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Performance Evaluation and Improvement on Quality of Service of Global System for Mobile Communications in Nigeria

J. J. Popoola [1]
University of Witwatersrand
Johannesburg, South Africa

I. O. Megbowon[2]
Fed. Univ. of Technology
Akure, Nigeria

V. S. A. Adeloye[3]
Fed. Univ. of Technology
Akure, Nigeria

Abstract

This paper presents an insight into network performance evaluation and quality of service (QoS) improvement of GSM cellular system in Nigeria. The components of QoS and mechanisms of analyzing and evaluating them are discussed. The paper also identifies the important key performance indicators (KPIs) for QoS evaluation which are used in evaluation the GSM network. Four assessment parameters (network accessibility, service retainability, connection quality and network coverage) for evaluating QoS on the network were employed. The parameters were applied on four GSM networks in Nigeria using customers' complaints method. The result of the study shows that the Qos of GSM system in the country is unreliable. It is also found from the study that the GSM network accessibility and retainability in the country are unsatisfactory. The paper is concluded with recommendations on how to improve both the QoS and the positive impact of GSM in the country in order to enhance telecommunication system of the country.

Keywords: GSM generations, Key performance indicators (KPIs), Reuse distance, GSM frequencies, Assessment parameters.

Introduction

From time immemorial, information and communication have formed the basis of human existence. People want to reach others and to be reached. This desire has been a driving force, motivating men to continuously seek for a new and effective means of dissemination of information to one another on real time basis irrespective of distance. The explosion in technology ushered in this desire with advent of the first generation cellular telephone systems that enable people to communicate with one another irrespective of time and place. This first generation cellular telephone system, which was analog system, was launched in 1960s before digital communication became prevalent (Goldsmith, 2005).

By the end of the 1980s, it became apparent that the analog cellular systems would not be able to meet continuing demand in instantaneous information of the next century unless something was done about two inherent limitations of the analog cellular systems: severely confined spectrum allocations; and incompatibility among the various analog systems available

(Redl *et al*., 1995). This led to the convergence of the Europeans on a uniform standard for second generation digital systems called GSM, originally stood for Group Spéciale Mobile, but later changed to Global Systems for Mobile Communications. This development of GSM in the world was prompted by the need to provide seamless telecommunications throughout Europe. The initial release of GSM was called GSM Phase 1 and generally referred to as the 1G or first generation (Ajiboye *et al*., 2007). This release made provision for the basic voice, short message service (SMS) and circuit switched data (CSD).

At the beginning of the 1990s, the lack of a common mobile system was seen to be a general, worldwide problem. This led to the birth of the second generation or GSM Phase 2 (2G) which was released in 1995 with enhanced supplementary services. From this development, the GSM system has spread to the Eastern European countries, Africa, Asia and Australia (NOKIA, 2002). However, the GSM usage did not commence in Nigeria until August 2001. Nevertheless, since the inception of GSM in Nigeria, mobile telephony has rapidly become the most popular method of voice communication in the country. Its growth has been so rapid that Nigeria has been rightly described in various media as one of the fastest growing GSM markets in the world (Adegoke *et al*., 2008).

Before the advent of GSM in Nigeria, telephones were a luxury that a few privileged Nigerians enjoyed. However, with the advent of GSM in the last seven years, communications in the country had witnessed a tremendous boost. According to Hassan *et al*. (2009), from less than 500,000 active fixed telephone lines as at middle of 2001, the total number of connected (fixed and mobile) telephone lines had increased to about 22.9 million as at March 2006. The figure has increased dramatically to 12 million by the end of 2007, with GSM or mobile lines accounted for about 91% of the total active telephones (fixed and mobile) lines (Ajiboye *et al*., 2007).

However, as the number of services and subscribers of GSM in Nigeria increases, the demand for good QoS has become an issue in the country. The agitation has become a national issue which had been brought before the country House of Representative on July 18, 2007 and the Nigerian Communication Commission (NCC) (Adegoke *et al*., 2008). In finding the lasting solution to the problem, the NCC, body responsible for the regulation of GSM in Nigeria, on 6th July 2007 issue out the threshold levels on the key performance indicators (KPIs) for ascertaining QoS of all the GSM networks in the country. The KPIs on which the GSM networks were tested according to Kollár (2008) include: call set-up success rates (CSSR), call drop rate (CDR), call completion success rates (CCSR), handover success rates (HSR) and traffic channel congestion rate (TCHR). These KIPs are defined as follows.

Call Set Up Success Rate (CSSR)

This indicator measures the ease in which calls are established or set up. The higher the value of CSSR, the easier it is to set up a call. For instance a CSSR of 71% means that out of every 100 call attempts, only 71 are successful while the remaining 29 are unsuccessful. The indicator is calculated using the expression:

$$CSSR = \frac{Number\ of\ unblocked\ call\ attempts}{Total\ number\ of\ call\ attempts} = \left(1 - Blocking\ probability\right) \times 100\% \quad (1)$$

Call Drop Rate (CDR)

This indicator measures the network ability to retain call conversation when it has been established or set up. A value of 7% of CDR means that, out of every 100 calls established or set up, 7 will drop before any of the calling parties voluntarily terminate the set up call. The indicator is calculated using the expression:

$$CDR = \frac{Number\ of\ dropped\ call}{Total\ number\ of\ call\ attempts} = \left(1 - Call\ complete\ probability\right) \times 100\% \quad (2)$$

Call Completion Success Rate (CCSR)

This indicator can be derived either from network statistics or from drive test statistics. The indicator takes into account the fact that all failures are either drops or unsuccessful call set ups. It is a good parameter for evaluating the network accessibility and retainability as perceived by the customers. The indicator is derived using the expression:

$$CCSR = \frac{Total\ number\ of\ completed\ calls}{Total\ number\ of\ call\ attempts} \quad (3)$$

Handover Success Rate (HSR)

This indicator measures the success of handovers. This value is expected to be very minimal; as it minimal value improves CDR.

Traffic Channel Congestion Rate (TCHC)

This congestion is the first level of congestion experienced by the customer. It measures the relative ease by which the customer seizes a traffic channel to set up a call after a signaling seizure has been successful. The higher this value, the relative difficulty it is in making a call.

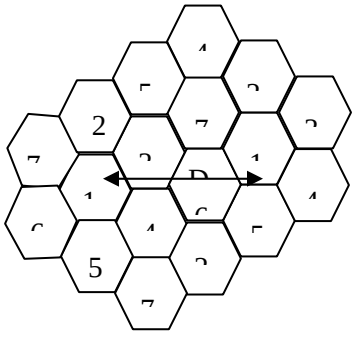
Structure of Nigeria Telecommunications Sector

Traditionally, the main players in the Nigeria telecommunications sector are the Federal Government of Nigeria (FGN), the Ministry of Communications, NCC, and the telecommunications service providers. The FGN role in telecommunications in Nigeria has been very direct one; owner and operator of the incumbent public telecommunications firm. This was shifted with the deregulation of the telecommunications sector in 1992 with the establishment of a regulatory body, the NCC. Since then, the NCC has been in control of telecommunications licensed issuing to private telephone operators which authorizes private telephone operators to roll out telephone services. This has led to the issuing of GSM licenses to the first set of GSM operators: MTN (Mobile Telecommunication of Nigeria), EWN (Econet Wireless Nigeria, which in 2004 changed to Vee Networks of Nigeria, Vmobile, and was acquired by Celtel in 2006, and currently acquired by Zain Nigeria) and M-Tel (Nigerian Mobile Telecommunications Limited, the mobile subsidiary of the National Carrier, Nigerian Telecommunications Plc, NITEL) in 2001 while Glo (Globacom Limited) joined in 2003.

In addition to these national and privates telephones operators, there are some small private operators (e.g. Multi-Links Telecommunications Ltd., Odu'a Telecoms (O'Net) and Intercellular Nigeria Ltd.) operating in certain part of the country such as Lagos. These primarily deploy fixed wireless technologies and are used by businesses and high net worth individuals while some large companies, such as Shell Nigeria, constructed their own private radiocommunications networks (Doyle and McShane, 2003).

GSM Frequency in Nigeria

Like other parts of the world, GSM in Nigeria is based on the concept of frequency reuse. That is, the limited spectrum allocated to the service is partitioned into N non-overlapping channels sets, which are then assigned in a regular repeated pattern to a hexagonal cell grid (Rahnema, 1993). This hexagonal cell grid is just a convenient idealization that approximates the shape of a circle but forms a grid with no gaps or overlaps as shown in Fig. 1. The propagation environment determines the interference received from the neighboring co-channel cells which in turn govern the reuse distance, that is, the distance allowed between co-channel cells (i.e., cells using the same set of frequency channels).



D = Reuse Distance

Figure 1. Hexagonal Cellular Structure

Generally, there are five frequency bands designated by International Telecommunications Union (ITU) for the operation of the GSM mobile phone: GSM-400, GSM-850, GSM-900, GSM-1800, and GSM-1900. In Nigeria, GSM-900 and GSM-1800 are being used. The radio channels are based on a time division multiple access (TDMA) structure that is implemented on multiple frequency sub-bands (TDMA/FDMA). Each base station is equipped with a certain number of these pre-assigned frequency/time channels. The TDMA structure is applied in both the forward (mobile station to the base transceiver or network station) and reverse (base transceiver or network station to mobile station) directions. On GSM-900, the forward or uplink direction uses 890 – 915 MHz while the reverse or downlink direction is on 935 – 960 MHz, providing 124 radio frequency channels spaced at 200 kHz and duplex spacing of 45 MHz. Also, in Nigeria, GSM-1800 uses 1710 – 1785 MHz to send information from the mobile station to the base transceiver station (uplink) and 1805 – 1880 MHz for the other direction (downlink), providing 374 channels at duplex spacing of 95 MHz. Full details on other GSM frequency bands using across the world is shown in Table 1.

*Table 1***.** World-wide GSM Frequency Bands

System	Band (MHz)	Uplink (MHz)	Downlink (MHz)
GSM-400	450	450.4 – 457.6	460.4 – 467.6
GSM-400	480	478.8 – 486.0	488.8 – 496.0
GSM-850	850	824.0 – 849.0	869.0 – 894.0
GSM-900	900	890.0 – 915.0	935.0 – 960.0
GSM-900 (E-GSM)	900	880.0 – 915.0	925.0 – 960.0
GSM-900 (R-GSM)	900	876.0 – 880.0	921.0 – 925.0
GSM-1800	1800	1710.0 – 1785.0	1805.0 – 1880.0
PCS-1900	1900	1850.0 – 1910.0	1930.0 – 1990.0

Source: Free Encyclopedia website (Free Encyclopedia)

Motivation and Objective of the Study

Following the rollout of GSM services across the nation, the socio-economic landscape of Nigeria has been positively altered. Its explosive growth has brought huge revenues to the operators as well as the government through tax and license fees (Adegoke *et al.*, 2008). Similarly, the citizenries have benefited immensely from the services, not only as a means of communication but it has provided job opportunities for thousands of people. However, the principal development that mars these benefits is the aggressive complaining raised by GSM subscribers regarding abysmal quality of services (QoS) rendered by the GSM operators in the country. The unfortunate aspect of this evil is the fact that all the GSM subscribers irrespective of the operator are being affected.

Based on this ugly experience, this study was embarked upon to find out what are the causes of the problem and find ways of ameliorating the observed defects. The paper therefore, focuses on GSM QoS as well as mechanism available for monitoring, analyzing and improving QoS. Four assessment parameters are used in assessing the performance of the four GSM networks in the country. Three out of these parameters that are normally used in assessing the performance of networks subjected to constantly changes in response to increasing coverage and capacity demands as reported by Pipikakis (2004) were considered. These three parameters are: accessibility (i.e. getting on the network), retainability (i.e. staying on the network) and connection quality or service integrity (i.e. having a good service experience while using the network). The fourth parameter introduces in the study is the network coverage.

In carrying out a study like this, there are three mechanisms normally use to monitor, analyze and evaluate QoS and take corrective actions. They are drive tests, network statistics and customer complaints (Pipikakis, 2004). The first two approaches had already been used, NCC (2005) - drive tests; Kuboye *et al.,* (2009) - network statistics, in assessing the performance of the four GSM networks in Nigeria. Therefore, in order not to reinvent the wheel, this study will centre on the last approach by using questionnaire in getting the customers' complaints. However, the data from the present study is compared with the results of the previous studies presented in Kuboye *et al.,* (2009) in order to ascertain the accuracy of the work.

Research Methodology

The investigation was conducted for period of 4 months (May 2006 - August 2006) in the country Federal Capital Territory (FCT) and some selected cities in all the six geo-political zones (North-West, North-Central, North-East, South-West, South-South and South-East) of the country, where all the four GSM networks considered were operating. The GSM networks studied are Celtel, MTN, Glo and M-Tel. The study was conducted using structured questionnaire. The primary data obtained from this investigation was later compare with secondary data from other previous related studies.

Structure of the Questionnaire

This involved the designing and administering of the well structured research questionnaire to the customers of the four GSM networks in the studied areas. The questionnaire was divided into two sections. The first section is the introductory part, where the aim of the study was stated. The section also contains words of assurance and encouragement, assuring respondents that the information provided by them would be treated with utmost confidentiality.

The second section of the questionnaire consists of questions related to objective of the study. The section was divided into four subsections. The first subsection contains four questions on network accessibility. Questions on call set up rate such as how easy is it to set up call, number of attempts they do make before having a successful call, etc. were asked. In the second subsection, questions on retainability on the network after successful call set up were asked. Question such as how often do they experience call termination before completing their conversation were asked. Two questions were asked in this subsection from which service retainability degree of each of the four networks studied were evaluated. The third subsection contains three questions on the

connection quality or service integrity of each of the networks considered. Questions on voice quality and SMS delivery of each operator were asked. In the fourth subsection, two questions were asked on network coverage or network availability of the four GSM operators. In all, a total of eleven questions were asked, which were structured in such a way that one question leads to the next.

Administration of the Questionnaire

This phase of the work was carried out in the selected areas in the FCT and some cities in each of the six geo-political zones where the four GSM operators are operating. Table 2 shows the detail on the retrieved questionnaires from each of the studied areas. The responses gather were converted to percentage so that the result analysis can be on the equal basis.

Table 2. Questionnaire Distribution

	GSM NETWORK			
Zone	Celtel	MTN	Glo	M-Tel
North-West	1060	1383	699	342
North-Central	559	1208	840	393
North-East	476	364	253	221
South-West	839	1072	534	155
South-South	832	1774	677	571
South-East	229	419	768	184
FCT (Abuja)	473	587	506	454
Total	4468	6807	4277	2320
Overall Total 17872				

Results and Discussion

Network Accessibility

The measure of the accessibility to services provided by GSM network is the call set-up rate. Network accessibility verifies mobile station's ability to establish and maintain calls. It analyses the ability to successfully establish voice communications between two ends, a mobile network terminal and a fixed network terminal, and the ability of networks to maintain this call during a pre-established period of time. When it is not possible to establish communication or

communication dropped during the conversational phase, the cause for this failure or drop need to be identified. This makes the data on both call set-up rate and call drop rate on a network important.

The call set-up rate is the rate at which a subscriber initiates a call get his/her call established. The higher the number of attempts made before getting a call established or set-up the worse the congestion situation of the network. This means the accessibility to the network is difficult. On the other hand, if the subscriber can get a call established with his/her first attempt, it is an indication of non-congested situation and high accessibility. When a subscriber has to make more than one attempts before getting his/her call connected or established, this means that the call set-up failure rate of the network is high. The response on the call set-up rate from the study is shown in Figures 2 and 3.

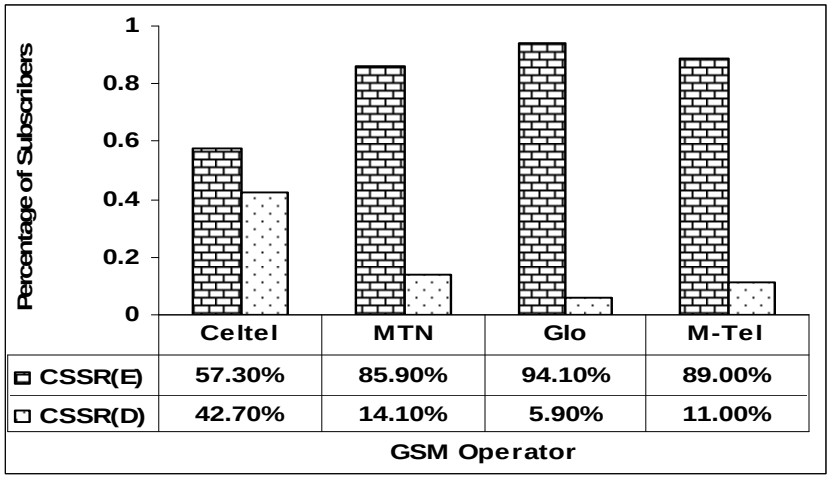


Figure 2. Call Set up Success Rate (Easy/Difficult)

Fig. 2 shows the rate of call set-up or accessibility to each of the GSM network. CSSR(E) means easy call set-up rate while CSSR(D) means difficult call set-up rate. The Figure (i.e. Fig. 2) shows that among all the four GSM operators studied Glo has the highest easy call set-up success rate, CSSR(E), of 94.10% while Celtel has the lowest easy call set-up success rate, CSSR(E), of 57.30%. This implies that the accessibility into Glo network is the easiest follow by M-Tel with CSSR(E) of 89.00%. Similarly, the accessibility to MTN with 85.90% CSSR(E) is easier than that of Celtel with 57.30% CSSR(E).

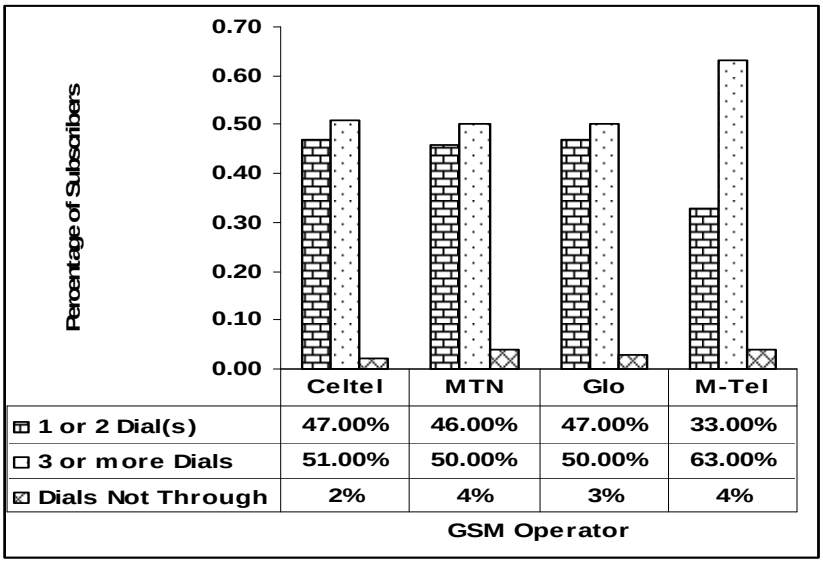


Figure 3. Number of dials before call set-up

The degree of accessibility is better shown in Fig. 3, which indicates the number of attempts a caller makes before a call can be established. From the figure (i.e. Fig. 3), it was found that for every 100 calls made on M-Tel network, 63 of them occur after 3 or more dials or attempts while only 33 of such calls are set-up with one or two attempts. However on the Celtel network, the study revealed that for every 100 calls attempt, there is high probability of having 47 successful calls with the first or second dials while 51% of those successful calls only occurred with three or more numbers of attempts on Celtel network. Also, Fig. 3 reveals that accessibility to both Glo and MTN networks can be accomplished with fewer numbers of attempts. In all, this high number of attempts before a call can be established or set-up is an indication of high congestion on all the GSM networks considered in the study.

Service Retainability

Service retainability shows how long a subscriber stays on a network after the call has been set-up or established. It is a measure of probability that an established call will not disconnect while conversation is in progress. The KPIs for evaluating the service retainability on a network are both the CDR and CCSR. The response on the retainability question on the survey is presented in Fig. 4. From Fig. 4, it is found that majority of the subscribers experience call drop while conversation is still in progress. The result shows that M-Tel has the highest CDR of 71%, follow by MTN, 67% while Celtel and Glo have CDR value of 64% each. The CCSR and CDR are inversely related. With M-Tel higher CDR value, it means it CCSR value (29%) will be lowest. However, for Glo and Celtel that have the lowest CDR, their CCSR are the highest. This indicates that subscribers on Glo and Celtel have higher probability of completing their conversation when compare with subscribers on MTN and M-Tel networks.

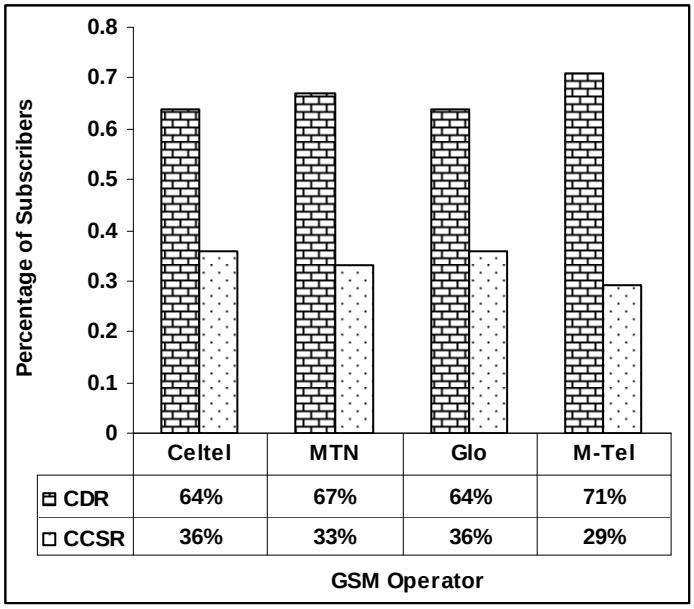


Figure 4. Call Drop and Call completion Success Rates

In all the networks considered, it was found that 36% is the maximum CCSR value the subscribers do experience. This implies fact that for every 100 successful call set-up, only 36 of them will not drop before the parties completed their conversation. The value reveals the fact that retainability on all the four national GSM networks in the country is low. This is an indication that their services are unreliable and unsatisfied.

Connection Quality

Connection quality or service integrity is the third assessment parameters that is normally used in assessing the performance of the network that is being subjected to constantly changes in response to increasing coverage and capacity. It deals with having a good service experience while using the network. On a telephone network, voice quality is an indicator of end-to-end speech transmission or connection quality. As reported by Kuboye *et al*., (2009), it is being computed using the mean opinion scores (MOS) which estimate the overall acceptability of quality of voice communication base on rating. In this study, the subscribers were asked to indicate if they do hear other party audibly during conversion on their GSM networks. The response collated is shown in Fig. 5. Over 80% of all the subscribers in each of the network respond that the voice quality on all the GSM networks was excellent while less than 20% respond the voice quality on all the GSM bad.

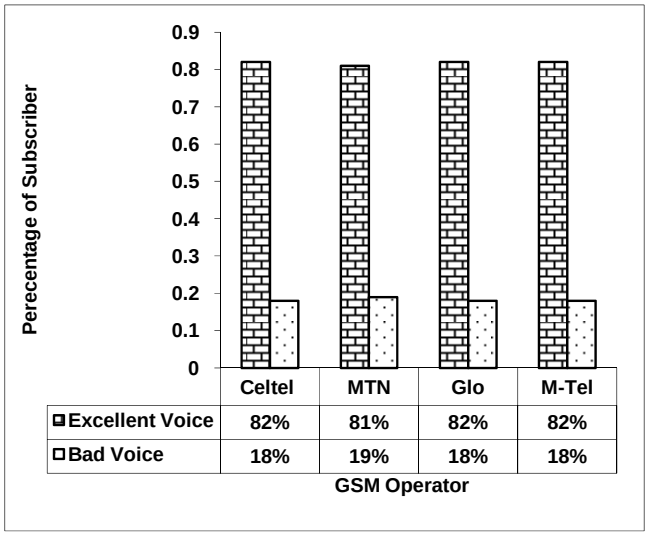


Figure 5. Audio Quality of the GSM Operators

In addition, the subscribers were asked about the SMS delivery on the four GSM networks studied. Question on the reliability of SMS delivery system on the four GSM networks were asked. The obtained data from the respondents are presented in Fig. 6 below. From the figure, i.e. Fig. 6, it was found that less than 40% of all the respondents in all the four GSM networks studied considered the SMS delivery system to be reliable while over 60% of the respondents considered it to be reliable. This indicates that connection quality impact on voice communication is the only impressive quality experience by the subscribers in all the four national GSM networks studied.

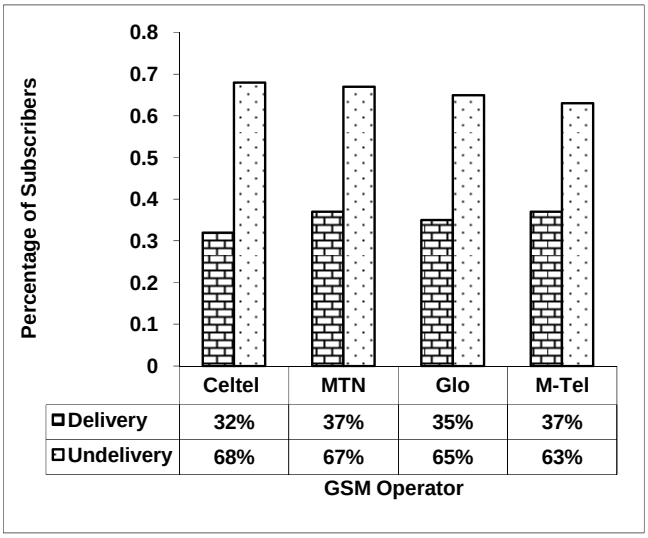


Figure 6. Subscribers billing for unsent SMS

Network Coverage

Apart from the three parameters (network accessibility, retainability and connection quality) reported by Pipikakis (2004) as parameters for evaluating the performance of GSM networks. This study included the use of network coverage as a new parameter. The parameter is included in the questionnaire to verify both the signal availability of the GSM networks considered.

Under a normal working condition, all base transceiver stations (BTSs) are supposed to produce a broadcast channel (BCH) which is switch on all the time. The BCH signal is received by all mobiles in the cell, whether they are on call or not, in order to be connected to the network. This makes the network coverage forms the bedrock of mobile communication service as the non-availability of the network indicator on a mobile station indicates non-connectivity of the mobile station to get the BTS.

Based on this importance of network coverage, question on availability of network coverage of each of the four GSM operators considered was asked. The percentage of subscribers' responses is shown in Fig 7. From Fig. 7, it is observed that M-Tel has the highest network failure while Celtel network coverage is judged best. The non-availability of network coverage arises most often when the BTS is too far from the location of the subscriber or the BTS is down. From the result from this question, it apparent that the network coverage of all the four GSM operators considered are not sufficient for the entire nation. Therefore, they need to build more BTSs.

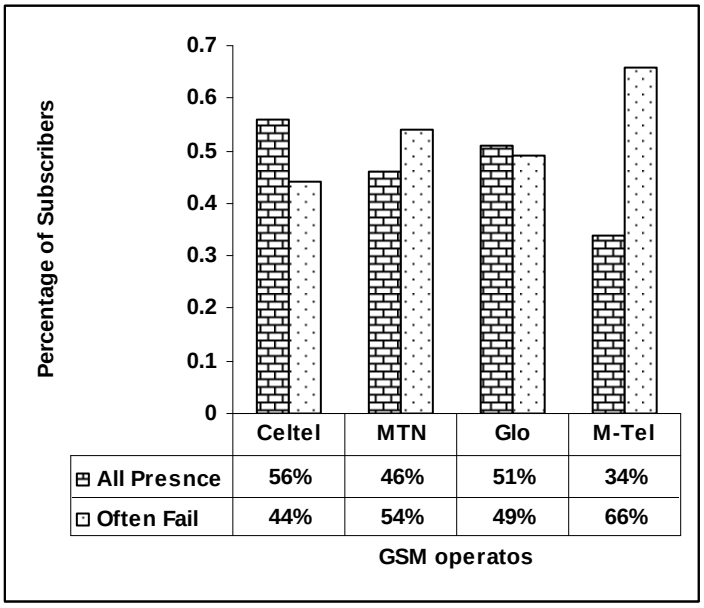


Figure 7. Subscribers billing for unsent SMS

Comparism of the Evaluation Methods

In evaluating the accuracy of the study, data from studies carried out by NCC (2005) using drive test method reported by Kuboye *et al*., (2009) and the result of Kuboye *et al*., (2009) using network statistics method are presented in Table 3. The three approaches are compared not only to verify the accuracy of each method but also to verify Pipikakis (2004) suggestion.

From Table 3, it is found that the CSSR values by NCC (2005) and the present work are the same. Though the result by Kuboye *et al*., (2009) differ from the present work, it is interesting to note that the overall data in the three studies follow the same pattern. For instance, from the three studies, it is observed that the M-Tel network has the worst CDR value. This buttresses Pipikakis (2004) statement that the three methods are sufficient for evaluating the QoS of the networks that are being subjected to constantly changes in response to increasing coverage and capacity.

Table 3. Study Approaches Evaluation

Study		Parameter			
		Network Accessibility	Service Retainability		Connection Quality
NCC (2005) Reported by Kuboye *et al*. (2009): Drive Test Method	GSM Network	CSSR	CDR	CCSR	Audio Quality
	Celtel:	57.30%	1.10%	56.20%	Not Available
	MTN:	85.90%	1.40%	84.50%	
	Glo:	94.10%	2.30%	91.80%	
	M-Tel:	89.009%	2.40%	86.60%	
Kuboye *et al*. (2009): Network Statistics Test Method	Celtel:	95.87%	4.13%	99.05%	Good (Quality better than analog System
	MTN:	94.17%	5.83%	98.50%	
	Glo:	95.29%	4.71%	99.25%	
	M-Tel:	80.40%	19.60%	97.80%	
Present Work: Customers' Complaints Method	Celtel:	57.30%	42.70%	64.00%	Good (All response above 80% in ranking)
	MTN:	85.90%	14.10%	67.00%	
	Glo:	94.10%	5.90%	64.00%	
	M-Tel:	89.00%	11.00%	71.00%	

Conclusion and Recommendation

From the results of this study, it is evident that the four GSM operators in Nigeria are far from providing reliable services. None of the GSM operators considered in the study has up to 90% call completion success rate. This is an indication that the service retainability of all GSM networks in the country is very low. In fact, less than 80% of subscribers in each network get their calls completed before the call drop. This is an indication that the call drop rates on the networks are high.

Likewise, the network accessibility on all the networks considered is low with half of the subscribers in each of the network need to dial three or more times before having access into various networks. This is an indication that the congestion rates on the networks are high. It shows that all the GSM operators considered have more subscribers but lack sufficient equipment to support their daily increasing customer base. In addition, the result of the study as shown in Fig. 7, shows that the network coverage of all the four GSM operators considered are not sufficient for the entire nation. The study, however, reveals better performance of all the networks in terms of service integrity most especially in voice quality. However, the over all assessment is an indication of poor performance as the customers express satisfaction in only one of the four parameters used in evaluating the four GSM networks.

With these findings, it can be concluded that the QoS and over all performance of the GSM operation in Nigeria is poor, unreliable and unsatisfied. It is an indication that Nigerians are yet to really enjoy the impact of GSM as a new effective means of telecommunication. In order to correct this ugly situation in the country and any other countries with similar situation, suggestions on how to improve the QoS of the GSM operation in the country need to be made. It is on this basis that the following recommendations are made in order to ameliorate the observed defects:

- NCC will be advised to inspect the GSM networks in the country regularly. This will aid the GSM operators in improving their networks base to meet their ever increasing subscribers' base. By this, the network accessibility in the country will improve while high congested networks currently experience shall be reduced.

- The GSM operators in the country should focus in building more BTSs in order to increase their network coverage rather than the current competitions or bonanzas they are doing in order to win more customers.

It is believed that if the above recommendations are adhered to, the QoS and the overall performance of the GSM operation in the country shall definitely improve. Also, it will indeed improve the communication systems of the country as well as increasing the revenue of the government, the citizenries and the operators. Finally, the authors also believe that if the recommendations are adhered to, Nigerians will soon feel the positive impact of GSM communication system.

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References

Adegoke, A. S., Babalola, I. T., and Balogun, W. A. (2008). Performance Evaluation of GSM Mobile System in Nigeria, *Pacific Journal of Science and Technology, 9*(2), 436-441.

Ajiboye, J. O., Tella, A., Adu, E. O., and Wojuola, J. I. (2007). Stakeholders' Perceptions of the Impact of GSM on Nigeria Rural Economy: Implication for an Emerging Communication Industry, *Journal of Mobile Communications, 3*(1), 1-7.

Doyle, C. and McShane, P. (2003). On the design and implementation of the GSM auction in Nigeria- the world's first ascending clock spectrum auction, *Telecommunications Policy*, 27, 383-405.

Free Encyclopedia. *GSM frequency ranges: Encyclopedia*, Retrieved on August 4, 2009, from http://en.allexperts.com/e/g/gs/gsm_frequency_ranges.htm, 1-3.

Goldsmith, A. (2005). *Wireless Communications*, Cambridge University Press.

Hassan, O., Oluwaranti, N., and Isola, O. (2009). Evaluation of Nigeria's Telecommunications Policy, *Journal of Mobile Communications, 3*(1), 1-7.

Kollár, M. (2008). Evaluation of Real Call Set up Success Rate in GSM, *Acta Electrotechnica et Informatica, 8*(3), 53-56.

Kuboye, B. M., Alese, B. K., and Fajuyigbe, O. (2009). Congestion Analysis on the Nigerian Global System for Mobile Communications (GSM) Network, *The Pacific Journal of Science and Technology, 10*(1), 262-271.

Nigerian Communication Commission (NCC) (2005, March 22). A Report on Network Quality of Service and Performance of the GSM Networks in Nigeria, *The Guardian Newspaper*.

NOKIA (2002). *Introduction to GSM Training Document*, TC Finland, 1-9.

Pipikakis, M. (2004). Evaluating and Improving the Quality of Service of Second-Generation Cellular Systems, *Bechtel Telecommunications Technical Journal, 2*(2), 1-8.

Rahnema, M. (1993). Overview of the GSM System and Protocol Architecture, *IEEE Communications Magazine, 31*(4), 92-100.

Redl, S. M., Weber, M. K., and Oliphant, M. W. (1995). *Introduction to GSM*, The Artech House Mobile Communication Series, USA.

[1] Mr. Popoola is a lecturer in the Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Ondo State, Nigeria. He is currently a PhD student in School of Electrical and Information Engineering, University of Witwatersrand, South Africa. He can be reached on cell phone: +27798127144 or at e-mail: jidejulius2001@yahoo.com

[2] Dr. Megbowon is a lecturer in the Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Ondo State, Nigeria. He can be reached on cell phone: +2348069380130 or at e-mail: imegbowon@yahoo.com

[2] Dr. Adeloye is a lecturer in the Department of Electrical and Electronics Engineering, Federal University of Technology, Akure, Ondo State, Nigeria. He can be reached on cell phone: +2348033950280 or at e-mail: vsaadeloye@yahoo.com