics of data packets in cellular networks but did not ascertain end-user QoE. They carried out a crowd-sourced measurement from 23 subscribers on HSPA and HSPA+ networks with a total of 6,048 sets of experiments. They used User Datagram Protocol (UDP) flows to have control over packet size and sending rate. The measurements were carried out using their self-developed Android application, ISPCheck. Their findings include an inter-packet arrival time of 10 ms for HSPA and 4 ms for HSPA+, large variation in the instantaneous throughput over short periods of time even when the mobile device is stationary, and high latency leading to low throughput. But the work did not evaluate user QoE. Edy (2017) developed an application referred to as the Android End-to-End QoS tool to measure the performance of the cellular data network of three service providers in Indonesia. With the client software, they could measure packet loss of 0-3%, throughput values, and latency. Their findings are that downlink throughput was higher than the uplink throughput in most cases, and both are influenced by location and time. Downlink latency has higher values than uplink latency for each mobile service provider, and at 5000 and 10000 bytes of packet, latency began to taper; this they claimed was attributed to buffering as adapted by the service providers. But the work did not ascertain end-user QoE on the networks, and findings cannot be used to judge commercial networks. Andrea and Radu (2015) carried out an assessment of packet latency on the S1-U interface of 4GLTE and its overall impact on end-user throughput. They used the IP impairment tool Dummynet to emulate latency, packet loss, and jitter. The test was performed on LTE at 2.6 GHz and 10 MHz bandwidth. In the first instance, latency values were tested up to 50 ms in steps of 5 ms for good (-69 dbm), medium, and bad radio conditions, and later from 50 ms to 250 ms in steps of 50 ms, and afterwards up to extremely delayed values of 500 ms to 1200 ms in steps of 150 ms for medium radio conditions (-81 dbm).. Their findings revealed no significant impact of the different ranges of delay on throughput, except when the experiment extended to greater than 1 second (which is impracticable in real life) delay, then the throughput began to taper significantly. Though the work was able to investigate the impact of the impairments on the LTE network, the result is not real life. Also Boni et al. (2020) analyzed the behavior of several objective models of audio-video in web real-time communication systems in a full reference model by comparing some original media files with degraded ones. The different network conditions were modeled in terms of packet loss and jitter only. But this work is broadened to include latency and used inclusive internet services as captured packets. The investigation using the above-the-fold method was carried out by Diego et al. (2018), where 3400 web accesses were used as ground truth to compare with the objective models, particularly the ITU-T and IQX expert models, and they proved that the expert model had comparable accuracy with machine learning approaches. However, the objective model did not leverage real-life measurements like in this work, but simulation results hence cannot be a sure result to be deployed in real-life applications. In another development, Jori et al. (2014) predicted user QoE in current networks using an advanced QoE estimation model appropriate for browsing, downloading, and uploading using bitrate and initial loading delays as input parameters, unlike this work, which used jitter, packet loss, and latency.

There have been persistent complaints by subscribers concerning the quality of experience on their respective networks of choice. According to Vera (2017) and Nokia (2020), 90% of subscribers simply pull out of the network unannounced after a level of tolerance. To this end, this research seeks to investigate how variations in the various QoS parameters affect the quality of experience QOE of users of data in a cellular network in Nigeria and evaluate the user QoE using a mapping model from an existing benchmark. Most work in this area focused on wire/wireless LAN (IEEE802.3/IEEE802.11) using self-injected traffic, or simulation in some other cases. But this work shall be investigating the quality of data service (QODS) experienced by subscribers using a life cellular network. Again, identified works in this area were primarily on 3G and older technologies, but this investigation is focusing on 4G LTE, which is still a trending technology in Nigeria. Again, no work, as far as we know, has used existing benchmarks to interpolate onto the expert model that compute the QoE from field values of QoS parameters, but this work has done so.

2. Materials and Methods

This section covers the methods used in carrying out the experiment to generate measured values for the QoS metrics and signal parameters that were used to judge the end user's perceived quality on the mobile radio networks. There are two methods by which the quality of service experienced by the end user of a network can be ascertained. The two methods are subjective method and objective method. While the subjective method requires crowdsourcing (where the opinions of subscribers of service are sought), the objective method uses dedicated measurement applications to measure the QoS metrics and signal parameters and uses mathematical approaches to ascertain the end user quality perception. Ayisat et al. (2018). In this study, the objective method of user QoE assessment was adopted.

All measurements were obtained on electromagnetic waves radiated from eNodeBs of three deployed 4G networks of three mobile network operators (MNO), herein referred to as MNO1, MNO2, and MNO3, whose trade names are concealed for privacy rights. Measurement data were collected while the cell towers radiate all IP 4G LTE at 1800+ MHz. The various cells in the interplay were identified through their eNodeB and cell identity (CID) to avoid the effects of handover, which can result in a spike in signal power at the edge of a reference cell. Packet capture was carried out by interrogating the Google DNS for a duration of two minutes for the three MNOs, and values were recorded of key technical QoS influence factors, viz., packet losses, latency, and jitter, from the window command processor. Jitter values were obtained by processing the captured packet strings in the 3rd Echelon Jitter window. At least a total of 75 experiments were carried out, but a minimum of 65 data points are documented since instances of 100% packet loss were discarded because this is total network failure. The work spanned for a period of 4 months. Figure 1 shows sample captured packets, while the values of the resultant QoS parameters are recorded in Table 4. Table 1 is the QoS-QoE mapping table known as the mean opinion score (MOS) of the International Telecommunication Union (ITU-T P.863.1); Table 2 is the Cisco benchmark for quality of service parameters applied to the exponential model to enable mapping of the QoS variables to the QoE. While Table 3 depicts the standard jitter categories, which are set by the 3rd Echelon that hosts the cloud computing platform for jitters.



```
Reply from 216.58.223.196: bytes=32 time=248ms TTL=55
Request timed out.
Reply from 216.58.223.196: bytes=32 time=452ms TTL=55
Reply from 216.58.223.196: bytes=32 time=137ms TTL=55
Reply from 216.58.223.196: bytes=32 time=234ms TTL=55
Reply from 216.58.223.196: bytes=32 time=138ms TTL=55
Reply from 216.58.223.196: bytes=32 time=126ms TTL=55
Reply from 216.58.223.196: bytes=32 time=109ms TTL=55
Reply from 216.58.223.196: bytes=32 time=38ms TTL=55
Reply from 216.58.223.196: bytes=32 time=68ms TTL=55
Reply from 216.58.223.196: bytes=32 time=31ms TTL=55
Request timed out.
Reply from 216.58.223.196: bytes=32 time=281ms TTL=55
Reply from 216.58.223.196: bytes=32 time=47ms TTL=55
Reply from 216.58.223.196: bytes=32 time=107ms TTL=55
Reply from 216.58.223.196: bytes=32 time=88ms TTL=55
Request timed out.
Reply from 216.58.223.196: bytes=32 time=389ms TTL=55
Reply from 216.58.223.196: bytes=32 time=140ms TTL=55
```

Figure 1: Sample captured packets

Table1: QoS-QoE Mapping

Score	Rating
1	Bad
2	Poor
3	Fair
4	Good
5	Excellent

Table 2: QoS According to Cisco Benchmark

QoS Parameters	Values
Packet loss	≤ 1%
Latency	≤ 150ms
Round trip Latency	≤ 300ms
Jitter	≤ 30ms

Table3: Ranges of jitter values (courtesy of 3rd echelon)

Jitter Level	Acceptability
<1	Excellent
<5	Extremely good
<20	Very good
<50	Good
<80	Good to fair
<100	Fair

3. Results and Discussion

Objective QoS Values

This section presents the obtained QoS parameters of networks in the study area comprising the packet loss, latency and jitter subsequently used to determine the operator's quality of service and user quality of experience (QoE). Table 4 is the table showing the measured QoS parameters and the entries represent the averages from frequency distribution of the raw data.

Table4: Measured QoS Parameter Values

	MNO1	MNO2	MNO3
Average Packet loss (%)	4.03	1.85	2.86
Minimum Packet loss(%)	0.00	0.00	0.00
Maximum Packet loss(%)	61.00	22.00	42.00
Avg Latency(ms)	141.85	99.48	152.79
Min Latency(ms)	69.19	45.96	28.30
Max Latency(ms)	123565	105334	181933
Average Jitter(ms)	59.22	53.85	130.01
Min Jitter(ms)	4.12	3.76	3.77
Max Jitter	300.02	247.76	1,190.45

3.1. Comparison of Measured QoS with Cisco Benchmark

In this section, the comparison of the measured QoS with Cisco benchmark, shown in Table 2, was carried out. The Cisco benchmark is used as the regionof QoS influence factors for which user can have at least, a good data experience. However, MNO2 has the best packet loss amongst all. So services such as video streaming which are mostly impacted by packet loss might be interesting to subscribers in this environment since the values of packet loss rates are low across networks. For Latency, MNO, MNO2 and MNO3 are good as their QoS are within acceptable limits. Therefor network user in the indoor environment are not expected to be seriously affected by congestion or queuing. MNO2 has the best round trip latency value and this has resulted in the best upload speed and better download speed. Jitter is another major QoS influence factor use to ascertain cellular data quality of experience. It can be observed that the average jitter values for all the network operators are above the acceptable threshold of ≤30ms with MNO3 having the worst value. Streaming services will be characterized with ghost image formations in this environment. See Figures 1,2 and 3 for the graphs of relationship between measured QoS values and Cisco benchmarks for the various QoS influence factors.

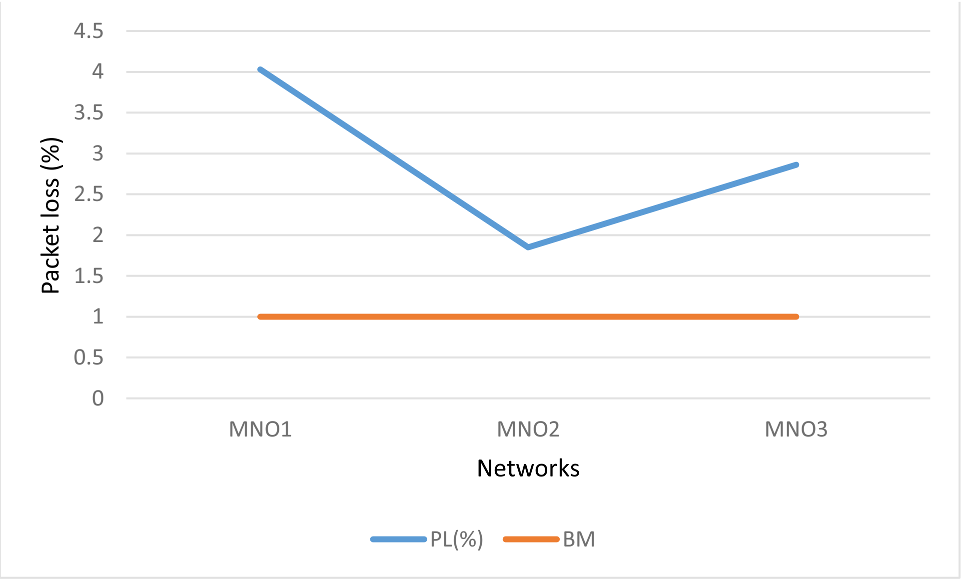


Figure 1. Comparing packet loss per network with benchmark

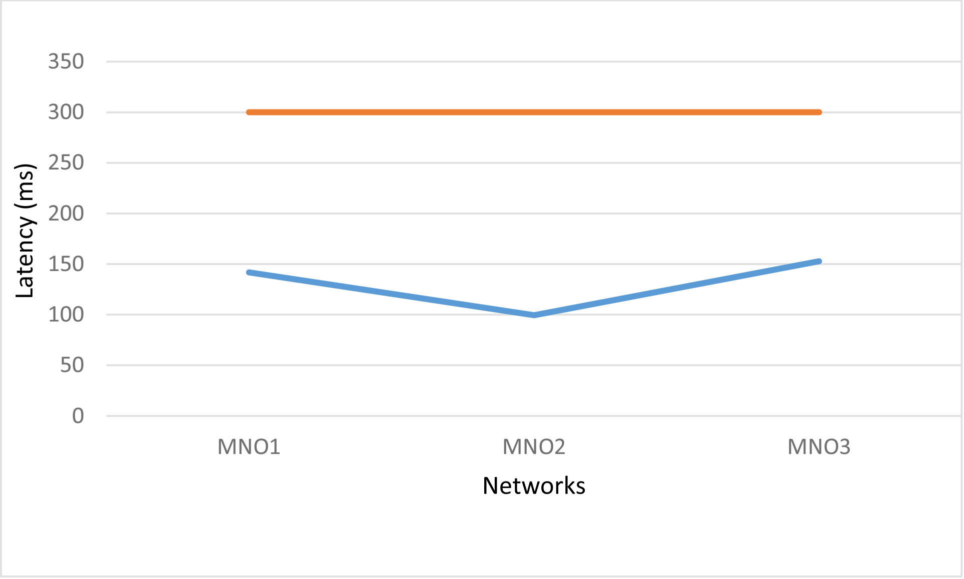


Figure 3. Comparing Latency per network with benchmark

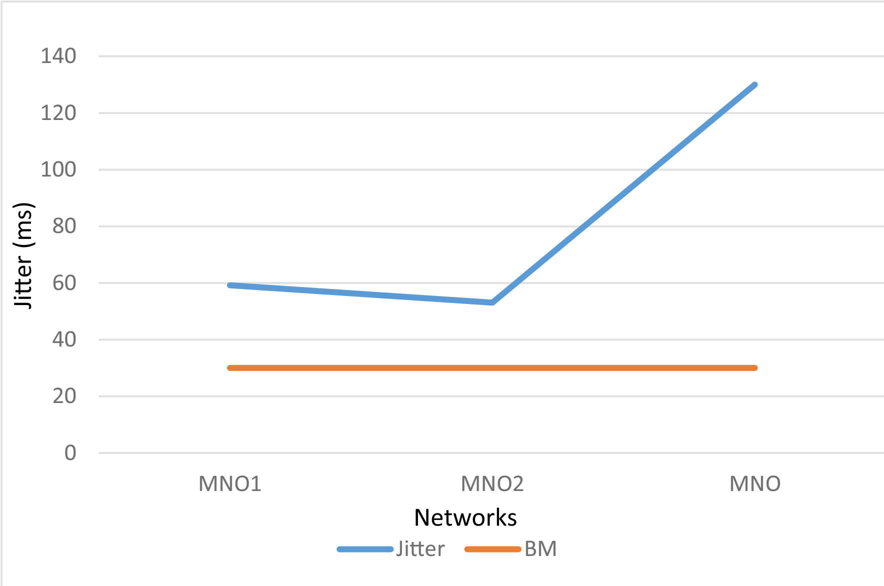


Figure 3. Comparing Jitter per network with benchmark

3.2 Estimation of the User QoE

Since it has been confirmed that QoS and QoE maintain exponential fit, we can obtain the QoE from QoS using equation 1refered to as IQX hypothesis,(Fiedler et al., 2010; Boni et al., 2020; Doego et al., 2018; Singh et al., 2013).

Where Yi represents QoE in terms of MoS and Xi the Qos influence factor.Alsoεiis an independent normal of zero mean and constant variance so it is weighted zero. Linearizing the response function results in:

If Xi is packet loss rate (PLR), We obtain regression coefficients which results in Equation 3:

$Y_i = \theta_0 e^{-\theta X_i} + \varepsilon_i$ (1)

Where Y_i represents QoE in terms of MoS and Xi the Qos influence factor.Alsoεiis an independent normal of zero mean and constant variance so it is weighted zero. Linearizing the response function results in:

$InY_i = - \theta_1 X_i + In\theta_0$ (2)

If Xi is packet loss rate (PLR), We obtain regression coefficients which results in Equation 3:

In QoE = -0.0643775Qos + In5 (3)

Using expected values E(x)= 4.03%, 1.85%, and 2.86% respectively for the MNOs 1, 2, and 3 under study.
Therefore using benchmarks of PLR=0%; MOS=5 and PLR =25%; MOS=1, we obtained the regression coefficients applying the IQX hypothesis of Equation1 and obtained $\theta_0 = 0.0643775$. Substituting the expected QoS values into the resulting model, we got QoE of 3.85, 4.05, and 3.87 for MNOs 1, 2, and 3 respectively. These values can be interpreted as between fair and good on the MoS scale (see Table 1). So the subscribers in this area can have good QoE, judging by packet loss and will have good but not excellent streaming services. However, MNO2 has the best performance, having the highest MOS rating, and this is in tandem with our earlier comparison of section 3.1.

3.2.1 Considering Latency

Mapping using cisco benchmark as baseline when two way Latency=0;MOS=5, when two way latency=300;MOS=1. Therefore solving for the regression coefficients will result in Equation 4.

In QoE = -0.005364Qos + In5 (4)

Solving the regression equations to obtain the sensitivity and range parameters we have that the QoE=2.33 for MNO1 (a relatively fair experience). For MNO2 we obtained the QoE as 3.0 which is interpreted as fair on the MOS scale. For MNO3 the QoS-QoE mapping is obtained as 2.2 which means Poor quality of experience. So the subscribers of MNO2 are bound to have lesser congestion in their data experience.

3.2.2 Estimation using Jitter

The 3rd Echelon worst value for jitter on LTE is ≥100 as shown it Table 3. So in mapping the extreme benchmark values we have the following QoS-MOS pairs: Jitter=0; MOS=5, and Jitter=100; MOS=1. Solving for the regression coefficients simultaneously, will result in Equation 5.

$$In\,QoE = -0.0160943791Qos + In5 \quad (5)$$

For MNO1 expected value of jitter from the frequency distribution is E(x) = 59.22317 and this results in QoE-MOS mapping of 2 when substituted to equation 5, which indicates poor QoE Similarly, the MNO2 and MNO3 having respective expectations of E(x)=53.85098 which gave corresponding MOS of 2.1 corresponding to a poor quality of experience and E(x)=130.01 with MOS of 0.6 which corresponds to very bad subscribers' experience. This is in tandem with the comparison with Cisco benchmark of Jitter above ≥30ms.

4. Conclusion

The viability of a network was at first considered network-centric, i.e., measured in terms of the ability of the service provider to meet its target quality of service. But today, effort has shifted to user-centric, i.e., satisfaction expressed by the user. The work analyzed the quality of service cum experience of users of three different service providers by rating the user experience using a proven exponential model with the benchmark values as the baseline. Furthermore, it based the quality assessment on an objective method and measured three data performance parameters, namely, packet loss, latency, and jitter of life for 4GLTE data services of three service providers. The results obtained were actual values within the MOS scale. The method that led to these results can be relied upon when evaluating the quality of experience in any deployed cellular network, irrespective of the access technology. Further exploration may consider validating machine learning approaches with this outcome. Research can also try a lump model and include LTE-only signal metrics in estimating user quality of experience.

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