Statistical Evaluation of Quality of Service Offered by GSM Network Operators in Nigeria

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***Abstract*—The need for reliable connectivity places a serious challenge on mobile network operators, even as the number of connected things are expected to increase exponentially by 2020. In order to ensure the readiness of Nigeria to adopting emerging wireless technologies in smart cities, it becomes necessary to assess the level of compliance of mobile network operators to best international practices. In this paper, the Quality of Service (QoS) offered by GSM network operators in Nigeria was examined. Significant difference in the Key Performance Indicators (KPIs) of Airtel, Etisalat, Glo, and MTN was tested using the Analysis of Variance (ANOVA). In addition, Tukey Post hoc test was carried out to determine the extent of the variations among the four mobile network operators. Relative to the quality targets set by the Nigerian Communications Commission (NCC), analysis results show that all the mobile network operators maintain a good QoS across board. Nevertheless, the QoS offered to GSM subscribers in Nigeria significantly vary from one mobile network operator to another.**

***Index Terms*— Call Setup Success Rate, Drop Call Rate, Stand-alone Dedicated Control Channel Congestion, Traffic Channel Congestion, QoS**

I. Introduction

QoS is the industry standard that is set to measure or quantify the ability of a service provider to satisfy stated and implied needs of the users using relevant KPIs [1-4]. A good QoS is necessary to ensure high voice quality and uninterrupted data transmission in GSM networks. Efficient network performance is required for emerging critical applications and services of low latencies. These emerging applications include Machine-to-Machine (M2M) communications and Internet of Things (IoT). The soaring number of connected objects represents a massive opportunity for mobile operators. But for success with applications in M2M and IoT, reliable and trusted connectivity is essential. In order to ensure the readiness of Nigeria to adopting M2M and IoT applications in smart cities, there is an urgent need to evaluate the QoS offered by GSM network operators in Nigeria.

The QoS of GSM services can be assessed based on four KPIs namely: Call Setup Success Rate (CSSR); Drop Call Rate (DCR); Stand-alone Dedicated Control Channel (SDCCH) congestion; and Traffic Channel (TCH) congestion. A call is setup when there is an exchange of signaling information in the call process, leading to TCH seizure. A successful call setup procedure is required to ensure that a call attempt is connected to the dialed line. However, due to different factors, it is not all call attempts that eventually gets connected to the called party. Meanwhile, if a call is connected successfully but the dialed number is busy, the call is considered to be successful. CSSR, as a QoS KPI in GSM networks, measures the ratio of the number of calls that ended up being connected to the total number of call attempts that were made. The ratio is often expressed in terms of percentage. DCR is the fraction of the call attempts that were ended abruptly while the calling party and the called party were still actively on conversation, and none of them had dropped the call. This is usually caused by technical factors. The probability of failure of accessing a SDCCH during call setup is referred to as SDCCH congestion. TCH congestion rate is the percentage of the number of TCH assignment failures to the number of TCH seizure requests. A high TCH congestion rate connotes poor quality of service.

Different related work have been reported in the literature. Ozovehe and Usman [5] compared the performance of GSM networks operators (W, X, Y and Z) in Minna, Niger State, Nigeria based on drive test measurements. Considering the number of blocked calls, dropped calls and handover failures, Operator Y was reported to have the worst performance, followed by Operator Z. Meanwhile, Operator X demonstrated the best QoS followed by Operator W. In another study, Olabisi [6] evaluated the performance of mobile cellular base station based on eight KPIs over a period of thirty days. Mojisola and Gbolahan [7] proposed a model for crowdsourcing the evaluation of the QoS provided by three GSM network operators in Nigeria. The authors reported the gap between the technical capabilities of the telecoms infrastructure and the QoS experienced by the users. Nnochiri [8] investigated the KPIs of GSM network providers and the causes of poor QoS in Nigeria. In addition, a novel method was designed for subscriber authentication in mobile cellular networks. Ozovehe et al. [9] collected real live traffic data from integrated GSM/GPRS network for traffic congestion analysis. The analysis was carried out on ten congesting cells using Network Management System (NMS) statistics data that spanned three years period. Lawal et al. [10] assessed the GSM QoS provided by MTN at Eagle Square, Abuja, Nigeria. However, there is no sufficient statistical evidence to support the claims in previous work.

Manuscript received July 04, 2017; revised August 01, 2017.

The authors wish to appreciate the Center for Research, Innovation, and Discovery (CU-CRID) of Covenant University, Ota, Nigeria, for the partial funding of this research.

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In this paper, we evaluate the QoS offered by GSM network operators in Nigeria. A null hypothesis was formulated, stating that there is no significant difference between the QoS (based on CSSR, DCR, SDCCH, and TCH) offered by the four GSM network operators in Nigeria (Airtel, Etisalat, Glo, and MTN). The hypothesis was tested using the ANOVA. In addition, Tukey Post hoc test was carried out to determine the extent of the variations among the four mobile network operators.

The rest of this paper is organized as follows: Section II describes the methodology adopted in this study while Section III presents the results and discusses the implications; finally Section IV concludes the paper.

II. Methodology

The following QoS KPIs of Airtel, Etisalat, Glo, and MTN were obtained from the database of the NCC [11]: CSSR; DCR; SDCCH; and TCH. These KPIs were calculated based on the data that were collected from the Network Operating Centres (NOCs) of the mobile network operators during busy hours at the Base Station Controller (BSC) level. Subsequently, the data were analyzed using monthly weighted averages to ascertain each operator's performance. The data that were included in this study spanned over a period of three years (2014-2016).

Mathematically, CSSR is expressed by equations (1) and (2).

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

$$CSSR = (1 - Blocking\ Probability) \times 100\% \quad (2)$$

The fraction of the dropped calls were measured as a percentage relative to all call attempts as given by equation (3).

$$DCR = \frac{Number\ of\ dropped\ calls}{Total\ number\ of\ call\ attempts} \times 100\% \quad (3)$$

Equation (4) gives the mathematical expression for the SDCCH congestion.

$$SDCCH = \frac{Failed\ SDCCH\ seizures\ due\ to\ the\ busy\ SDCCH}{Total\ requests\ for\ the\ SDCCH} \quad (4)$$

The mathematical formula for TCH congestion is given by equation (5).

$$TCH\ Congestion = \frac{Number\ of\ TCH\ assignmnet\ failures}{Number\ of\ TCH\ seizure\ requests} \quad (5)$$

A descriptive statistical analysis was conducted to evaluate the QoS offered by the four GSM network operators in Nigeria. The statistical parameters that were considered include: the mean; the standard deviation; the skewness; and the kurtosis. The arithmetic mean measures the central tendency of the KPIs. The standard deviation measures the spread of the distribution relative to the mean. A large standard deviation indicates that the data points can spread far from the mean and a small standard deviation indicates that they are clustered closely around the mean. The skewness and the kurtosis are the measures of the shape of the data distribution. Skewness quantifies the asymmetry of the distribution while kurtosis quantifies the '*tailedness*' of the distribution.

Based on ANOVA, the hypothesis was tested to determine if there is a significant difference in the QoS KPIs of the four GSM network providers. Post hoc tests were conducted to where the differences occur, if any, between the KPIs of the GSM network operators. Data sorting and pre-processing were done in Microsoft Excel 2013 [12] and MATLAB 2016a [13]. A null hypothesis was formulated, stating that there is no significant difference between the QoS (based on CSSR, DCR, SDCCH, and TCH) offered by the four GSM network operators in Nigeria (Airtel, Etisalat, Glo, and MTN). The hypothesis was tested using the ANOVA. In addition, Tukey Post hoc test was carried out to determine the extent of the variations among the four mobile network operators. Statistical evaluations were performed in IBM SPSS 20 [14].

III. Results and Discussion

Figure 1 shows the variations in QoS among the four GSM network operators in Nigeria (Airtel, Etisalat, Glo, and MTN) over the period of three years.

Airtel offered the lowest mean CSSR (98.024%) while the highest mean CSSR (99.173%) was provided by Etisalat. Glo and MTN had mean CSSRs of 98.187% and 98.300% respectively. The 95% confidence intervals for mean CSSRs were all within the threshold of ≥ 98%, as set by NCC, except that of Airtel whose lower bound was 97.853%. The standard deviations of CSSR for Airtel, Etisalat, Glo, and MTN were 0.5049, 0.1806, 0.3272, and 0.7563 respectively. The distribution of the CSSR data are negatively skewed for all the network operators. However, the CSSR data of Airtel, Etisalat, and Glo were highly skewed (-1.232, -2.440, and -2.376 respectively) while MTN CSSR data were moderately skewed (-0.774). Quantifying the effect of outliers, it was found that CSSR data of Airtel and MTN were both platykurtic (kurtosis of 0.806 and -0.957 respectively) while those of Etisalat and Glo were leptokurtic (kurtosis of 9.226 and 7.939 respectively).

Table 1: Descriptive Statistics of QoS of Mobile Network Operators

		Mean	Standard Deviation	Skewness	Kurtosis
CSSR (≥ 98%)	*Airtel*	98.02	0.5049	-1.232	0.806
	Etisalat	99.17	0.1806	-2.440	0.393
	Glo	98.18	0.3272	-2.376	7.939
	MTN	98.30	0.7563	-0.774	-0.957
DCR (≤ 1%)	*Airtel*	0.73	0.0674	-0.088	-0.609
	Etisalat	0.54	0.1195	0.952	1.671
	Glo	0.65	0.2321	1.473	2.396
	MTN	0.85	0.2873	0.519	-1.024
SDCCH (≤0.2%)	*Airtel*	0.25	0.1728	1.647	1.999
	Etisalat	0.12	0.0572	2.280	6.294
	Glo	0.94	0.7527	0.303	-1.629
	MTN	0.21	0.1651	1.943	3.112
TCH (≤ 2%)	*Airtel*	0.42	0.2398	1.160	0.512
	Etisalat	0.22	0.1575	3.443	14.966
	Glo	1.08	0.3717	0.316	-1.370
	MTN	0.49	0.2521	1.546	2.028

ISBN: 978-988-14047-5-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Etisalat offered the lowest mean DCR (0.5467%) while the highest mean DCR (0.8522%) was from MTN. Airtel and Glo had mean DCRs of 0.7397% and 0.6553% respectively. The 95% confidence intervals for mean DCRs were all within the threshold of ≤ 1% as stipulated by NCC. The standard deviations of DCR for Airtel, Etisalat, Glo, and MTN were 0.0674, 0.1195, 0.2321, and 0.2873 respectively. The distribution of the DCR data are positively skewed for all the network operators, except that of Airtel which is negatively skewed. In addition, the DCR data of Etisalat and MTN are both moderately skewed (0.952 and 0.519 respectively); those of Airtel are approximately symmetric (-0.088); while those of Glo are highly skewed (1.473). Quantifying the effect of outliers, we observed that the DCR data for all the network operators are platykurtic (-0.609, 1.671, 2.396, -1.024 respectively).

Etisalat offered the lowest mean SDCCH (0.1203%) while the highest mean SDCCH (0.9472%) was from Glo. Airtel and MTN had mean SDCCHs of 0.2506% and 0.2125% respectively. Only Etisalat has 95% confidence intervals for mean SDCCH within the threshold of ≤ 0.2% as stipulated by NCC. The standard deviations of SDCCH for Airtel, Etisalat, Glo, and MTN were 0.1728, 0.0572, 0.7527, and 0.1651 respectively. The distribution of the SDCCH data are positively skewed for all the network operators. However, the SDCCH data of Airtel, Etisalat, and MTN are all highly skewed (1.647, 2.280, and 1.943 respectively) while those of Glo are approximately.

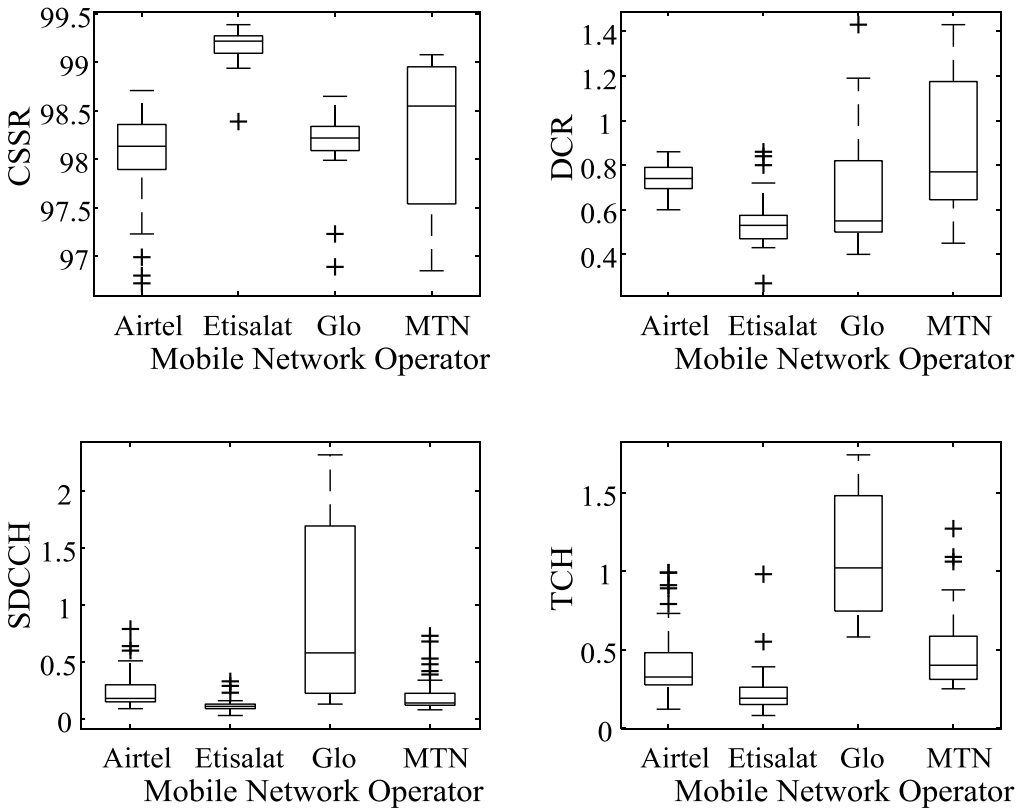

Figure 1: Variations in QoS among GSM Network Operators

Table 2: One-Way ANOVA Test Results

		Sum of Squares	df	Mean Square	F	Sig.
CSSR	Between Groups	28.548	3	9.516	39.375	0.001
	Within Groups	33.834	140	0.242		
	Total	62.382	143			
DCR	Between Groups	1.809	3	0.603	15.543	0.001
	Within Groups	5.431	140	0.039		
	Total	7.240	143			
SDCCH	Between Groups	15.623	3	5.208	33.224	0.001
	Within Groups	21.945	140	0.157		
	Total	37.568	143			
TCH	Between Groups	14.715	3	4.905	69.098	0.001
	Within Groups	9.938	140	0.071		
	Total	24.653	143			

ISBN: 978-988-14047-5-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

symmetric (0.303). Quantifying the effect of outliers, we observed that the SDCCH data for Airtel and Glo are platykurtic (1.999 and -1.629 respectively) while those of Etisalat and MTN are leptokurtic (6.294 and 3.112 respectively).

Etisalat offered the lowest mean TCH (0.2294%) while the highest mean TCH (1.0867%) was from Glo. Airtel and MTN had mean TCHs of 0.4244% and 0.4989% respectively. The 95% confidence intervals for mean TCHs were all within the threshold of ≤ 2% as stipulated by NCC. The standard deviations of TCH for Airtel, Etisalat, Glo, and MTN were 0.2398, 0.1575, 0.3717, and 0.2521 respectively. The distribution of the TCH data are positively skewed for all the network operators. However, the SDCCH data of Airtel, Etisalat, and MTN are all highly skewed (1.160, 3.443, and 1.546 respectively) while those of Glo are approximately symmetric (0.316). Quantifying the effect of outliers, we observed that the SDCCH data for Airtel, Glo and MTN are platykurtic (0.512, -1.370, and 2.028 respectively) while those of Etisalat are leptokurtic (14.966).

The summary of the one-way ANOVA is presented in Table 2. The significant value is 0.001 (i.e. p = .001) for CSSR, DCR, SDCCH, and TCH. This is below 0.05. Therefore, there is a significant difference in the mean KPIs between different mobile network operators in Nigeria.

On CSSR, there is a statistically significant difference between the CSSR data of Airtel, Etisalat, Glo, and MTN as determined by one-way ANOVA [F (3,140) = 39.375, p = 0.001]. A Tukey post hoc test revealed that Etisalat CSSR (99.173 ± 0.1806%, p = 0.001) is statistically, significantly higher compared to Airtel CSSR (98.024 ± 0.5049%, p = 0.001), Glo CSSR (98.187 ± 0.3272%, p = 0.001), and MTN CSSR (98.300 ± 0.7563%, p = 0.001). There is no statistically significant difference between the CSSR data of Airtel, Glo, and MTN (p = 0.497, p = 0.084, and p = 0.761).

On DCR, there is a statistically significant difference between the DCR data of Airtel, Etisalat, Glo, and MTN as determined by one-way ANOVA [F (3,140) = 15.543, p = 0.001]. Tukey post hoc test revealed that Etisalat DCR (0.5467 ± 0.1195%, p = 0.001) is statistically, significantly lower compared to Airtel DCR (0.7397 ± 0.0674%, p = 0.001) and MTN DCR (0.8522 ± 0.2873%, p = 0.001). Also, Glo DCR (0.5467 ± 0.1195%, p = 0.001) is statistically, significantly lower compared to MTN DCR (0.8522 ± 0.2873%, p = 0.001).

On SDCCH, there is a statistically significant difference between the SDCCH data of Airtel, Etisalat, Glo, and MTN as determined by one-way ANOVA [F (3,140) = 33.224, p = 0.001]. Tukey post hoc test showed that Airtel SDCCH (0.0.2506 ± 0.1728%, p = 0.001), Etisalat SDCCH (0.1203 ± 0.0572%, p = 0.001), and MTN SDCCH (0.2125 ± 0.1651%, p = 0.001) are statistically, significantly lower compared to Glo SDCCH (0.9472 ± 0.7527%, p = 0.001).

On TCH, there is a statistically significant difference between the TCH data of Airtel, Etisalat, Glo, and MTN as determined by one-way ANOVA [F (3,140) = 69.098, p = 0.001]. Tukey post hoc test showed that Etisalat TCH (0.2294 ± 0.1575%, p = 0.001) is statistically, significantly lower compared to Airtel TCH (0.4244 ± 0.2398%, p = 0.001), Glo TCH (1.0867 ± 0.3717%, p = 0.001) and MTN TCH (0.4989 ± 0.2521%, p = 0.001). In addition, Airtel TCH (0.4244 ± 0.2398%, p = 0.001) and MTN TCH (0.4989 ± 0.2521%, p = 0.001) are statistically, significantly lower compared to Glo TCH (1.0867 ± 0.3717%, p = 0.001).

IV. Conclusion

The findings of this study show that there are statistically significant differences in the QoS KPIs of the four GSM network operators in Nigeria. All the network operators had CSSR values that are greater than the threshold set by NCC (i.e. ≥ 98%); but that of Etisalat was significantly higher compared to Airtel, Glo, and MTN. Meanwhile, there was no significant difference in the CSSR values of Airtel, Glo, and MTN throughout the three-year study period. Across the different networks, the DCR was kept below the threshold value of 1% as expected. However, DCR values were consistently lowest on Etisalat networks while Glo had significantly lower DCR values than MTN. The average SDCCH congestion experienced on Airtel, Glo, and MTN networks was beyond the threshold of 0.2%. It is worthy of note that Glo subscribers experienced the most frequent SDCCH congestion between 2014 and 2016. Despite the fact that all the operators maintained a mean TCH of less than 2%, there was a statistically significant difference between the TCH data of Airtel, Etisalat, Glo, and MTN. The TCH congestion was lowest on Etisalat networks.

Based on the quality targets set by the regulatory body in Nigeria, the mobile network operators maintain good QoS across board. Nevertheless, the QoS offered to GSM subscribers in Nigeria significantly vary from one mobile network operator to another.

Acknowledgment

The authors wish to appreciate the Center for Research, Innovation, and Discovery (CU-CRID) of Covenant University, Ota, Nigeria, for the partial funding of this research.

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APPENDIX A: MULTIPLE COMPARISON BASED ON TUKEY HSD POST HOC TEST

Dependent Variable	(I) Operator	(J) Operator	Mean Diff (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
CSSR	Airtel	Etisalat	-1.14944*	.11587	.000	-1.4507	-.8482
		Glo	-.16306	.11587	.497	-.4643	.1382
		MTN	-.27667	.11587	.084	-.5780	.0246
	Etisalat	Airtel	1.14944*	.11587	.000	.8482	1.4507
		Glo	.98639*	.11587	.000	.6851	1.2877
		MTN	.87278*	.11587	.000	.5715	1.1741
	Glo	Airtel	.16306	.11587	.497	-.1382	.4643
		Etisalat	-.98639*	.11587	.000	-1.2877	-.6851
		MTN	-.11361	.11587	.761	-.4149	.1877
	MTN	Airtel	.27667	.11587	.084	-.0246	.5780
		Etisalat	-.87278*	.11587	.000	-1.1741	-.5715
		Glo	.11361	.11587	.761	-.1877	.4149
DCR	Airtel	Etisalat	.19306*	.04643	.000	.0723	.3138
		Glo	.08444	.04643	.269	-.0363	.2052
		MTN	-.11250	.04643	.077	-.2332	.0082
	Etisalat	Airtel	-.19306*	.04643	.000	-.3138	-.0723
		Glo	-.10861	.04643	.094	-.2293	.0121
		MTN	-.30556*	.04643	.000	-.4263	-.1848
	Glo	Airtel	-.08444	.04643	.269	-.2052	.0363
		Etisalat	.10861	.04643	.094	-.0121	.2293
		MTN	-.19694*	.04643	.000	-.3177	-.0762
	MTN	Airtel	.11250	.04643	.077	-.0082	.2332
		Etisalat	.30556*	.04643	.000	.1848	.4263
		Glo	.19694*	.04643	.000	.0762	.3177
SDCCH	Airtel	Etisalat	.13028	.09332	.504	-.1124	.3729
		Glo	-.69667*	.09332	.000	-.9393	-.4540
		MTN	.03806	.09332	.977	-.2046	.2807
	Etisalat	Airtel	-.13028	.09332	.504	-.3729	.1124
		Glo	-.82694*	.09332	.000	-1.0696	-.5843
		MTN	-.09222	.09332	.756	-.3349	.1504
	Glo	Airtel	.69667*	.09332	.000	.4540	.9393
		Etisalat	.82694*	.09332	.000	.5843	1.0696
		MTN	.73472*	.09332	.000	.4921	.9774
	MTN	Airtel	-.03806	.09332	.977	-.2807	.2046
		Etisalat	.09222	.09332	.756	-.1504	.3349
		Glo	-.73472*	.09332	.000	-.9774	-.4921
TCH	Airtel	Etisalat	.19500*	.06280	.012	.0317	.3583
		Glo	-.66222*	.06280	.000	-.8255	-.4989
		MTN	-.07444	.06280	.637	-.2377	.0888
	Etisalat	Airtel	-.19500*	.06280	.012	-.3583	-.0317
		Glo	-.85722*	.06280	.000	-1.0205	-.6939
		MTN	-.26944*	.06280	.000	-.4327	-.1062
	Glo	Airtel	.66222*	.06280	.000	.4989	.8255
		Etisalat	.85722*	.06280	.000	.6939	1.0205
		MTN	.58778*	.06280	.000	.4245	.7511
	MTN	Airtel	.07444	.06280	.637	-.0888	.2377
		Etisalat	.26944*	.06280	.000	.1062	.4327
		Glo	-.58778*	.06280	.000	-.7511	-.4245

*. The mean difference is significant at the 0.05 level.

ISBN: 978-988-14047-5-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)