Article

Quality of service and RF optimization of GSM-based cellular mobile networks

Abdulwaheed Musa[1*], Samad Adeniran[2]

[1] Department of Electrical and Computer Engineering, Faculty of Engineering and Technology, Kwara State University, Malete, Nigeria; e-mail@e-mail.com
[2] Institute for Intelligent Systems, University of Johannesburg, South Africa; e-mail@e-mail.com
[2] Department of Electrical and Computer Engineering, Faculty of Engineering and Technology, Kwara State University, Malete, P.M.B. 1530, Ilorin, Nigeria.;
*Correspondence: twhid2001@yahoo.com;

Citation: A. Musa, S. Adeniran, "Quality of service and RF optimization of GSM-based cellular mobile networks," *International Journal of Energy and Power Systems*, vol. 2, pp. 22-29, 2022. https://doi.org/10.54616/ijeps/20220601

Academic Editor: Firstname Lastname
Received: date
Accepted: date
Published: date

Publisher's Note: IJEPS stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Abstract: The increased growth of Global System for Mobile Communication (GSM) networks is not without challenges such as dropped or blocked calls, poor internet access, occasional service outages, and network congestions among other poor service challenges. This paper investigated and analysed the performance of GSM networks for optimization of Quality of Service (QoS) at Malete, Kwara State. Due to the inability to make calls, poor data service, network congestions, etc., 2G, 3G and 4G drive test analyses were conducted and a questionnaire method was adopted to compare customer feedbacks with the test results. Key Performance Indicators (KPI) and parameters such as Call Setup Success Rate (CSSR), Call Completion Rate (CCR), Call Drop Rate (CDR), and Call Handover Success Rate (CHSR) were considered and investigated. The data collected through Test Mobile System (TEMS) software were analyzed using map info professional to identify the cause of these problems with a view to providing efficient and effective solutions to the problems. Destitute network and QoS performance were encountered in some parts of the research area and parametric optimization was given as a way of improving the network performance for better QoS, reception, revenue generation and economic growth.

Keywords: GSM network; Quality of Service; Network optimization; Drive test; Key performance indicators.

1. Introduction

The Global System for Mobile Communication (GSM) is currently the most extensive coverage, and with highest reliability, maximum capacity, confidentiality and strong public wireless digital transmission system [1-3] in Nigeria. The introduction of GSM mobile communication network system has no doubt played significant and meaningful roles in people's lives [4-5]. Aside voice call, an important service from the GSM, other value addition services such as Short Message Service (SMS) and internet services have allowed for and enhanced a number of applications ranging from e-mail, e-learning, e-banking, to social networking. The revolutionary tempo has further been raised by the internet and the web especially through the enhancement of e-learning. E-learning encompasses a wide set of applications and processes, such as web-based and computer-based learning, virtual classrooms, and digital collaboration. It involves the delivery of contents through the internet and intranet, audio and video tape, interactive TV, and satellite broadcast [6].

Over time, the GSM services have witnessed transformation from 1G to 4G and recently to 5G. It is obvious that the reasons for this transformation are qualitative voice calls, high speed data and internet connections. Mobile voice communication was achieved by the first generation (1G), while the second generation (2G) also added coverage and capacity. This was followed by the third generation (3G), which is searching for higher-speed data to open the gates to a truly "mobile broadband" experience that the fourth generation (4G) further established. The 4G offers access to a wide range of telecommunications services, including advanced mobile services, enabled by increasingly packet-based mobile and fixed networks, as well as support for applications with low to high mobility and a wide range of data rates, in line with the requirements of multi-user services [7]. The evolution of wireless access technology is at its fifth generation (5G) and will interconnect the entire planet.

The telecommunication industry is faced with both rapid growth and challenges associated with Global System for Mobile Communication (GSM)-based cellular mobile networks. As the number of services and subscribers of GSM in

Nigeria increases, the demand for good Quality of Service (QoS) has become an issue in the country [8]. More users are connected to the existing networks on daily basis; hence the need to continuously monitor the QoS delivered by service providers. High QoS in this environment is a huge benefit for service providers. With the growth of mobile services, it has become very important for an operator to measure the QoS and Quality of enduser Experience (QoE) of its network accurately, effectively and cost-efficiently to achieve customer loyalty and maintain competitive edge [9]. Since GSM services are locally provided by Base Transceiver Stations (BTS), it is pertinent to carry out performance analysis of a number of cells (BTSs) covering a community or a particular location.

Service providers are increasing immensely and these networks provide different QoS. An efficient and effective telecommunication sector is very important in the economic growth of a country. QoS is simply the description or measurement of the overall performance of a service.

As the number of staff, students, civil servants and villagers increase in Malate, Kwara State, due to the growth and progress of the university, inability to set up calls, abrupt calls drops, occasional service outages, cross-talks and network congestions among others became imminent and subscribers do not receive satisfaction due to the poor nature of the services available on these networks. Surfing the internet has been a major issue for staff and students. Thus, the lack of adequate amount of base stations, poor network and overall QoS performance in the area of study form the major reasons why this study was carried out.

This paper investigated the performance of network in Malete, Kwara State, analyzed the data collected through Test Mobile System (TEMS) software and TEMS Discovery, and then evaluated the performance of the work. The research was organized into three phases namely: the data collection phase, data analysis phase and the proposals for improvements. The outcome of the research will assist network operators to measure effectiveness against their long-term corporate objectives. It will also help the regulatory body, Nigeria Communications Commission (NCC), to establish a more comprehensive structure for rapid growth in telecommunications. QoS and performance analysis of GSM services ususally form the bases of Key Performance Indicators (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) [1, 4-5].

This article has been structured and presented in such a way that Introduction which include review of related works was given in section one, Research Method was discussed in Section Two, the Results and Discussion were presented in Section Three and Conclusion was given in Section Four.

1.1 Literature Review

Authors [1–6] as well as [10-21] evaluated the operational performance of some GSM networks. In some cases, such as [22] and others, optimization for cellular networks was also carried out. Lawal [6] conducted his search and analysis using network statistics method. Using drive test, Rakiya [10] analysed two network services to address congestion issue experienced in the area. The work in [20] optimized GSM network performance by conducting a pilot study. Data collected through drive test was processed. Another pilot study conducted by [23] deployed android application to measure the performance of five broadband operators. [24] also conducted a pilot study to improve mobile broadband internet service. A call admission control was proposed to reduce the rate of call drop associated with unsuccessful handover when a user moves out of a serving cell and the target cell has limited resources to serve the call connection.

The analysis performed in [12] covers the operation of a broadcast cellular time-varying link and produced an expression, based on the maximization of the achieved spectral efficiency, for the optimal number of simultaneously active users per cell. The authors in [25] 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 [26] where analysis of mobile devices in terms of mobility and traffic was presented to optimize capacity for both circuit and packet-switched services. Table 1 compares some of the related works highlighting the problems, methodologies and limitations.

Table I
Related Works

Author	Problem	Methodology	Limitation
[10]	GSM congestion	Test Mobile System (TEMS)	2G/GSM networks only.
[11]	Call Drop problem	Test Mobile System (TEMS)	Study area not clearly defined.
[17]	Mobile cellular network optimization and QoS	Chi-Square test	Non graphical result presentation.
[19]	GSM network congestion	Erlang –B call loading formula	Solutions not suggested.
[20]	Wireless communication networks optimization	Test Mobile System (TEMS)	Area of study not clearly defined.
[23]	Mobile wireless performance bottlenecks	Android application using My Speed Test PK	Bandwidth and accuracy limitations.
[25]	Poor cellular network	Test Mobile System (TEMS)	No network users' feedback.
[26]	GSM network traffic	Knapsack model	Channel holding time was not considered in the traffic model.
[27]	QoS challenges	Real Time Methodology	Empirical data not included.
[28]	GSM Network challenges	Study and review	No project or practical work was carried out

2. Research Method

The research method, design and procedure are explained in this section. In conducting a study related to analysis and optimization of GSM-based cellular mobile networks, [29] listed drive tests, network statistics and customer complaints and feedback as the three QoS measurement methods normally used to obtain data to monitor, analyze and evaluate QoS as well as for optimization. The drive test method is suitable when measurements covering a large number of cells, such as QoS evaluation for a whole country, state, local government area, or a city, are required. While the network statistics method involves obtaining data through in-situ measurements that do not require any pre-mathematical processes, the customer feedback method involves preparing questionnaire for network users to fill.

In this study, both QoS measurement using drive test and customer feedback methods have been adopted because of their popularity and reliability. A popular GSM service provider having some of the largest number of mobile subscribers in Nigeria according to [30] was selected. All the vital drive test tools were procured. Important information required for the successful completion of the test including identification of the test routes, the type of test to be carried out, the long and short calls duration and other necessary data were obtained.

The test locations were intended to cover all areas served by the various sectors of the sites under investigation. Important routes and avenues round the base stations were also selected. The test routes entered the surrounding neighboring cells overlapping regions. This ensured good coverage of the sites and proper verification of the handover functions.

Drive test measurements were conducted in four strategic study areas in Malete, namely: Kwara State University campus, West End, Safari and Amina Castle. The tests were conducted on a market day (Day One) expected to have heavier traffic and a weekend day (Day Two) with relatively lesser traffic. Results from the measurements were obtained and data containing the major Key Performance Indicators (KPIs) such as Received Signal Quality (RxQual), Received Signal Level (RxLevel), Received Power Level (RSRP) – used to denote measurement of 4G network received power level, Received Reference Signal Quality (RSRQ), Call Set-up Succession Rate (CSSR), Call Completion Rate (CCR), Call Drop Rate (CDR), and Call Handover Success Rate (CHSR), etc. were statistically computed and analyzed.

These data were collected using TEMS tool. The process involved pre-installation of TEMS investigation software on a laptop. CellREF as well as the streets were also loaded. A car was used as the mode of transportation, while the laptop was turned on with the dongle, GPS device and hub connected. SIM card of the network to be investigated was slotted into four MS, turned on and later connected to the system through the hub. The system was then activated. For data collection process, the "Record" button was clicked to initiate and save the data collected on the pre-determined test routes. A "Save As" dialogue to specify the directory, file name and file type popped up. The file type has to be TEMS log files (.log) since all TEMS files has .log extension in which 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 log file. Figure 1 shows the flow chart of this method.

After drive test data collection using TEMS software, the collected data was imported to analyze the event summary such as call attempts, call completed, dropped calls, and blocked calls. Furthermore, a questionnaire was prepared and administered to users of the network in the areas under study to compare the customers' feedback data with the data obtained from the test. This was done to efficiently investigate and analyze the performance of the network.

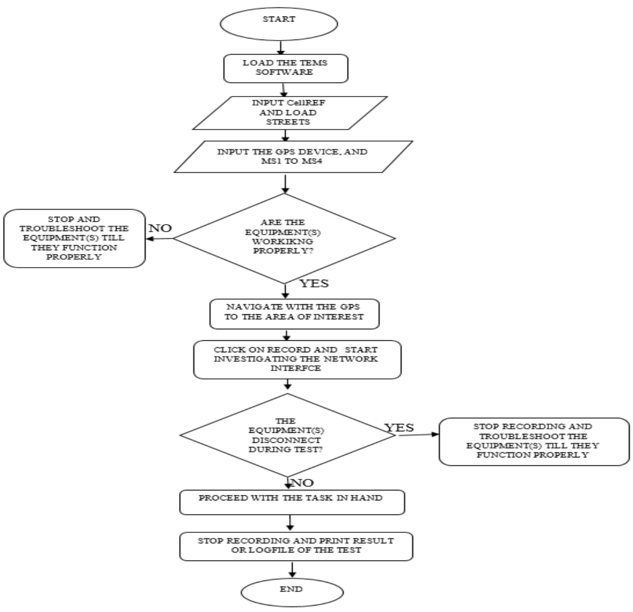

Figure 1. Flow chart of the research method

2.1 Key Performance Indicators and Evaluation of Quality of Service

Communication is said to take place when data flows from source to destination and QoS guarantees a specified level of bit rate, jitter, delay and packet drop probability to the flow. QoS, in telecommunication, stands for the resource reservation control mechanism, instead of the translation of term as achieved service quality. QoS is simply the description or measurement of the overall performance of a service or the level of satisfaction a customer or an end-user gets from a service. ITU-T Recommendation defines QoS as the collective service performance effort which determines the degree of satisfaction of the subscriber [31-33]. QoS assurance is important for real time traffics such as Voice over IP (VoIP), online gaming, IP TV and video streaming. QoS enables network administrators to avoid network congestion and manage the network resources efficiently. Customer satisfaction is critical for a sustainable competitive edge in the market [8]. It plays an important role in the growth rate and development of any business.

One of the fundamental considerations in QoS measurement is the traffic over the network [9]. Although the QoS parameters are not always directly measurable, however, the performance of cellular radio networks can be measured using different KPIs. For effective radio network optimization, it is necessary to pre-select relevant KPIs to be considered, and closely observe when the network monitoring process is going on. In voice telephony, QoS majorly depends on some properties such as voice clarity, call set-up time delay, traffic congestion and network failure which can prevent setting-up calls or prematurely terminate a live call. The most important KPIs from the operator's perspective as described in [3] include bit error rate (BER), frame erasure rate (FER), bit error probability (BEP), and mean opinion score (MOS). However, the main KPIs that are used by the NCC for effective communication and evaluating the QoS of cellular networks in Nigeria [33-34] include the following:

Call Set-up Success Rate (CSSR): this indicator measures the ease with which calls are established or setup. It is the ratio of the number of successive calls initiated by callers to the total number of attempted calls. The higher the CSSR, the better the performance of a cell. High call setup success rate is achieved when standalone dedicated control channel (SDCCH) seizures and traffic channel (TCH) allocation are easily achieved to set up a call [1]. CSSR can be determined by dividing the number of the unblocked call attempts by the total number of call attempts as expressed in (1).

$$CSSR\ (\%) = \frac{No\ of\ Successful\ Call\ Setup}{\text{Total No of Call Attempts}} \times 100 \qquad (1)$$

Call Drop Rate (CDR): this indicator measures the network ability to retain call conversation when it has been established or setup. CDR is also called Drop Call Rate (DCR). A dropped call is a call that is prematurely terminated before being released normally by either the one initiating the call or the one being called. They occur as a result of degraded signal quality, interference, poor handover success rate (HOSR), hardware faults, high traffic channel (TCH) congestion rate and other related coverage issues [6]. Service providers pay attention to CDR values because its increase signifies serious network problem that needs to be urgently fixed. The CDR is the number of dropped calls divided by the total number of call attempts as in (2).

$$CDR\ (\%) = \frac{No\ of\ Dropped\ Call}{\text{Total No of Call Attempts}} \times 100 \qquad (2)$$

Traffic Channel Congestion Rate (TCHCR): this indicator measures how busy a cell is during call setup due to traffic congestion. A higher TCHCR shows difficulty in setting up a call or establishing a channel [6]. Once the channels configured or allocated to a BTS are exhausted, it becomes impossible to establish a new call to the other party. BTS usually have high number of traffic channels (TCHs) which must be higher than the maximum number of users within the BTS coverage area. The maximum TCHCR recommended by the regulatory agency is 2%. The traffic channel availability can be mathematically determined as:

$$TCHCR\ (\%) = \frac{No\ of\ \text{calls blocked due to unavailable resources}}{\text{Total No of Requests}} \times 100 \qquad (3)$$

Hand Over Success Rate (HOSR): this is the ability of established channels or ongoing call on a particular network core to be successfully transferred to another network core. The HOSR is an important KPI that indicates the percentage of successful handovers of all handover attempts. Handover success rate directly affects the user performance when an active network user traverses different cells unhindered. In other words, it is the ratio of successful handover to the total handover requests [35] as given in (4).

$$\text{HOSR}\ (\%) = \frac{No\ of\ \text{successfully completed handovers}}{\text{No of initiated handovers}} \times 100 \qquad (4)$$

While the NCC recommended value or target for HOSR stands at 99%, some of the possible causes of poor HOSR include poor radio coverage, network congestion, high interference, link connection, error associated with locating parameter setting and handover relations [1].

It is important to note that the KPIs, some of which have been discussed above, are associated with what can be classified as accessibility (e.g. CSSR, TCHCR), retainability (e.g. CDR, HOSR), service integrity (e.g. Receive Quality or RxQUAL, Received Signal Strength Indicator or RSSI).

3. Results and Analysis

This In this section, the results of the research have been presented and explained. Analysis and comprehensive discussion of the results obtained for 2G, 3G and 4G are also given. The data obtained from the drive tests covering the research area on both eventful and non-eventful days, the processed data from the administered questionnaire, the statistics obtained from necessary mathematical computations and their analysis have been presented either in graphs, figures or tables, as the case may be, in this section.

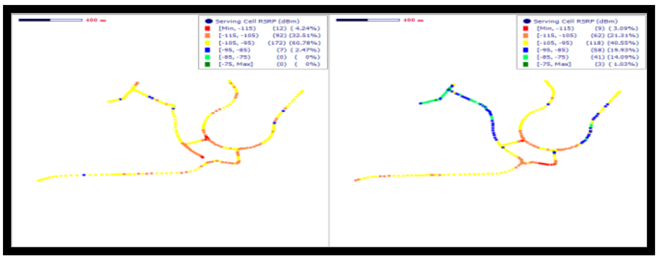

Figure 2. 4G RSRP route overview

3.1. 4G Networks

Figure 2 shows the 4G RSRP route overview for the eventful and non-eventful days for the study location.

In Figure 2 and other subsequent similar figures, the Serving Cell RSRP (dbm) box at the top of the overview shows the RX Level dBm values from its minimum to maximum range and the corresponding counts and percentages to each number of occurrence.

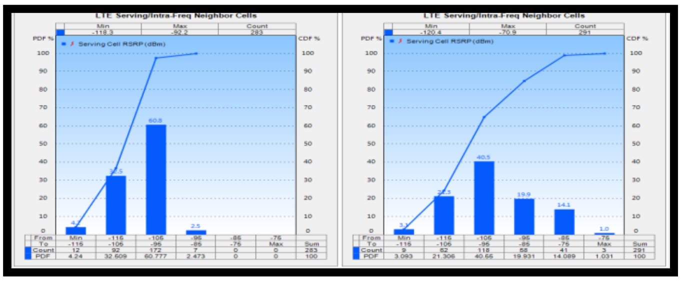

Figure 3. Chart for the 4G RSRP

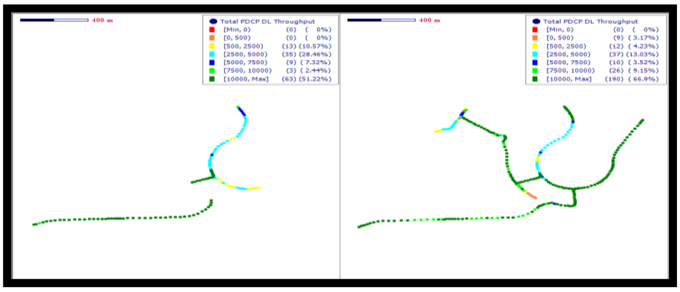

Figure 4. 4G data throughput route

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 3, established using the TEMS discovery, is the chart for the 4G RSRP. It is a plot of the percentage of minimum to maximum range, i.e. from -115 to -75. Count represents the number of occurrence of each range. For instance, the minimum range -115 with red as identification color recorded 12 and 9 (red dots) for eventful day and non-eventful day respectively. While pdf is the corresponding percentages to each number of occurrence or counts, sum is the total counts and percentage.

Figure 4 and Figure 5 respectively show the overview and the chats of the 4G data throughput route for the eventful and the non-eventful days. 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. The PDCP DL throughput (at the top of the overview) shows the RX Level dBm values from minimum to maximum range and the corresponding counts and percentages to each number of occurrence. This is further succinctly shown in Figure 5. The Figure shows a percentage range from 0 to 10000 as well as 123 and 284 as the Sum for eventful day and non-eventful day respectfully.

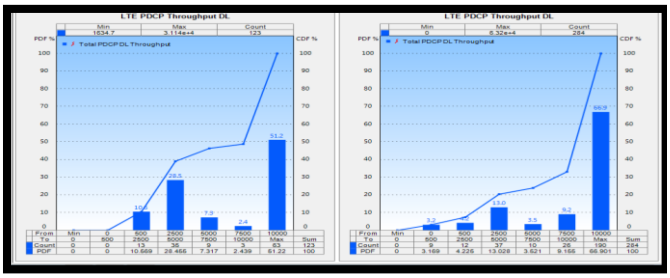

Figure 5. Chart for the 4G data throughput (%)

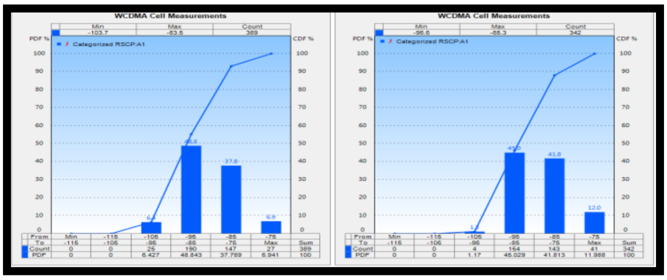

Figure 7. Chart for the 3G RSCP

3.1.1. 4G KPI Calculations

$$\text{RSRP (\%)} = \frac{\textit{No of } \text{occurence MS receives Rx Level at acceptable range}}{\text{Total no of occurence MS receives Rx Level}} \times 100 \tag{5}$$

$$\text{Data throughput} = \frac{\textit{No of } \text{occurence MS receives data at acceptable range}}{\text{Total no of occurence MS receives data}} \times 100 \tag{6}$$

While the 4G RSRP for the eventful and the non-eventful days are 2.47% and 35.05% respectively, the 4G data throughput are 60.97% and 79.57%. Average data speed per seconds of 7018.3 Mb/Sec and 8271.12 Mb/Sec are obtained using (7).

$$\text{Average mean} = \frac{\Sigma fx}{\Sigma f} \tag{7}$$

3.2. 3G Netwroks

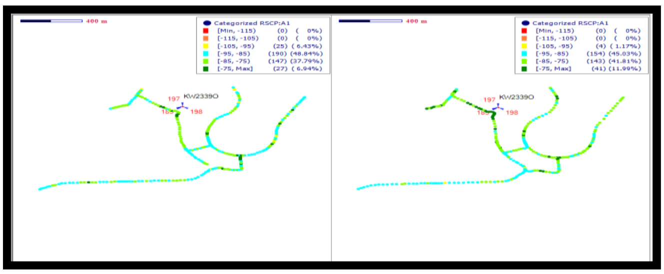

Figure 6. 3G RSCP route overview

The results of the 3G networks are analyzed here. Figure 6 and Figure 7 are the 3G RSCP route overview and chats for the eventful day and non-eventful day. Areas where RSCP is greater than −105 dBm represent the red dots with poor signal levels. Areas with RSCP from -85 to 0 dBm represent the light green and dark green dots with good signal levels.

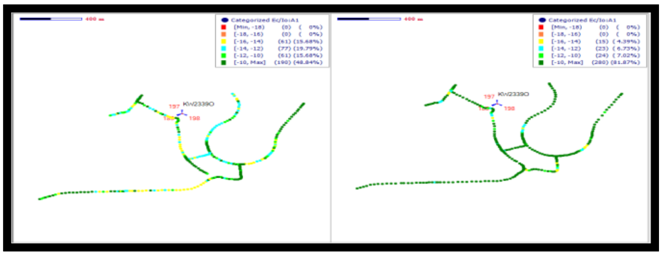

Figure 8. 3G EC/Io route overview

Figure 8 to Figure 11 show the overviews and the corresponding chart of the 3G EC/Io route and the 3G data throughput. In Figure 8, areas where EC/Io is greater than −16 dBm represent the red dots with poor signal levels while those with EC/Io from -12 to 0 dBm represent the light green and dark green dots with good signal levels. Figure 9 shows the percentage of each minimum to maximum range from -18 to -10.

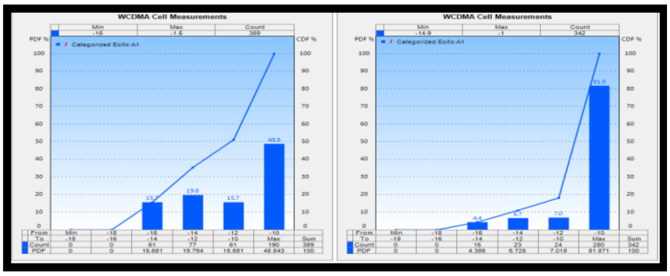

Figure 9. Chart for 3G EC/Io.

For the data throughput presented in Figure 10, the red spots 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. The HS-DSCH throughput total (kbps) in Figure 10 and Figure 11 show the RX Level dBm values from minimum to maximum range (i.e. from 1 to 4096) and the corresponding counts and percentages to each number of occurrence.

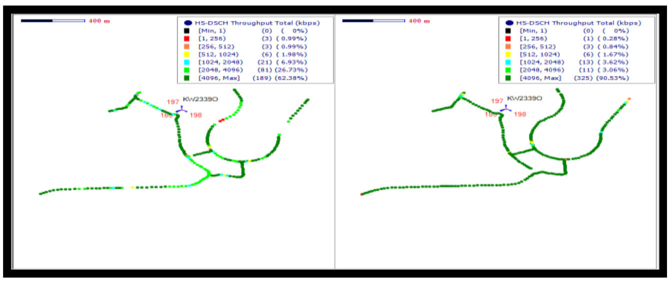

Figure 10. 3G data throughput route.

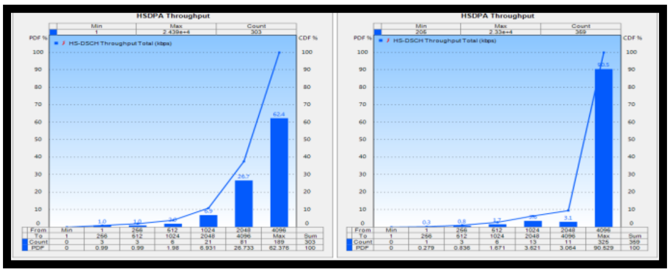

Figure 11. Chart for 3G data throughput (%)

3.2.1. 3G KPI Calculations

From the 3G event statistics and using the appropriate equations, the Accessibility (CSSR), EC/IO (3G Signal Quality), RSCP (3G Signal Strength) and the 3G data throughput are determined and presented in Table 2. Similarly, those of 2G especially the Rx Level and RxQual are also determined and recorded.

3.3. Summary of KPI Analysis

The summary of the results obtained are presented in this section. Table 2 presents the results of the KPI analysis acquired from Drive Test for 2G, 3G and 4G. In Table 3, the KPI analysis obtained from customers' feedbacks are also presented.

A comparison of the main KPIs involving CSSR, CDR, network coverage and call quality for MOS values in Table 3 with the Drive test analysis in Table 2 shows that the users' feedback suggested that the network performance was satisfactory, but not close to being excellent. Furthermore, it is observed from the results that the QoS a user will most likely experience in the area of study is not unexpected.

Throughout the study, all 2G and 3G calls attempted in the area of study were established successfully, which proved that the call set-up success rate was very high and efficient. Likewise, a dropped call never occurred. This is an indication that the network retainability in the investigated areas was very high. Furthermore, this study revealed that the 2G network voice quality gave a better performance than the 3G network. However, the 4G coverage was terrible and does not come close when compared with the results obtained from 2G and 3G.

Table II
KPI analysis acquired from Drive Test (QoS)

Networks	KPI	Eventful Days	Non-Eventful Days
2G	Rx QUAL	95.44%	95.41%
	Rx Level	27.27%	45.24%
	CSSR	100%	100%
3G	CSSR	100%	100%
	RSCP	93.57%	98.83%
	EC/Io	84.31%	95.61%
	Data throughput	96.03%	97.21%
	Average data speed (Mb/secs)	3502.83	3874.22
4G	RSRP	2.47%	35.05%
	Data quality	60.97%	79.57%
	Average data speed (Mb/secs)	7018.3	8271.12

Table III
KPI analysis from customers (MoS)

Networks	KPI	Values
	CSSR	86%
	CDR	10%
2G	Network coverage	76%
	Call quality	73%
3G	Data speed	78%
	Data coverage	83%
4G	Coverage	46%
	Data speed	80%

Furthermore, the internet access performance via 3G and 4G was reliable both during the eventful and the non eventful days. Expectedly, 4G performed better in terms of speed, as it was on an average speed of 7478.022Mb/Sec on eventful day and 9026.87 Mb/Sec on non eventful day. These were higher than the 3502.83M Mb/Sec and 3874.22Mb/Sec result respectfully obtained for the 3G network.

4. Conclusion

This work examined and evaluated the performance of GSM networks in Malete, Kwara State of Nigeria. The relevant KPIs were used as key parameters for both carriers and subscribers. Log files from the active GSM networks were generated using Ericson W995 phone with built-in TEMS software package. The post analysis of these log files identified parametrical problems. The research results revealed that the network failed to meet the regulatory (i.e. NCC) recommendations for CSSR, CDR, HSR, and call blocking in some instances. Generally, the KPIs values from the BTS on non-eventful day rarely meet up with the NCC's recommendations. This was observed to be worst-off during the eventful period. The eventful period is characterized by higher population of subscribers.

The GSM operators have only L800 4G band in the area of study, which made all the available 4G devices operate on the single band causing reduction in the efficiency of the band due to high traffic. The addition of L1800 or L2600 band will bring a huge increase in the coverage as well as the QoS of the 4G network. The GSM operator needs to increase the number of BTS or implement sector addition, as only one BTS was available in the area of study. This will increase the network coverage, decrease the traffic, and a possibility of inter-frequency handovers.

Parametrical optimization was given as a way of network improvement for better reception and revenue generation. Physical optimization measures such as swapping of RF antenna cables, azimuth adjustment and retune of broadcast control channel (BCCH) frequencies are required in order to resolve the problems associated with some of the networks. Finally, the NCC is advised to inspect the GSM performance profile of operators, so as to ensure that the operators are meeting the ever increasing needs of subscribers.

Some of the problems faced in the course of this research include cell site authorization, unavailability of cell reference data of some network providers, and difficulties associated with tools used. Aside the highlighted strengths of the solutions being proposed, which include but not limited to network accuracy, proficiency and improved QoS, a similar research may be recommended to cover higher speed heterogeneous networks such as 5G whenever it is deployed. However, the effectiveness of the proposed solutions may not be as good in such scope. This is a weakness that can serve as future scope.

Acknowledgments

The authors wish to express their sincere gratitude to OMNICOM Solutions, Merit Telecoms and Kwara State University, Malete, Nigeria for making available some of the devices, equipment and facilities used in conducting this work.

References

[1] Galadanci, G. S. M.; and Abdullahi, S. B. “Performance Analysis of GSM Networks in Kano Metropolis of Nigeria,”(AJER), vol. 7, no. 5, pp-69-79, 2019.

[2] Ozovehe; Usman, A.U. “Performance Analysis of GSM Networks in Minna Metropolis of Nigeria,” (NIJOTECH), vol. 34, no. 2, pp. 359 – 367, Apr. 2017.

[3] Upadhyay, R. K.; Singh, V. K.; & Kumar, R. “Performance analysis of gsm network”, (IJARSE), 8354(3), 244–253, 2016. Retrieved from http://www.ijarse.com

[4] Seytnazarov, S. O; "RF optimization issues in GSM networks," 2010 4th International Conference on Application of Information and Communication Technologies, Tashkent, 2010, pp. 1-5, doi: 10.1109/ICAICT.2010.5611802.

[5] Dutta,; Sarin, S.; "Performance optimization in GSM networks through dynamic power control," 5th IEEE International Conference on High Speed Networks and Multimedia Communication (Cat. No.02EX612), Jeju Island, South Korea, 2002, pp. 197-201, doi: 10.1109/HSNMC.2002.1032575.

[6] Lawal, Y.; Ukhurebor, K. E.; Adekoya, M. A.; Aigbe, E. E. “Quality of Service and Performance Analysis of A GSM Network In Eagle Square, Abuja and Its Environs, Nigeria,” (IJSER) Volume 7, Issue 8, pp. 1992-1999, August-2018.

[7] Sharma., P.; “Evolution of Mobile Wireless CommunicationNetworks-1G to 5G as well as Future Prospective of Next Generation Communication Network,” (IJCSMC), Vol. 2, pp. 47 – 53, August 2015.

[8] Kadioglu, R.; Dalveren, Y.; Kara, A. “Quality of Service assessment: a case study on performance benchmarking of cellular network operators in Turkey,” (Turk. J. Electr. Eng. Comput. Sci.), vol. 23, pp. 548-559, February 2017.

[9] Caroline, O.E.; Adeola, A.A.; Oluwatosin, S.A. “Assessment of GSM Network Failures, Quality of Service Evaluation and Its Impacts on E-Learning,” (IJSEAS), vol 1, Issue-5, ISSN: 2395-3470. Pp. 121, Aug, 2018.

[10] Rakiyat, “A Comparative Study of GSM congestion in Ilorin West Local Government Area,” (AJERD), Vol. 2, pp. 26-35, 2019.

[11] Sharma; G.; Bansal, A.K. A Practical Approach to Improve GSM Network Quality by RF Optimization. (IJEAT), vol. 3, no. 4, pp. 95-99, April 2018.

[12] Varzakas, P. "Optimal Radio Capacity for an Hybrid DS/SFH CDMA System in Cellular Radio", IEE Electronics Letters, vol.40, no.7, April 2004, pp.440 - 442.

[13] Dheepak, M.; and Saravanan, S. V. “RF Optimization for Quality Improvement in GSM Network”, (IJEET), Volume 6, Issue 8, pp.53-62, Sep-Oct, 2015.

[14] Ekiz, N.; Salih, T.; Sibel,; Fidanboylu, K. "An Overview of handover Techniques in Cellular Networks"-, (IJIT) Volume 2 Number 3 2005 ISSN 1305-239.

[15] Ayo-Bello, O. A.; Aibinu, A. M.; Onumanyi, A. J. Automatic determination of call setup time and ring tone quality in Gsm network, Conference: International Engineering Conference IEC 2016, pp. 424-430.

[16] Arulananth, T.S.; Jayasingh, T. N.; Gangatharan,; Baskar, M. “GSM Optimization of Coverage Area Using Agilant Tool,” (IJAREEIE) 04(05):4093-4098, May 2015.

[17] Alexander, N. N.; Anthony, U. O.; Emmanuel, O. I.; Davies, K. N. “Evaluation and Optimization of Quality of Service (QoS) of Mobile Networks in Nigeria,” (IJICTRAME), 3(10), 2018.

[18] Mughele, E. S.; Wole, O.; Tunde, A. “Congestion Control Mechanisms and Patterns of Call Distribution in GSM Telecommunication Networks: The Case of MTN Nigeria,” 4(3): 29-42, 2018.

[19] Kuboye, M. “Optimization models for minimizing congestion in Global System for Mobile Communications (GSM) in Nigeria,” (JMCS), 2(5): 122-126, 2010.

[20] Agajo, J.; Theophilus, A. L.; and Kenneth, A. I. “Optimization of Network Performance in Wireless Communication Networks,” (APST), 13(1), 2012.

[21] Kuboye, M.; Alese, B. K.; Fajuyigbe, O.; Adewale, O. S. “Development of Models for Managing Network Congestion on Global System for Mobile Communication (GSM) in Nigeria,” (JWNC), 1(1): 8-15, 2019.

[22] Hu, H.; Zhang, J.; Zheng, X.; Yang, Y.; & Wu, P. “Self-configuration and self-optimization for LTE networks”, IEEE Communications Magazine, 48(2), 94–100, 2020. https://doi.org/10.1109/MCOM.2010.5402670

[23] Arshad, T.; Awan M. F.; Ahmad, T. "Performance Evaluation of Mobile Broadband Cellular Networks in Pakistan." In Local Computer Networks Workshops (LCN Workshops), 2016 IEEE 41st Conference on, pp. 104-111, 2018.

[24] Awan, M. F.; Ahmad, T. S.; Qaisar, N.F.; Sundaresan, S. "Measuring broadband access network performance in Pakistan: A comparative study." In Local Computer Networks Conference Workshops (LCN Workshops), 2015 IEEE 40th, pp. 595-602. IEEE, 2015.

[25] Oseni, F. “Radio Frequency Optimization of Mobile Networks in Abeokuta, Nigeria for Improved Quality of Service,” (IJRET), Volume 03, August 2014.

[26] Biebuma, J. “Traffic Modelling for Capacity Analysis of GSM Networks in Nigeria,” Continental J. (ITWJ), vol. 4, 2010.

[27] Nochiri, C.C.; Osuagwu K.C.; Okafor, “Empirical Analysis On The GSM Network KPI’S Using Real-Time Methodology for Novel Network Integration”, Progress in (JSAER), vol. 02, no. 03, pp. 092-107 2014.

[28] Budhiraja, R.; and Jadon, J. S. “Study and Implementation of Drive Test for Development of GSM Network”, (IJETT) – Volume 4 Issue 10 - Oct 2013.

[29] Pipikakis, M. “Evaluating and Improving the Quality of Service of Second-Generation Cellular Systems,” (BCTJ), vol. 2, no. 2, pp. 1-8, 2004.

[30] Subscriber/Operator Data for July 2015-June 2016 www.ncc.gov.ng/index.php?option=com_content&view=article&id=6 8&Itemid=67 August, 2016. (URL for Nigerian Communications Commission).

[31] ITU-T recommendation G.1000 (2001), Communication quality of Service: A framework and definition

[32] International Telecommunication Union (2021). Quality of Service Definitions. http:// www.itu.int.

[33] Wireless Communications, Principles and Practice, 2nd edition, Theodore S. Rappaport, Pearson publications.

[34] Library, D. E. (2014). Introduction to Wireless Telecommunications, Network Architecture and Functions (2nd ed.). New york, USA: The McGraw-Hill Companies.

[35] Andleeb M.; Abbas Ali, S. “A Study on the Hourly Behavior of Key Performance Indicators of Global System for Mobile Communications,” (JETTCS), vol. 6, no. 3, ISSN 2079-8407, pp. 170, March 2019.

Biography

Abdulwaheed Musa holds a B. Eng. (Electrical and Computer Engineering) from the Federal University of Technology, Minna, Nigeria, MSc (Communication Engineering) and a PhD from the International Islamic University Malaysia, Kuala Lumpur. He joined the Kwara State University (KWASU), Malete, Nigeria in 2016 and has served in different capacities. Dr. Musa is the Founding Director of the Centre for Telecommunication Research and Development (CTRD), KWASU where he provides professional services on telecommunications. He is a Senior Research Associate at the Institute for Intelligent Systems, University of Johannesburg, South Africa, senior member of the Institute of Electrical and Electronics Engineering (IEEE), and registered engineer with the Council for the Regulation of Engineering in Nigeria (COREN). He has written scholarly papers published in top journals and conference proceedings. His research interests include communication systems, propagation physics and microwave propagation.

Samad Adeniran obtained his Bachelor Degree in Electrical and Computer (Second Class - Upper) from Kwara State University, Malete in 2020. His research interests include telecommunications and electronics engineering. Samad enjoys application of technical knowledge and skills for personal development, research and community service. He hopes to be affiliated with the Council for the Regulation of Engineering in Nigeria (COREN) in the nearest future as a practicing telecommunication engineer.