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Research Article

Performance analysis of cellular mobile networks for QOS optimization

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Abstract: Records and performance analysis of cellular mobile networks usage can provide valuable information for understanding the network performance for Quality of Service (QoS) optimization by the mobile network providers. The network providers are interested in knowing their performance and that of their competitors based on location, phone category and operating system for various cellular networks technology. This can enhance an intelligent guide to invest in locations where they operate with poor performance. Thus, Key Performance Indicators (KPI) are usually of interest to all service providers. In this paper, the researchers investigate and analyze the 3rd generation (3G) and 4th generation (4G) mobile network performance in Malete, Kwara State using questionnaire and Testing Equipment for Mobile System (TEMS) software with map info professional for eventful and non-eventful days. Focusing on three different locations of TEMS, crowd-sourced dataset allows us to evaluate the network performance and determine the Call Setup Success Rate (CSSR), Call Completion Rate (CCR), Call Drop Rate (CDR), Call Handover Success Rate (CHSR), among others, of the locations investigated.

KEYWORDS: Cellular Mobile Networks, QoS, QoE, optimization, Drive Test, 3G and 4G.

1. INTRODUCTION

Rapid growth and development of Malete in Moro Local Government Area of Kwara State, Nigeria, understandably because of the location of Kwara State University has resulted in increased population such that the existing infrastructure, including that of telecommunications, is barely sufficient for the growing population. Inability to set up calls, abrupt calls drops, occasional service outages, cross-talks and network congestions among other challenges have become imminent. Surfing the internet is also a major issue for staff, students and others in and around the study area. Thus, cellular mobile network subscribers cannot be said to enjoy satisfaction of the service delivery. The poor network and Quality of Service (QoS) may be attributed to inadequate number of base stations, epileptic power supply, security breaches in the country and vandalism of network equipment.

An efficient and effective telecommunication sector is very key to economic growth of a country. Although cellular mobile network service providers are increasing, but their networks and services provide different QoS. The QoS is a description or measurement of the overall performance of a service. QoS and Quality of end-user Experience (QoE) are some of the major techniques for analyzing the performance of cellular mobile network services. The QoS is adjudged by the service providers and the QoE is determined from the network subscribers or end-users.

As the number of services and subscribers of cellular mobile network in Nigeria increases, the demand for good QoS has become a very important consideration (Kadioglu, *et. al.,* 2016). Almost on daily basis, more users are connected to the existing networks. Hence the need for continuous monitoring of the QoS delivered by the service providers because high QoS in this environment is a huge benefit to service providers. With the growth of mobile services, it has become very important for an operator to measure the QoS and QoE of its network accurately, effectively and cost-efficiently to achieve customer loyalty and maintain competitive edge (Caroline, *et. al.,* 2015). Since cellular mobile network services are locally provided by Base Transceiver Stations (BTS), it is pertinent to carry out performance analysis of a number of cells, i.e. the

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BTSs, covering the study areas. The network operators use Key Performance Indicators (KPIs) to analyze their network performance and evaluate the QoS for end user perspective and for necessary optimization.

This paper is an extension of a work originally contained in Musa and Samad (2021). The article contains additional results of 3G and 4G network coverage in three more different locations in Malete. The additional locations namely: Safari, Amina Castle and West End, are within the geographical coordinates of 8.709986 longitude and 4.466556 latitude. The work investigates and analyze the performance of the cellular mobile networks through data collection using Test Mobile System (TEMS) software and TEMS Discovery. The work is divided into three phases namely: the data collection phase, data analysis phase and the proposals for improvements.

In this article, 3G and 4G networks radio frequency (RF) performance evaluation is presented based on some major KPIs such as Call Set Up Success Rate (CSSR), Call Drop Rate (CDR), Traffic Channel (TCH) Congestion Rate and Handover Success Rate (HSR). QoS and performance analysis of cellular mobile services usually form the bases of KPIs by both the regulatory authorities and service providers. The KPIs are parameters measured and obtained directly from network infrastructures such as Base Transceiver Station (BTS) and Base Station Controllers (BSC) (Galadanci & Abdullahi, 2019).

The outcome of the research will assist network operators to measure effectiveness against their long-term corporate objectives. It will also help the regulatory bodies, such as the Nigeria Communications Commission (NCC), to establish a more comprehensive structure for rapid growth in telecommunications.

Meanwhile, a lot of research have been conducted on GSM network performance analysis. Authors such as Galadanci and Abdullahi (2019), Lawal *et al* (2016), Rakiyat *et al* (2017) and Kuboye *et al* (2011) evaluated the operational performance of some GSM networks. Lawal *et al* (2016) conducted their research and analysis using network statistics method. Using drive test, Rakiyat *et al* (2017) analyzed two network operators to address congestion issue experienced at Oja Oba, College of Education and Airport Road, all in Ilorin.

Oluwaseun, *et al.,* (2021) evaluated the performance of mobile networks providing voice communication services in the University of Ilorin. Oje and Quadri (2017) also analyzed the KPIs for voice communication in the 3G UMTS network of four major Mobile Network Operators (MNO) in three separate locations at the University of Ilorin. The work concluded that that the overall network quality index is poor and deviations from the benchmark set by the NCC for the MNOs. Somewhat similar works on Radio Frequency (RF) in Ilorin have also been carried out by Abdul-Kareem (2017) and Oje and Edeki (2020).

Oseni *et al* (2014) emphasized optimization of radio frequency as an essential process for verification and monitoring of the efficiency of any cellular network. A research on traffic modeling for capacity analysis of some GSM networks was carried out by Biebuma (2010) where analysis of mobile devices in terms of mobility and traffic was presented to help optimize capacity for both circuit and packet-switched services.

The rest of this manuscript is organized in such a way that Section Two explains the KPIs and their calculations. Section Three describes the materials and methods used in carrying out the research. While the results are presented and discussed in Section Four, the paper is summarized in Section Five.

2. KEY PERFORMANCE INDICATORS

Key Performance Indicators (KPIs) are simply a quantifiable measure of network performance over time for a specific objective. KPIs are the key targets that communication companies use to show progress, track and maximize the quality of their networks to meet a certain threshold set by NCC and satisfy user's needs and overall QoS.

Some of the KPIs have been explained in Musa and Samad (2021), Ozovehe and Usman (2015), Lawal *et al.,* (2016) and Rakiyat *et al.* (2017). The KPIs such as Received Quality (RXQUAL), Received Signal Strength Indicator (RSSI), Speech Quality Index (SQI) and Frame Erasure Rate (FER) are connected to service integrity. Call Setup Success Rate (CSSR), Standalone Dedicated Control Channel (SDCCH) and TCH Congestion Rate are connected to accessibility, while Call Drop Rate (CDR) and Hand Over Success Rate (HOSR) are connected to service retainability. Details including the mathematical expressions of some of the KPIs such as CSSR, CDR, TCHCR (Traffic Channel Congestion Rate) and HOSR have been presented in (Musa and Samad, 2021), a few more bordering on service integrity are also given here.

Received Signal Strength Indicator (RSSI) – is a measure of the power present in a received radio signal.

The RSSI of an individual cell may be computed (Galadanci & Abdullahi, 2019) as follows:

$$RSSI\ (dBm) = R_0 - \varepsilon log d + \xi\ [dBm] \quad (1)$$

where R_0 is a constant determined by transmitted power, wavelength, and antenna gain of the cell, ε is a slope index, ξ is the logarithm of the shadowing component, and d is the distance between mobile station (MS) and base station (BS) of the cell. The slope index is typically 40 for microcells in a city

Frame Erasure Rate (FER) - is a speech quality degrade factor that shows fading and interference. The voice quality of a given service is adjudged based on the value of the FER (Ozovehe & Usman, 2015).

Speech Quality Index (SQI) – measures or reflects the quality of speech. The SQI computed on the basis of BER and FER (Yuwono & Ferdiyanto, 2015) is updated at 0.5 seconds intervals. The SQI estimates how codec type and radio link parameters such as the FER, BER, handover rates, etc. affect voice quality.

Using (2) and (3), the 4G RSRP and data throughput may be obtained.

$$\text{RSRP}\ (\%) = \frac{\text{No of occurence MS receives Rx Level at acceptable range}}{\text{Total no of occurence MS receives Rx Level}} \times 100 \quad (2)$$

$$\text{Data throughput} = \frac{\text{No of occurence MS receives data at acceptable range}}{\text{Total no of occurence MS receives data}} \times 100 \quad (3)$$

3. MATERIALS AND METHODS

This project focused on 3G Circuit Switching (CS) and Packet Switching (PS) as well as 4G PS network measurement and analysis. A drive test was conducted on three additional locations in Malete and the study also involved a modified questionnaire. The drive test routes were planned to all the areas covered by different sectors and around the base station under study. The drive test equipment set-up consists of a laptop, Transmission Evaluation and Monitoring System (TEMS), investigation software (to collect, process and analyze data), dongle, Global Positioning System (GPS) device, Subscriber Identity Module (SIM) card, CellREF, MS devices, data cable, USB, hub and a vehicle.

The handover functions were properly verified by ensuring that the test routes reached the over-lapping areas of surrounding neighbor cells. The idle mode, i.e. when no call was in progress even as the MS was on, was tested to acquire coverage statistics. The dedicated mode, i.e. when the MS was on and call was in progress, was also tested for network accessibility. Retainability and evaluations such as call drop rate, success rate of handover, etc. were also tested; as well as 4G data coverage and quality measurement and analysis.

To start the data collection process, the "Record" button was clicked to initiate and save the data collected on the pre-determined test routes. On clicking the record button, a Save As dialogue popped up to specify the directory, file name and file type. The file type must be TEMS log files (.log) since all TEMS files has .log extension where drive test data are saved. After the test routes were covered, the "Record" button was clicked to initiate the end of the process and acquire the logfile.

The logfile was analyzed using TEMS Discovery for event summary and KPIs such as Received Signal Code Power (RSCP), Received Power Level (RSRP), call established, dropped calls etc. A questionnaire was prepared and distributed to users of the network. The results of the customer feedback were analyzed and compared with the Drive Test results for additional accuracy and efficiency of this research work.

Figure 1A is the block diagram of the research method, some of which have been described.

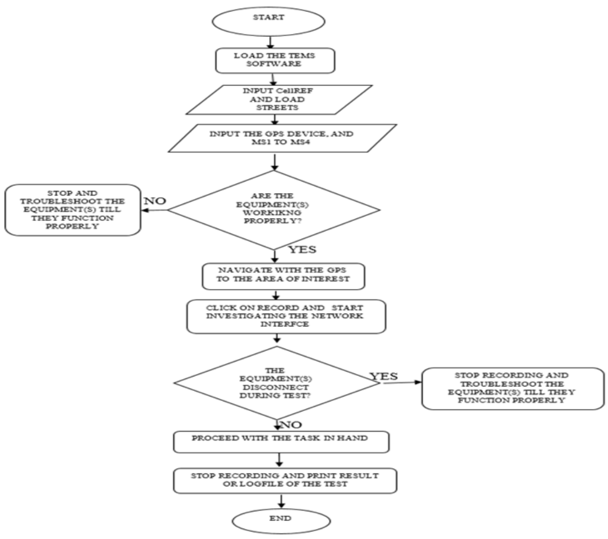

Figure 1A. Block diagram of research method

4. RESULTS AND DISCUSSION

This section presents and discusses the results obtained for the three studied areas namely: West End, Safari and Amina Castle areas. The three areas are respectively denoted as Area A, Area B and Area C. In Figure 1, the overview of the 4G RSRP route for the eventful and non-eventful days for Area A is shown.

Figure 1. 4G RSRP route overview for Area A

Areas where the RSRP value is greater than −105 dBm represent the red dots with poor signal levels. Areas with RSRP from -85 to 0 dBm represent the light green and dark green dots with good signal levels. The fan-like signs, with their respective cell identification codes, depict the cell sites. Figure 2 presents the chart of the 4G RSRP.

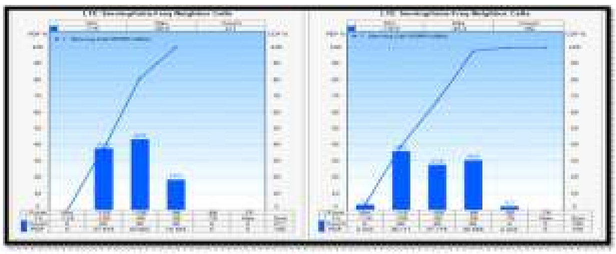

Figure 2. Chart for the 4G RSRP of Area A

Figure 3 and 4 respectively show an overview of the 4G data throughput route overview for the eventful and non-eventful days (Location A) and the corresponding chart. The red spots depict weak data rates with throughput less than 2500mb/sec to 0. While the light green and dark green patches depict strong data rates with throughput above 7500mb/sec, the fan-like signs, with their respective cell identification codes, depict the cell sites.

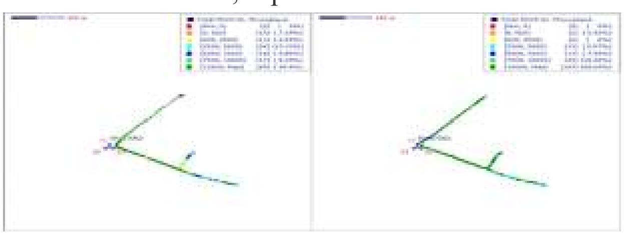

Figure 3. 4G data throughput route of Area A

Figure 4. Chart for 4G data throughput (%) of Area A

The values of 18.48% and 32.77% were obtained for the RSRP of the location. While 73.62% and 92.99% were computed as the data throughputs, the average data speed per seconds were 7478.022 Mb/Sec and 9026.87 Mb/Sec.

Additional results including RSCP, 3G EC/Io, RSRP and data throughputs of both 3G and 4G were obtained for Location B and Location C as shown in Figure 5 to 19. There are two routes and charts in each of the Figures representing eventful and non-eventful days. Meanwhile, only the curves have been presented for Location B, both the curves and the routes have been shown for Location C.

Some spots in the area with very poor signal levels where RSCP was greater than −105 dBm were recorded. Places with RSCP from -85 to 0 dBm representing good signal levels were also recorded. The chart in Figure 5 was established using TEMS discovery. It is a plot of the percentage of each minimum to maximum range i.e. from -115 to -75. The count represents the number of occurrence of each range. The pdf is the corresponding percentages to each number of occurrence or counts, while the sum is the addition of every count and percentage.

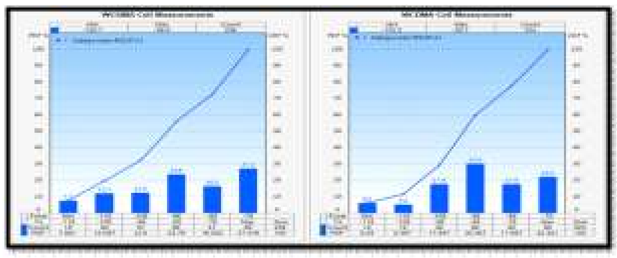

Figure 5. 3G RSCP (%) Chart of Area B

The values of EC/IO greater than −16 dBm depicting poor signal levels and values from -12 to 0 dBm representing good signal levels were recorded. The plot of the percentage of each minimum to maximum range i.e. from -18 to -10 is shown in Figure 6.

Figure 6. 3G EC/Io (%) Chart of Area B

Figure 7 shows the 3G data throughput (%) chart of Area B with a plot of the percentage of each minimum to maximum range i.e. from 1 to 4096. A weak data rate with throughput less than 512mb/sec to 0 was recorded, while a strong data rates with throughput above 2048mb/sec was also recorded.

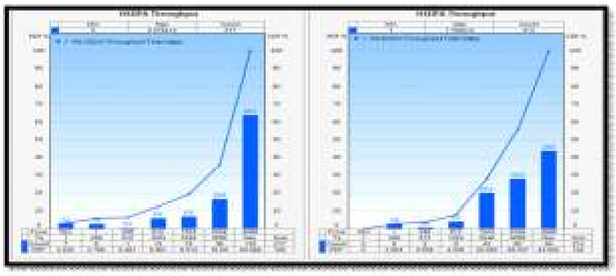

Figure 7. 3G data throughput (%) chart of Area B

Locations where the RSRP is greater than −105 dBm represent poor signal levels, while those with RSRP from -85 to 0 dBm represent good signal levels. Figure 8 is a plot of the percentage of each minimum to maximum range i.e. from -115 to -75.

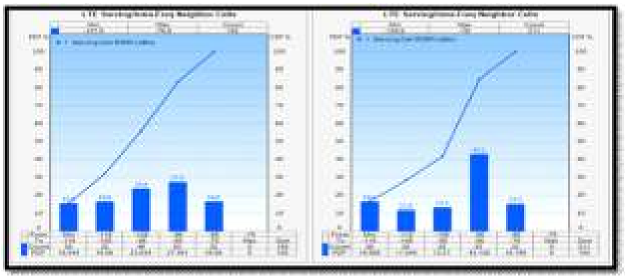

Figure 8. 4G RSRP (%) of Area B

Weak data rates with throughput less than 2500mb/sec to 0 and strong data rates with throughput above 7500mb/sec were recorded. The PDCP DL Throughput indicates the RX Level dBm values from its minimum to maximum range and the corresponding counts and percentages to each number of occurrence. In Figure 9, the 4G data throughput (%) of Area B showing plots of the percentage of the minimum to maximum range i.e. from 0 to 10000 is drawn.

Figure 9. 4G data throughput (%) of Area B

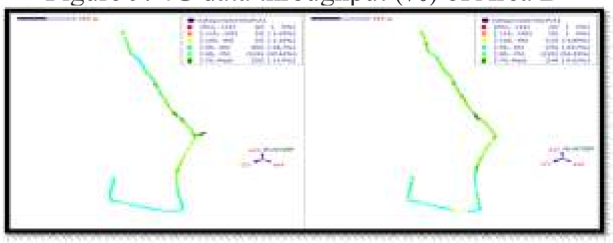

Figure 10. 3G RSCP route of Area C

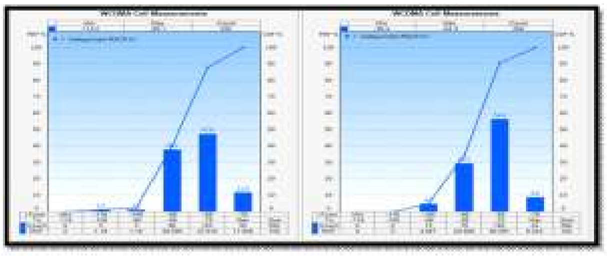

Figure 11. 3G RSCP (%) chart for Area C

Figure 10 to Figure 19 are for the routes and charts of the results of Area C. The 3G RSCP route is shown in Figure 10 with locations where RSCP is greater than −105 dBm being poor signal levels and RSCP from -85 to 0 dBm being good signal levels.

Figure 12. 3G EC/Io route of Area C

Figure 12 is the 3G EC/Io route with value greater than −16 dBm for poor signal levels and from -12 to 0 dBm for good signal levels. Figure 13 is chart showing plots of the percentage of minimum to maximum range from -18 to -10.

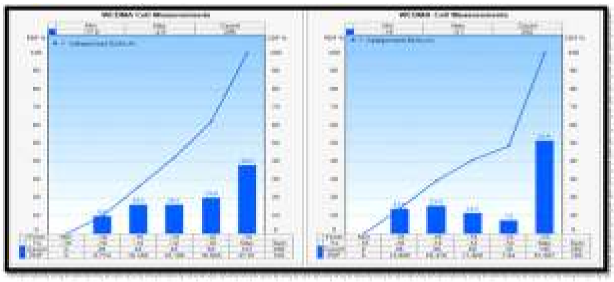

Figure 13. 3G EC/Io (%) chart for Area C

The red spots in Figure 14 depict weak data rates with throughput less than 512mb/sec to 0. The light green and dark green patches depict strong data rates with throughput above 2048mb/sec. Figure 15 plots the percentage for minimum to maximum range (1 to 4096).

Figure 14. 3G data throughput route of Area C.

Figure 15. 3G data throughput (%) for Area C

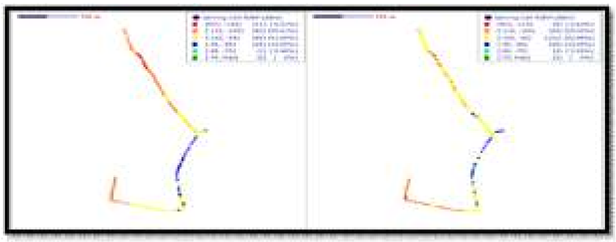

Figure 16. 4G RSRP route of Area C

The 4G RSRP route of Area C in Figure 16 shows points where the RSRP is greater than −105 dBm (red spots with poor signal levels) and RSRP from -85 to 0 dBm (light green and dark green dots with good signal levels). The 4G RSRP (%) chart for the area is shown in Figure 17.

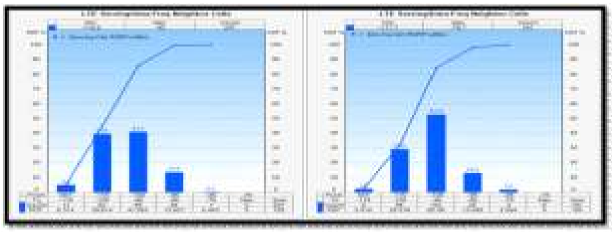

Figure 17. 4G RSRP (%) chart for Area C

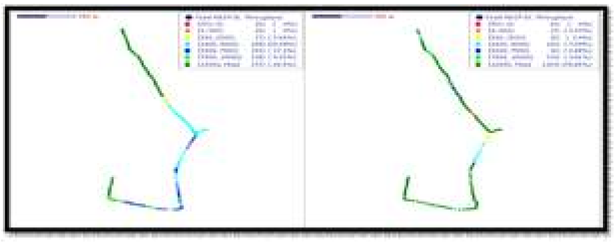

Figure 18. 4G data throughput route of Area C

Figure 18 is the 4G data throughput route of Area C. The red spots depict weak data rates with throughput less than 2500mb/sec to 0. The light green and dark green patches depict strong data rates with throughput above 7500mb/sec. The corresponding chart for the area established using TEMS discovery is shown in Figure 19. It is a plot of the percentage of minimum to maximum range (from 0 to 10000).

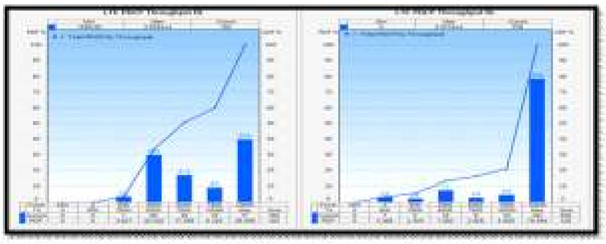

Figure 19. 4G data throughput (%) chart for Area C

Using the appropriate formulas earlier presented, a comprehensive computation of the KPIs acquired from the drive test was carried out and the results obtained have been presented in Table 1. The KPIs include CSSR, RSCP, EC/IO, RSRP, data quality and throughputs.

Table 1. KPI analysis (QoS)

KPI	Safari		Amina Castle		West End	
	Eventful Days	Non-Eventful Days	Eventful Days	Non-Eventful Days	Eventful Days	Non-Eventful Days
CSSR (3G)	100%	100%	100%	100%	66.66%	100%
CDR	0%	0%	0%	0%	33.33%	0%
RSCP (3G)	67.74%	70.53%	97.61%	95.11%	79.70%	81.77%
EC/IO (3G)	60.48%	64.73%	70.63%	74.06%	37.12%	41.77%
Data throughput (3G)	87.55%	92.05%	98.67%	98.31%	94.17%	94.24%
Av. data speed (Mb/sec) (3G)	3290.8	3008.6	3743.7	3781.4	3554.2	3767.6
RSRP (4G)	44.04%	56.29%	14.00%	15.18%	18.48%	32.77%
Data quality (4G)	57.43%	91.98%	66.32%	86.53%	73.62%	92.99%
Av. data speed (Mb/sec) (4G)	6570.5	9121.5	7055.7	8818.5	7478.022	9026.87

Table 2. KPI analysis from customers (MOS)

KPI	Area A	Area B	Area C
3G Network Coverage	71%	71%	76%
Call Quality	69%	53%	73%
CSSR	86%	83%	81%
CDR	18%	10%	8%
3G Data Speed	79%	77%	80%
4G Coverage	52%	60%	46%
4G Data Speed	83%	80%	82%

Table 2 shows the results of the KPIs analysis as obtained from customers (subscribers)' feedback for Area A (West End), Area B (Safari) and Area C (Amina Castle). The KPIs for both 3G and 4G networks include the network coverage, call quality, CSSR, CDR, and data speed.

Comparing the main KPIs (CSSR, CDR, network coverage and call quality) of the MOS values in Table 2 with the Drive test analysis in Table 1, users mentioned that the network performance was satisfactory, but not close to being excellent. Suffices to point out however that apart from the 3G CSSR, other KPIs for analysis of the performance of GSM cellular mobile networks in the study areas failed to meet the minimum standard requirement set and specified by the regulatory agency (NCC, 2020) shown in Table 3. This confirms an abysmal and poor network performance of the areas.

Table 3. KPIs Recommendations of the NCC

KPI	CCSF	CDR	HoSR	TCHCR	CSSR
NCC value	≤ 1.3%	≤ 2.0%	≥ 98.0%	≤ 2.0%	≥ 98.0%

5. CONCLUSION

Performance assessment and analysis of GSM cellular mobile networks is usually based on some Key Performance Indicators (KPIs). Some of the KPIs including CSSR, CDR, RCSP, RSRP, data throughput, etc. of 3G and 4G network coverage have been utilized in this paper to assess the performance of the GSM QoS provided by a network provider in three areas in Malete during eventful and non-eventful periods. The obtained results show that the KPIs deviate from the recommended values.

Meanwhile, it is not surprising to observe that the non-eventful period recorded better results than the eventful period, since the eventful period is characterized by higher populations and network users. Although, a dropped call occurred on Area A, the call set-up success rate and the network retainability in the investigated areas were generally very high. In addition, the voice coverage and quality of the 3G network were also high in the community.

Furthermore, the 3G internet access performance were mostly positive at the time this study was carried out, which means that access to the internet via 3G was guaranteed and swift in most areas. However, the Amina Castle area proved to be better than the Safari area as it was on an average speed of 3743.7Mb/Sec and 3781.4Mb/Sec for day one and two respectively compared to 3290.8 and 3008.6 Mb/Sec that was achieved at the Safari area.

The 4G network coverage was very poor in the areas. But that of Safari area was better when compared with that of Amina Castle area. Amina Castle performed better than Safari in data quality as shown in the results obtained. For instance, the average speed of 7055.7 and 8818.5 Mb/sec were recorded in Amina Castle and 6570.5 and 9121.5 Mb/sec were obtained for Safari. For optimal QoS optimization, significant improvements are necessary in the face of rapid subscriptions by end users in the areas. Frequent site audit should be carried out by the service providers to detect limited and poor services and by the NCC to ensure compliance and that the operators meet the ever increasing needs of subscribers. Increase in the number of existing BTS maybe necessary for more coverage, traffic decrement and higher QoS. Since this is expensive, sector addition which is a less expensive option compared to BTS increase can be adopted. This will enhance the performance of the network and allows for QoS optimization. Lastly, it appeared that the GSM operators have only L800 4G band in the areas of study. This means that all the available 4G devices operate on the single band, thereby causing reduction in the efficiency of the band due to high traffic. Addition of L1800 or L2600 band will bring about significant improvement in the coverage and the QoS

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