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RADIO ACCESS EVALUATION OF CELLULAR NETWORK IN AKURE METROPOLIS, NIGERIA

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ABSTRACT
The higher subscription, relative importance of voice calls, client's complaints and economy depression that now make clients to get value for money paid and need for more revenue by mobile network operator (MNOs) justified this work. The objective of this work is to measure, analyse, evaluate the performance of MNOs, and to recommend ways to improving their quality of service (QoS). Drive test approach was used for the measurements and statistical methods for the analysis. Results of the analysis shows that the quality of Voice service offered by MNOs is not optimal and there is room for improved quality service. Based on the key performance indicators, the mobile operators did not perform up to expectation. There are differences in the quality of voice service offered across mobile network operator networks based on the time of the day and the area under consideration. MNO1, MNO2, MNO3 and MNO4 gave varying quality of service. MNO4 had absolutely no dropped calls and performed best and consistently gave a retainability ratio above the target. MNO1 performance metrics were below the key performance indicator thresholds given by the Nigerian Communication Commission.

Keywords: *Performance Evaluation, Quality of Service, Voice Services, Mobile Communication*

1. INTRODUCTION
A very good platform for social, economic, political and other forms of communication is provided in telecommunication and in the Nigerian setting: mobile communication. It enhances business activities, government activities and has changed how people live, work, play and learn. The impact and coverage of mobile communication in Nigeria is particularly evident in Figure 1, which shows that the total number of active mobile subscribers is almost equivalent to the total number of active lines. This implies that more than 98% of active subscribers use mobile lines. The other lines which constitute the remaining 2% of active lines are Code Division Multiple Access (CDMA) lines, Voice over IP (VoIP) lines and fixed wireless/wired lines [1]

The market share among mobile network operators (MNOs) and total number of subscribers has increased rapidly over the past decade; as at December 2005 there were just 19,519,154 subscribers, by December 2016 there were 154,529,780 subscribers. This is equivalent to an average increase of 12,273,693 subscribers every year, by March 2017; there were 152,467,198 subscribers [1] and four mobile network operators. MTN remained the largest provider, and accounted for 36% of subscriber base, Airtel, Globalcom and others have 22.80%, 24.56% and 12.91% subscribers' base respectively. Teledensity grew from 16.27% in 2010 to 103.61% for the year 2017 [1].

Mobile communication is also a major source of Gross Domestic Product (GDP) for the country. Figure 2 shows Teledensity growth curve of Nigeria in relation to the GDP contribution by the telecommunication industry. GDP data in the telecommunication sector for the year 2004 -2009 was unavailable from. Data for years 2010 to 2017 (which is in presented in Figure 2) show that the telecommunication industry is a major player in the country's economy [1].

The telecommunication sector experiences various challenges despite numerous applications and advantages of mobile telephony.

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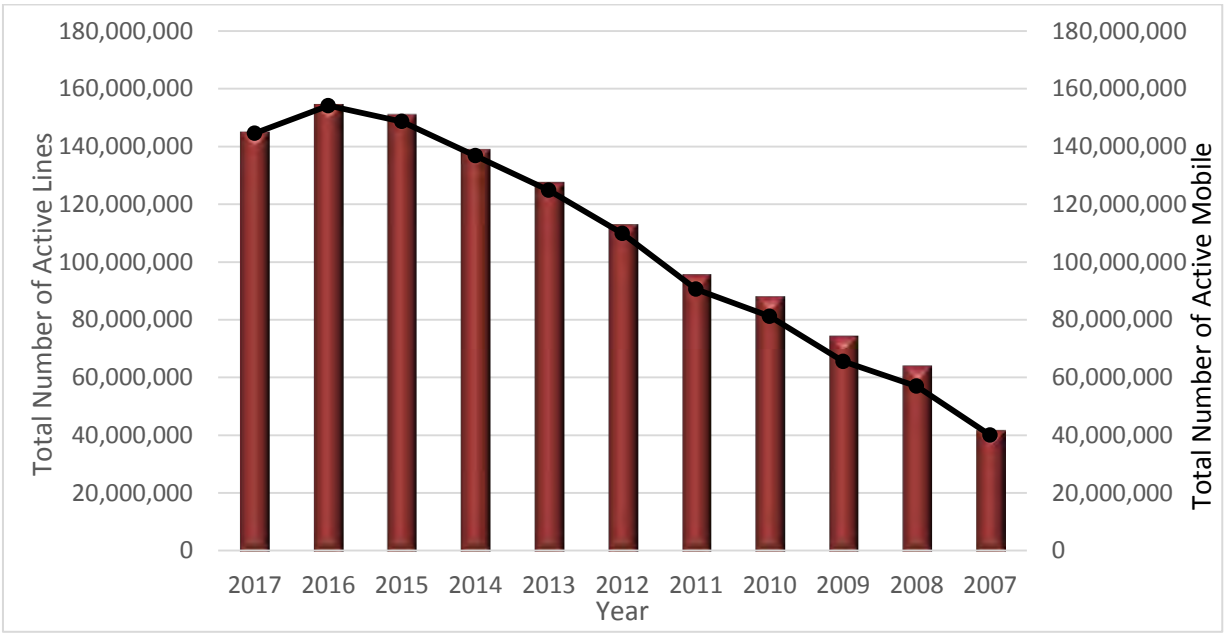

Figure 1: Total Number of Active Lines versus the Total Number of Active Mobile cellular Lines

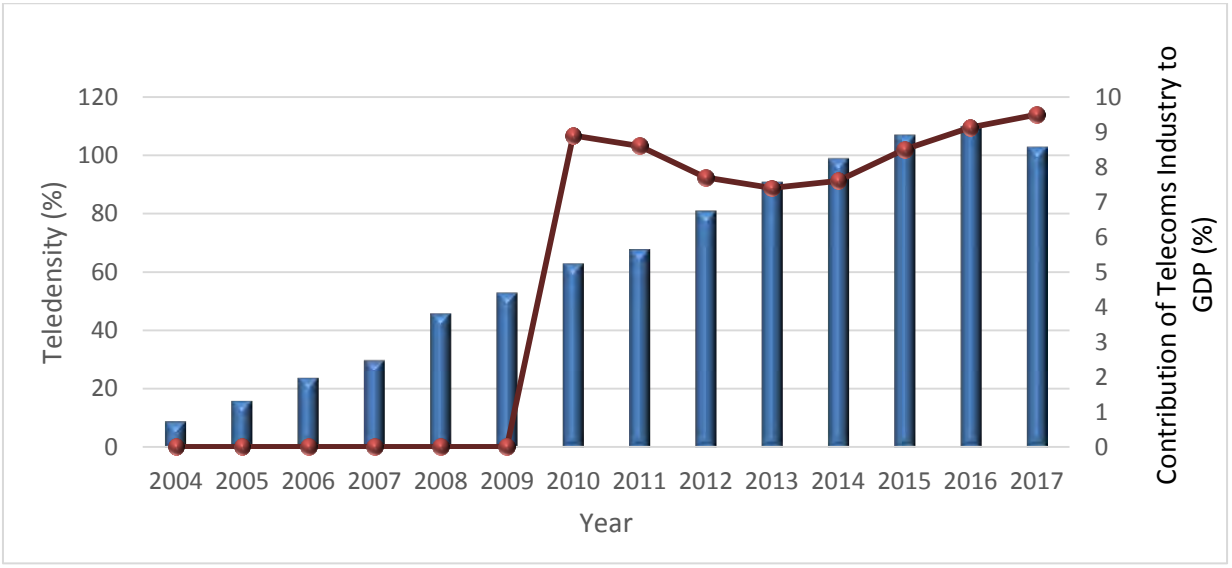

Figure 2: Teledensity Data and Contribution of the Telecommunication Industry to GDP

Some of the problems are subscriber's complaints due to low quality of service offered by the mobile network operators (MNO), requesting for valued service for money, etc. Mobile Network Operator's challenges includes irregular power supply for the Base Transceiver Station (BTS), use of expensive to manage and maintain generators, necessity to work alone sometimes instead of co-location sites, etc [8, 11].Based on the strength of subscriber complaint, MNO challenges and regulatory concerns, there is a need to measure, evaluate and optimize the quality of service of cellular network provided at every part of Nigeria. Measurements and evaluation of the voice calls in Nigeria is currently virtually dependent on data from network operators or their supervisory body [1, 2]. Hence, it is important to have another evaluation carried out by a third party to investigate the state of the network.

In mobile cellular networks, there are two important services made available by MNOs in the sector: data and voice services. As at December 2017, there are about 145 million active lines for voice services and 98 million subscriptions for data services [1]. This makes voice services very important having the widest coverage and deepest penetration, though there has been an appreciable increase in data services too as shown in Figure 3. Priority is therefore given to voice services as they are also considered the primary service.

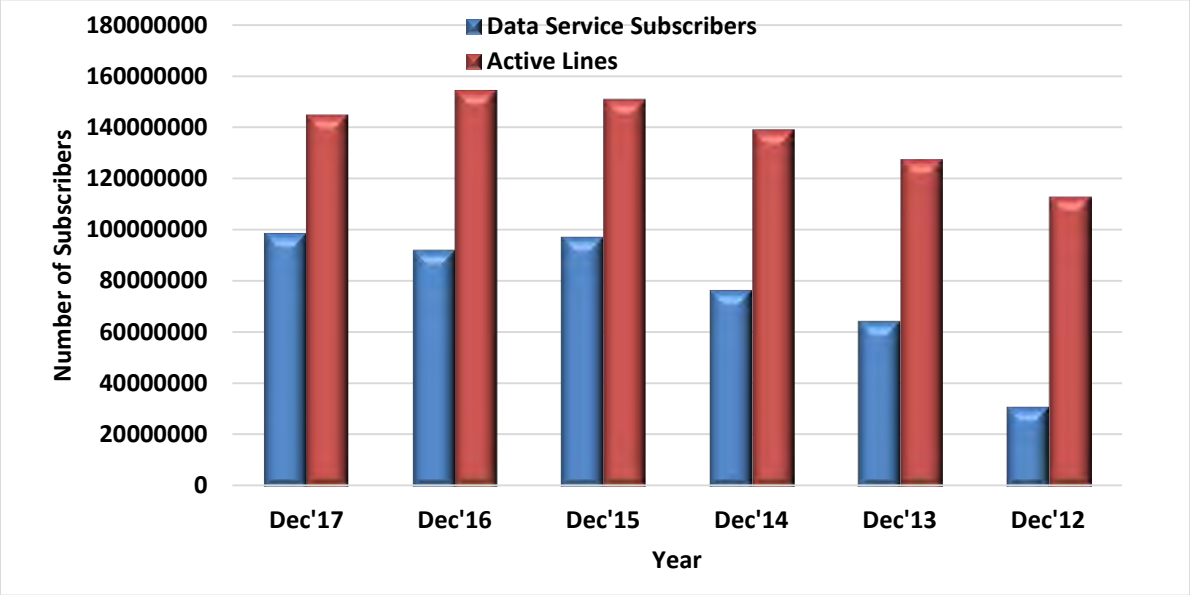

Figure 3: Number of Active Lines and Data Service Subscribers

There are two important parties involved in voice services: the calling and the receiving clients. At one end the caller initiates the call, at the other end, the receiver answers the call.

Based on the premise establishing the importance of voice services, this paper investigates the quality of service offered in Akure the capital city of Ondo State. Akure is mainly a civil servant and an agro-based state and therefore does not generate as much Average Revenue per User (ARPU) compared to Lagos, Port Harcourt, Kano and Abuja which are the business hubs of the Country. Mobile network operators tend to roll out better services at the aforementioned business hubs of the country.

Quality of Service (QoS) in telecommunication is the measure of quality of telecommunications services delivery based on some standard metrics. The measurement of QoS must be based on measures that can be readily interpreted by stakeholders to get realistic result and infer accurate information. Measurement of QoS of radio access quality must begin with a consideration for the users of that service and since it has to be carried out often, it must be cost effective.

There are four major techniques for measuring QoS parameters relating to voice services offered in mobile communication. The techniques include: questionnaire, drive test, network management system (NMS) and crowdsourcing [3 – 6].

Drive test methods were used by [4] and Emeruma [7]. Oseni, *et al.,* [4] investigated radio frequency optimization of mobile networks in Abeokuta, Nigeria for improved quality of service. Drive test method used to collect data and post-processing software tool as used to analyze collected data. Poor coverage and degradation in QoS was attributed to the land's topology and physical obstruction.

Ozoveh and Usman [8] and Emeruma [7] also used drive-test technique for performance evaluation. Emeruma [7] presented a comparative analysis of signal strength of some cellular network in Umuahia, eastern Nigeria. Data was collected using the drive test technique and regression analysis and line graph were used for the comparative analysis. Ozoveh and Usman [8] analyzed the performance of Global System for Mobile communication (GSM) networks using drive-test method in Minna metropolis, Nigeria. They concluded that the network will operate more optimally if researchers were given unfiltered access to the mobile operator's database thereby allowing them to proffer well- suited solutions to the tele traffic engineering challenges particularly relating to mobile communication within the country.

Kyriazakos *et al.* [9], did a comprehensive study and performance evaluation of the operations of GSM and General Packet Radio Service (GPRS) system under varying traffic condition. Network management system (NMS) tool was used for data collection.

Adegoke *et al.*, [10], Popoola *et al.*, [6] presented QoS analysis of voice services and collection of performance metrics data was carried out using questionnaire/survey method. Their work identified and investigated three QoS parameters (factors) namely accessibility, retainability and voice service quality. They also appraised the performance of GSM in Nigeria and methods of improving them. Some of the

identified problems are instability in power supply, security of infrastructure, inter-network connectivity. Other challenges are network congestion, call setup failure and call retention / call drop. The investigations by Adegoke *et al*. [10] covered 14 states in the federation while the paper by Popoola *et al.* [6] covered the whole country (Nigeria). Popoola *et al.* [11] provided comprehensive data on KPI parameters based on data collected from NCC, the data spans two years. The limitation of this research work is firstly; secondary data was used and detailed information from user's perspective in Akure city was not available.

In the light of the research gap highlighted from the reviews and other issues such as increased subscribers, importance of voice calls, client's complaints, need for clients to get value for money and improved revenue for mobile network operators (MNOs) justifies the importance and need for this paper. The objective of this work is to measure and evaluate the quality of voice service offered by MNOs in Akure metropolis.

Benchmarking is a technique applied in telecommunication to accurately measure mobile network operator's (MNO) performance against the standards, presented in Table 1. It assists in analyzing the performance of MNOs and information acquired can be used to check and improve network performance. The research paper analyzed the key performance indicators (KPIs) and RSCP data collected using test drive collection method to carry out an objective evaluation of the QoS offered by network operators in Akure. This work is divided into five sections, section one, two and three are the overview, materials and methods and evaluation criteria respectively. Section four presents and discusses the results and section five concludes the paper.

2. MATERIALS AND METHODS

Drive test technique was employed to collect the required data for this research work. Drive test is the process of collecting mobile network traffic data from the cellular network in order to know or have an idea of the subscribers' perception of the network from the view of a single subscriber It was carried out to check the network performance by means of coverage evaluation, system availability, network capacity, network retainability and call quality. The materials used are drive test equipment: Laptop, TEMS phones, USB Cables, GPS and Car inverter and software. The software used are TEMS Investigation and Data Collection and MapInfo@. The time of day analysis was also investigated to check if the timing of service affects the quality. Comparative analysis was also carried out across the mobile network operators available in the region of interest.

Summary of the collected data for the three test areas for morning, afternoon and evening (8am – 11am, 12 noon – 3 pm and 4pm – 7 respectively) are shown in the appendix. Only the soft handover details were covered.

3. EVALUATION CRITERIA

To accurately measure the MNO's performance, the key performance indicators (KPIs) as specified by NCC (NCC, 2018). The KPIs' and their benchmark for good quality of service are given in Table 1. The call drop rate (CDR) is the proportion of the calls that were cut off before the speaking parties had finished their conversation and before one of them had hung up. Traffic channel congestion rate (TCHCR) is failure in connecting to the service needed by the user after an SDCCH has been assigned. The received signal code power is also an important parameter which was measured. It gives an estimate of the power level the pilot channel of a cell is received and usually expressed in dBm. With this parameter, different cells using the same carrier can be compared and handover or cell selection decision can be taken.

Table 1: The KPIs, their definitions and set threshold (Source: [1, 13])

S/N	Key Performance Indicator	Accronym	Definitions	Target (%)
1	Call Setup Success Rate	CSSR	Number of the unblocked call attempts divided by the total number of call attempts. Or (1 - Blocking Probability) x 100%	≥98%
2	Traffic Channel Congestion (with and without Handover)	TCH Cong	Is the ratio of the number of unsuccessful TCH requests to the total number of TCH request attempts expressed as percentage	≤2% WOH ≤4% WHO
3	Call Drop Rate	CDR	CDR Is the number of dropped calls divided by the total number of call attempts Or (1 - Call Completion Ratio) x 100%	≤2%
4	Standalone Dedicated Control Channel Congestion	SDCCH CONG	Is a logical signalling channel that is used for call set-up. Once a call is successfully setup SDCCH is released and RTCH is assigned for the converation	≤1%

3.1 Geographic Description of the Coverage Area

Ondo State is located at the south western part of Nigeria which is an important zone of the country known for its commercial, educational, agricultural and political activities taking place around the area. Akure is the largest city and it is the capital of Ondo State situated at $7^{0}25'$ North Latitude, $5^{0}19'$ East Longitude. The city's projected population is 609,165 people for the year 2017. No previous work is available in literature on research carried out to investigate the quality of mobile phone services in the region. The quality of service measurements were collected from three major suburbs within Akure. The areas covered for this work are Federal University of Technology, Akure (FUTA), Alagbaka, and Oja – Arakale areas.

FUTA is the academic hub of the city, Alagbaka is a Government reserved area and therefore sparsely populated while Oja-Arakale area is the business district of the state and therefore densely populated. The different areas are chosen to help investigate the difference in quality of service based on population index of subscribers and average revenue per user (ARPU) status of the area.

3.2 Drive Test Routes Survey

The key areas covered around Alagbaka test route are Alagbaka Quarters, Police Command, Government Offices and Shoprite. The details of the test route is given in Figure 4. The FUTA campus and environment test route were covered as shown in Figure 5. The key areas covered are the major roads within FUTA and areas close to the two major gates including the University junction. The key areas covered in Oja - Arakale area test route are: Oba Adesida road, Ojomu Street, Arakale Road and Ondo Road as shown in Figure 6.

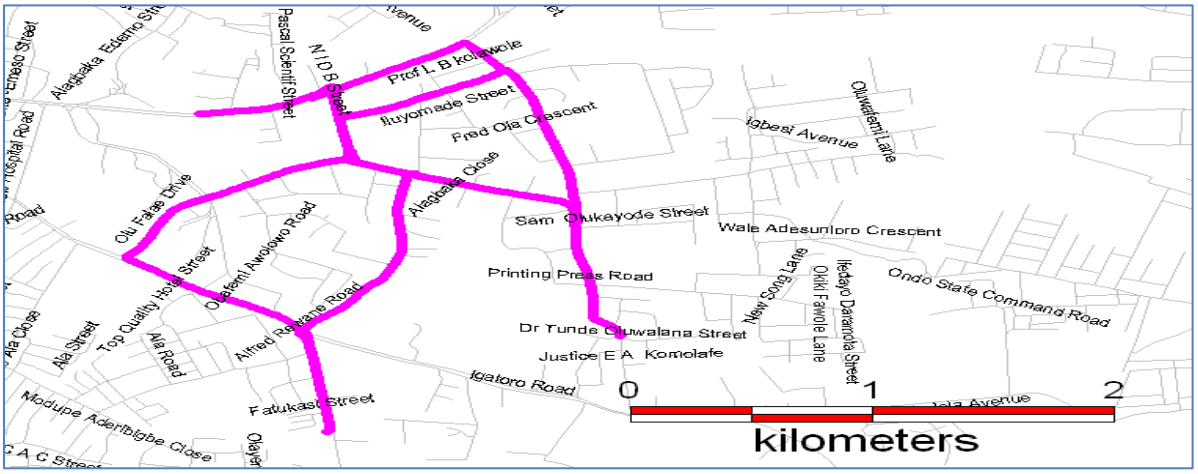

Figure 4: *Alagbaka area test route*

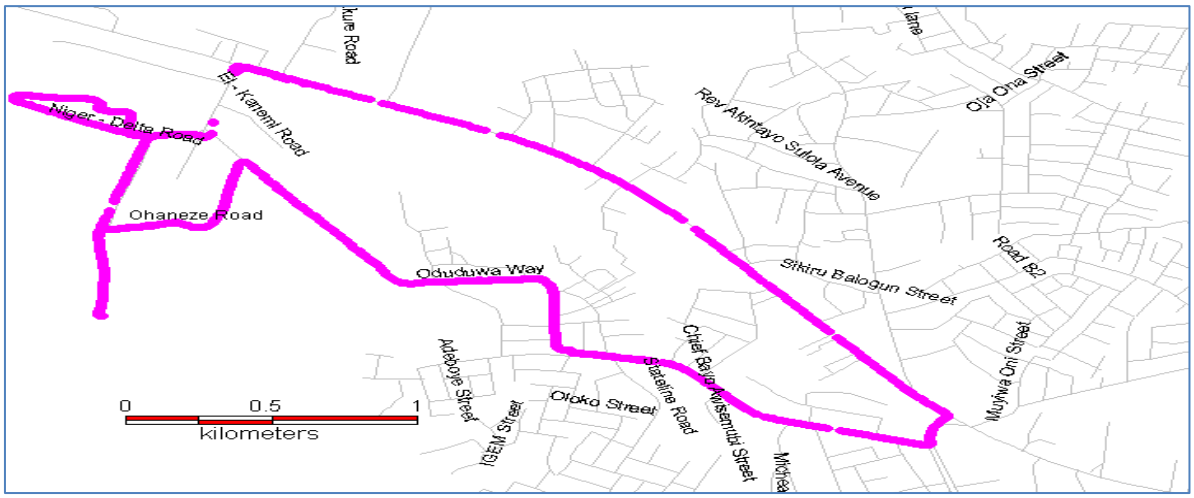

Figure 5: FUTA area test route

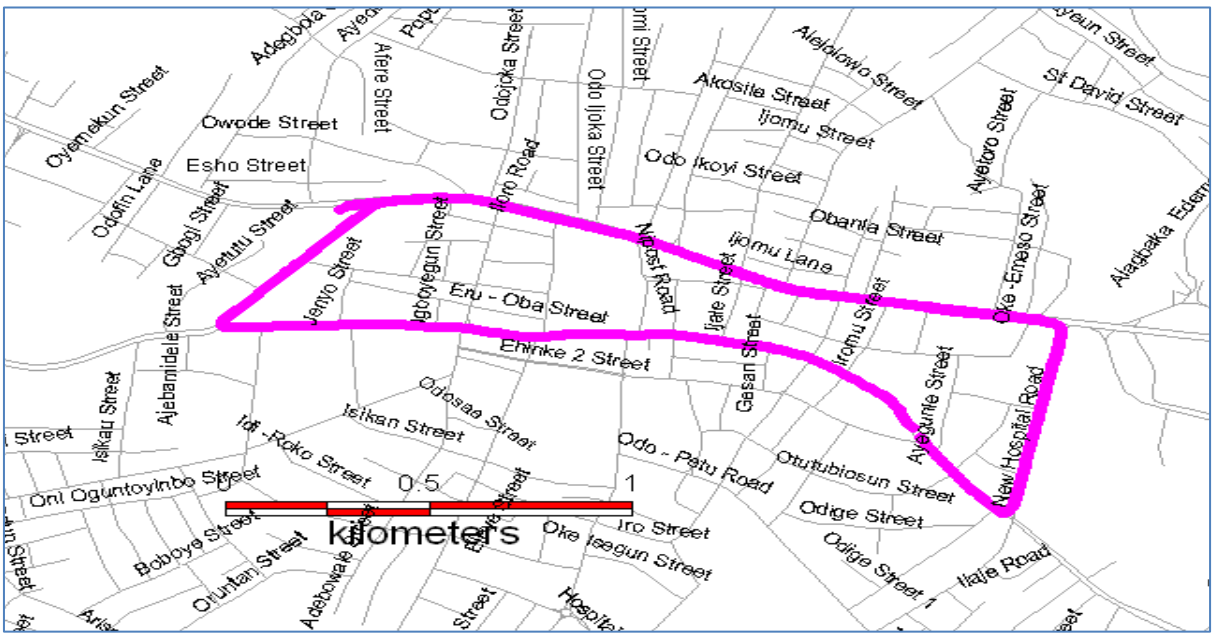

Figure 6: Oja - Arakale area test route

3.3 Drive Test Measurement Collection

Test data were collected from the four major mobile network operators in the country and will be referred to in this paper as MNO1, MNO2, MNO3 and MNO4. In terms of network signal coverage in Akure city there are 2G, 3G and 4G coverage. TEMS test phones used were locked on WCDMA/GSM Dual Mode access technology for all four mobile network operators considered. Data was collected for two - three hours every day, three times a day (morning, afternoon and evening data collection sessions) using the same test route.

4. RESULT AND DISCUSSION

Measurement collected during the drive test are summarized in Tables 1, 2 and 3. In the tables the received signal code power (RSCP) for all the MNOs are documented. The other KPIs, namely Call set up success rate (CSSR), Call drop rate (CDR), Retainability and Soft Handover (SHO) success rate for the four networks considered are equally presented.

4.1 Received Signal Code Power

At the Alagbaka region, for the morning session, MNO1 had average measurements 50.89% above the benchmark of -92dBm while MNO 2 and MNO3 had above 99%. At the FUTA area, MNO1 performed averagely below the benchmark in the evening at 40.83% while MNO2, MNO3 and MNO4 had measurements 91.54%, 98% and 89.7% above the benchmark respectively. Around Oja-Arakale area, MNO2 had 100% measurements above the benchmark and MNO1 had 68.91% in the morning; the least measurement of the area. MNO2 performed better at Oja-Arakale and FUTA areas while MNO3 performed better at the Alagbaka region. Overall, MNO2, MNO3 and MNO4 average received signal code power measurements were 90% above the benchmark. MNO1 has to increase its coverage area by increasing the number of base stations or increasing the power of her antennas if it is not already at the maximum approved range. Figures in Appendix A1, Figures 1-9 shows the RSCP plots of the Alagbaka, Oja-Arakale and FUTA test routes at different times of the day respectively.

Detailed analysis of the received signal strength (Received Signal Code Power- RSCP) and Energy per chip/Noise spectral density (EcNo) are presented in Tables A1-A6 in the Appendix. Figure 10, 11 and 12 shows the graphical presentation of the RSCP measurements of the mobile network operators at Oja-Arakale, Alagbaka and FUTA test route respectively.

Oja-Arakale area had the best average RSCP measurements across all networks. This might be because Oja-Arakale region is the business hub of the city and the best area to obtain an increasing average revenue per user (ARPU). It is also the best area to make a good impression and hence all networks put in their best to give optimal services at this area.

Looking at Figures 10-12 again, it will be noted that a large percentage of measurements from MNO1 were greater than -110 to -92 which signifies weak signal strength. With weak RSCP, subscribers will have more difficulties connecting to and maintaining the network link during calls. Averagely, all other networks performed well.

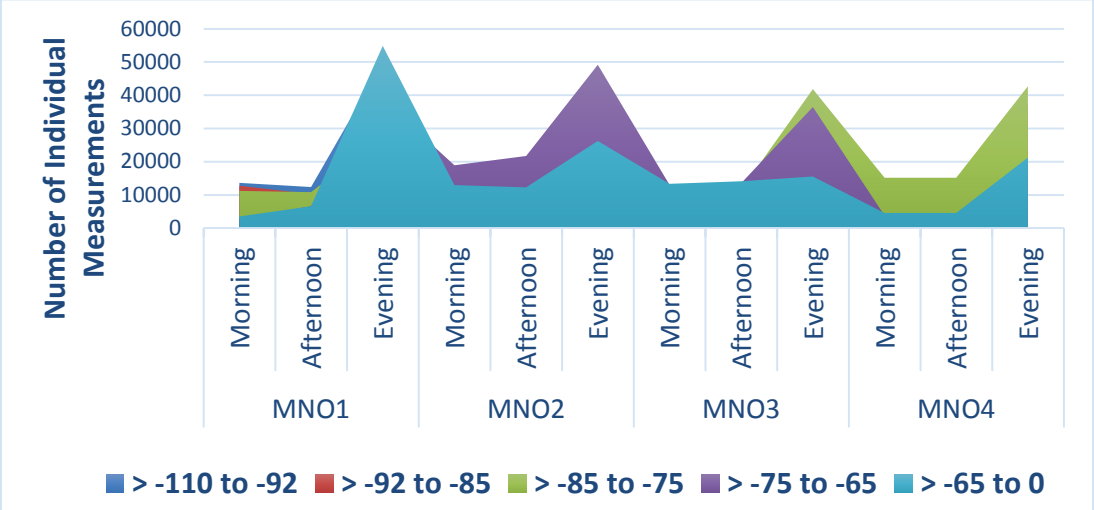

Figure 10: RSCP analysis of the mobile network operators at Oja-Arakale area test route

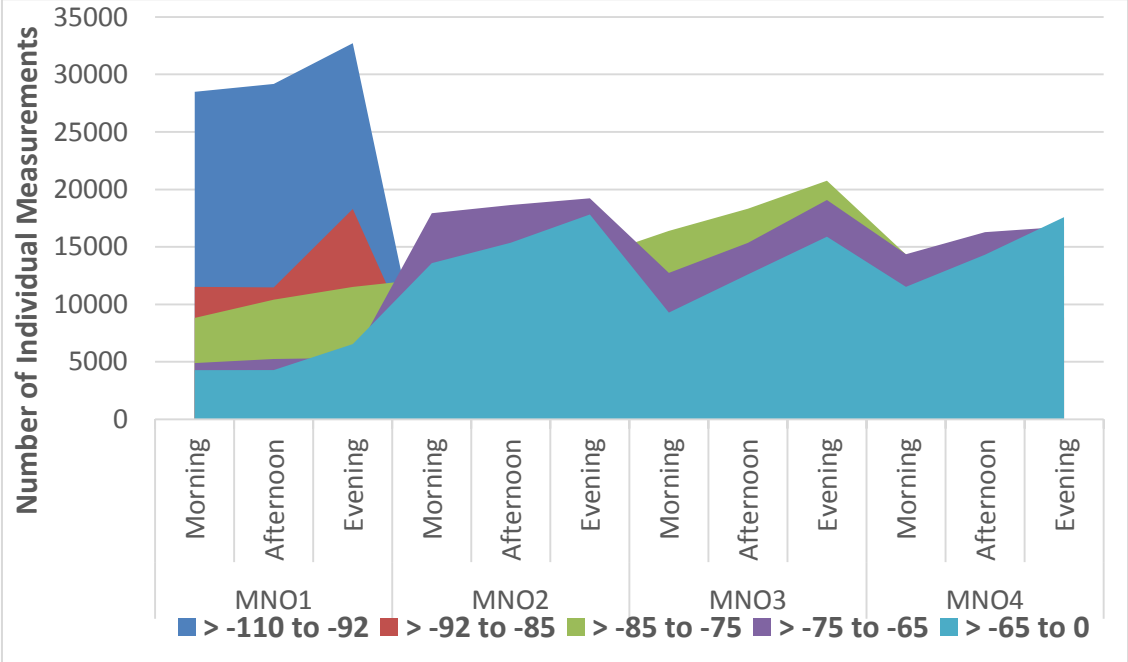

Figure 11: RSCP analysis of the mobile network operators at Alagbaka area test route

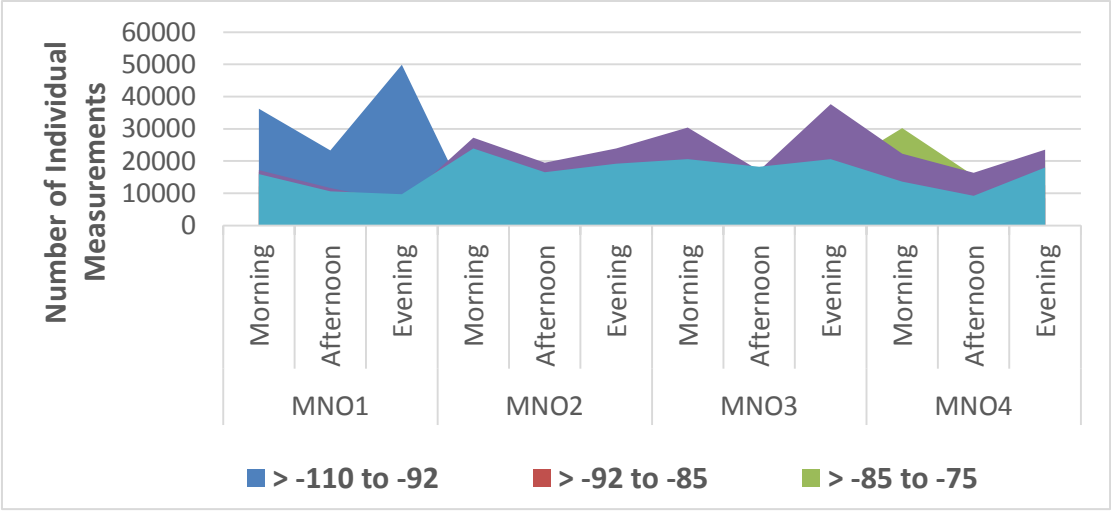

Figure 12: RSCP analysis of the mobile network operators at FUTA area test route

4.2 Call Set-up Success Rate (CSSR)

Figure 13 shows a graphical presentation of the call set-up success rate (CSSR) analysis of the coverage areas. Some measurement showed that some voice services rendered by the MNOs had CSSR values below the target, with MNO1 offering the worst CSSR at FUTA area. CSSR measurements were worst in the morning and gave much better values in the evening. MNO4 had the worst CSSR of 57.89% at Alagbaka area in the morning while MNO3 performed consistently below the CSSR target of 98% at all the coverage areas at all times. Averagely, MNO2 gave the best CSSR of 98.25% while MNO1 and MNO4 had 90.13% and 95.11% respectively. Tables A7-A9 in the Appendix summarizes the KPI measurements of the mobile network operators at Oja-Arakale, Alagbaka and FUTA test route respectively.

4.3 Call Drop Rate

The target dropped call rate (CDR) given by NCC is 2% and from Figure 14 it can be seen that at five different instances, the MNOs had an overshoot above the target. MNO2 consistently gave an average CDR above the target at Alagbaka: 2.56%, 2.86% and 9.09% for the morning, afternoon and evening measurements respectively. MNO1 had an overshoot at FUTA area in the morning and evening though worst in the morning with a value of 6.67% and 3.03% in the evening. There were no dropped calls at the Oja-Arakale region and MNO4 had absolutely no dropped calls and performed best. MNO3 also performed well and had CDR below the target.

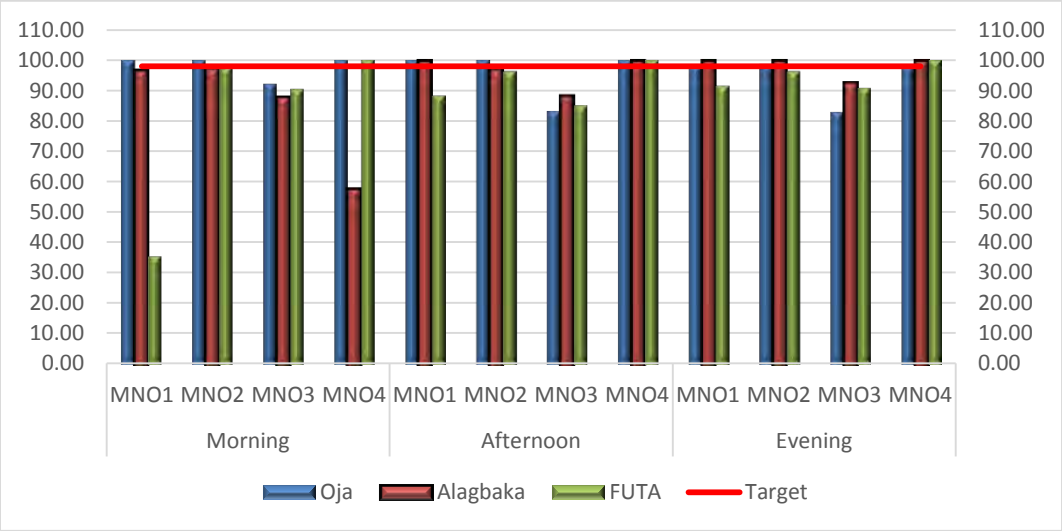

Figure 13: Call Setup Success Rate (CSSR) analysis of voice service provided by mobile network operators

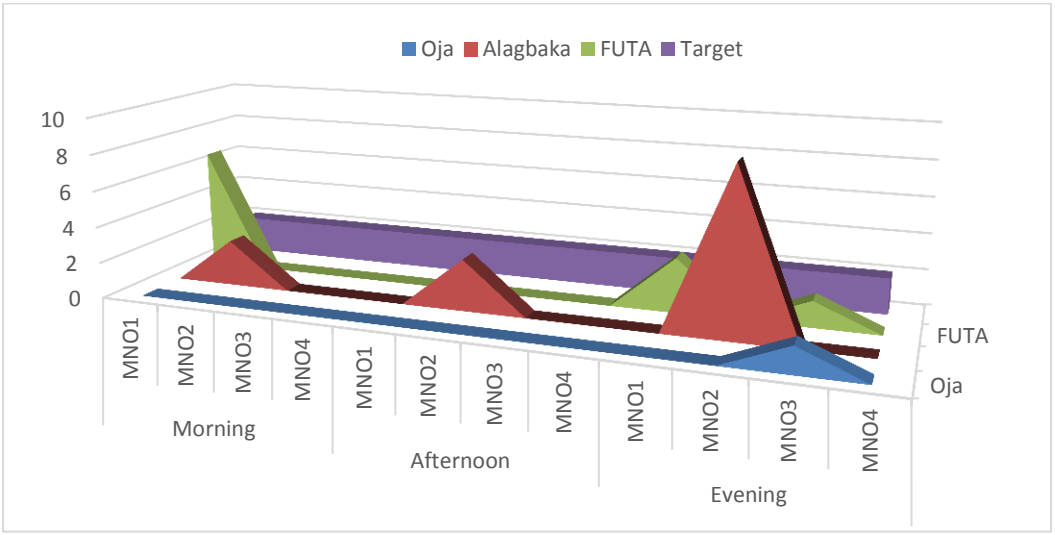

Figure 14: Call Drop Rate (CDR) analysis of voice service provided by mobile network operators

4.4 Call Completion Rate or Voice Service Retainability Ratio

At the FUTA area, MNO1 gave a service retention ratio of 93.33% and 96.97% for the morning and evening measurements which is below the target of 100% specified by NCC. MNO2 peformed below the target at Alagbaka for morning, afternoon and evening sessions; 97.44%, 97.14% and 90.91% respectively. While MNO3 had a retainability ratio below the target at Oja-Arakale area in the evening with 98.55%.

4.5 Other Key Performance Indicators (Kpi) Analysis

Soft handover (SHO) success rate was 100% across all mobile network operators for all areas and at all times. This signifies that all the base stations performed optimally considering the SHO. Radio resource control (RRC) protocol functions includes: establishing connection, release funtion, broadcast information, radio bearer establishment etc. RCC congestion rate was 100% for MNO 3 for all areas and at all times. MNO4 also had 100% RRC connection rate at all areas in the afteroon and evening, this is shown in Figure 16. The morning measurement for MNO 4 in the morning at FUTA region was below 60%. MNO1 gave the worst RCC congestion rate in the evening and performed much better in the morning and afternoon.

Critically evaluating the measurements, MNO1 had an average CSSR of 90.13% and overshoot CDR at FUTA area in the morning and evening, with average value of 1.07%. The average retention ratio was 98.92%

MNO2 gave the best CSSR of 98.25% but consistently gave an average CDR above 2% at Alagbaka area: 2.56%, 2.86% and 9.09% and retainability ratio below the target of 97.44%, 97.14% and 90.91% for the morning, afternoon and evening measurements respectively. MNO2 had an average CDR and retainability rato of 1.61% and 98.84% respectively.

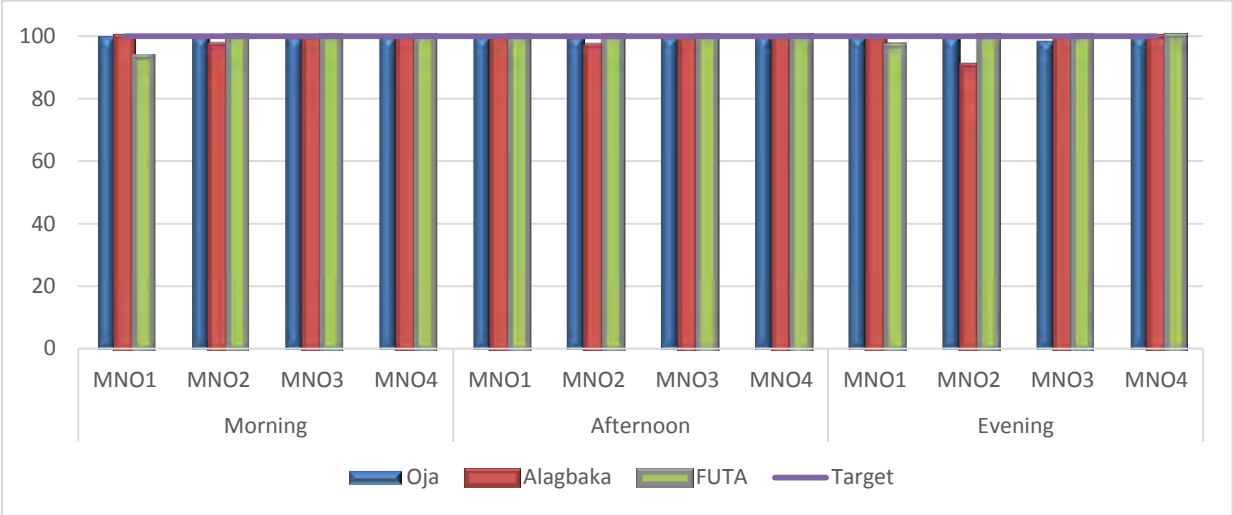

Figure 15: Retainability Ratio analysis of voice service provided by mobile network operators

Figure 16: Radio Resource Congestion Rate provided by mobile network operators

MNO3 had the worst CSSR of 88.33% and performed below the target at all the coverage areas at all times but once the subscriber is connected, the call drop rates were minimal and below 2%. The retainability ratio was normal except at the Oja-Arakale area where it was 98.55%.

MNO4 had an average CSSR value of 95.11% which is below the target of 98%, which was due to a very low CSSR value at FUTA area in the morning with of 57.89%. For all other times, the CSSR value for MNO4 was above 98%. MNO4 had absolutely no dropped calls and performed best and consistently gave a retainability ratio above the target.

5. CONCLUSION

This paper presents QoS data and analysis which compares QoS offered at different times of the day, covering three coverage areas and offered by different mobile network operators. There is a difference across networks in the performance of voice services based on the time of the day and the area under consideration. No mobile network operator offered services that met the required quality of service specified by the Nigerian Communication Commission (NCC) for data collected within three days and selected times of the day. The CSSR and CDR values were above the threshold of 98% for the former and below 2% for the later. The summarized analysis presented on the NCC website must be a reflection of what is happening at most areas of the country. Whereby when the measurements from the business hub of the country (Lagos, Abuja, Kano and Port-harcourt) are averaged with the measured values collected from other areas (such as Akure) the failure to meet specified quality of service metrics becomes less obvious. It is therefore important for stakeholders to use performance metric measurements for different regions of the country to make informed decisions instead of the lumped sum. Voice services rendered by mobile network operators to subscribers should be improved and customers should get value for their money.

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APPENDIX

A1. RSCP Plot

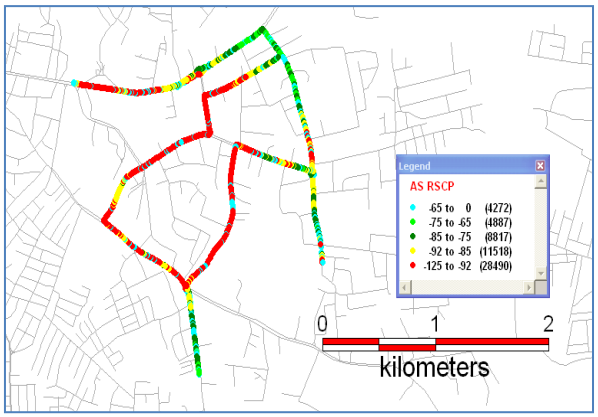

Figure 1a: MNO1 RSCP Plot Alagbaka Morning

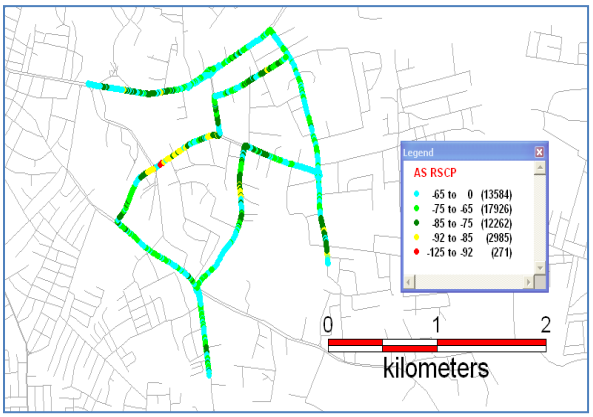

Figure 1b: MNO2 RSCP Plot Alagbaka Morning

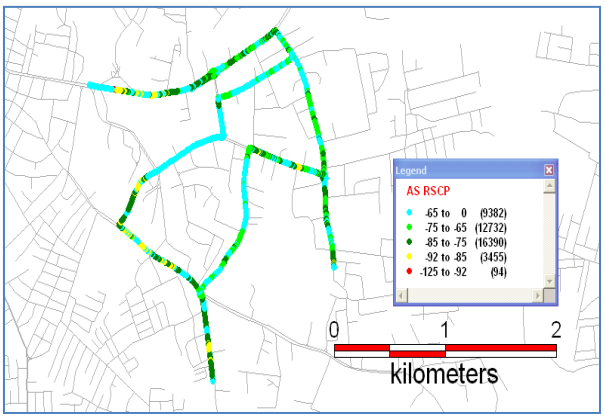

Figure 1c: MNO3 RSCP Plot Alagbaka Morning

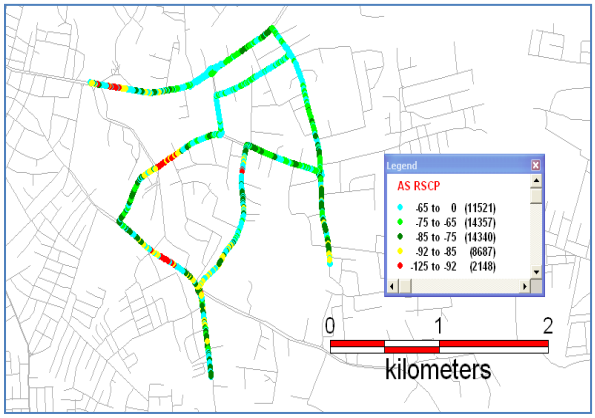

Figure 1d: MNO4 RSCP Plot Alagbaka Morning

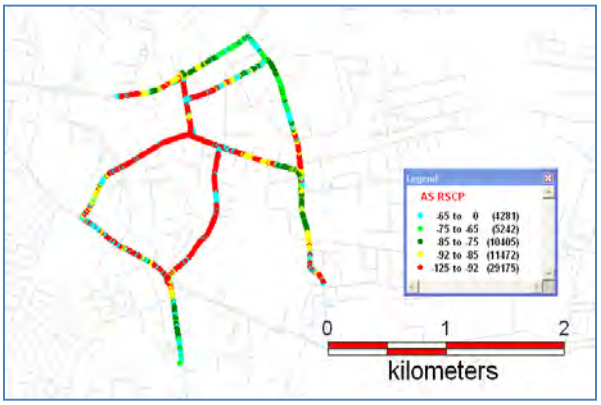

Figure 2a: MNO1 RSCP Plot Alagbaka Afternoon

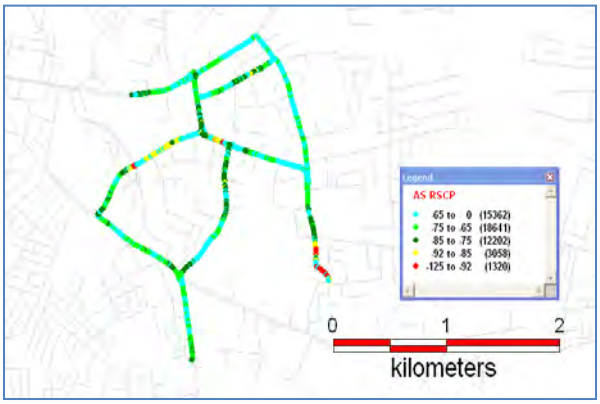

Figure 2b: MNO2 RSCP Plot Alagbaka Afternoon

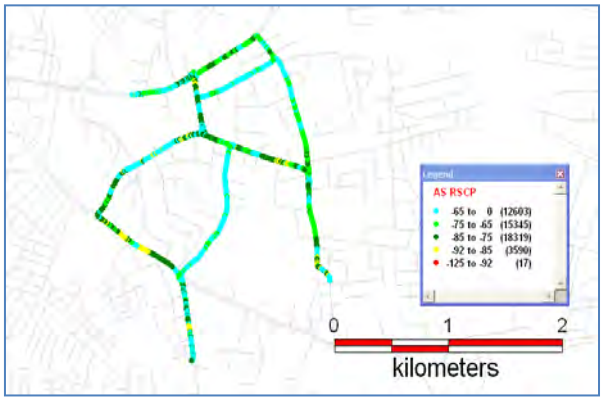

Figure 2c: MNO3 RSCP Plot Alagbaka Afternoon

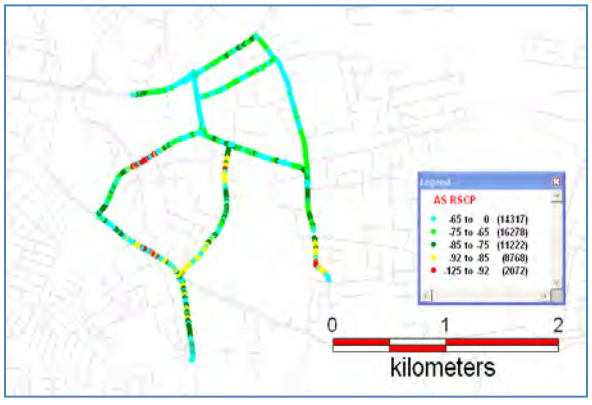

Figure 2d: MNO4 RSCP Plot Alagbaka Afternoon

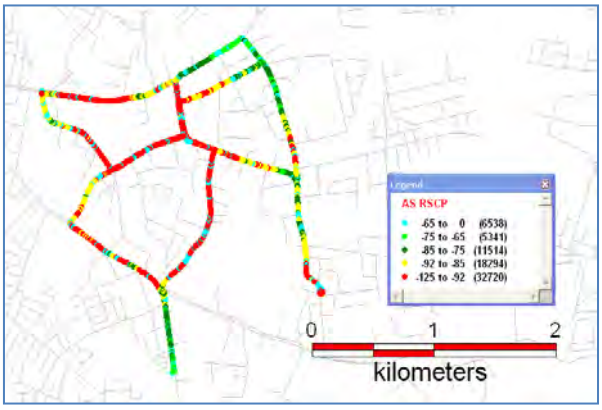

Figure 3a: MNO1 RSCP Plot Alagbaka Evening

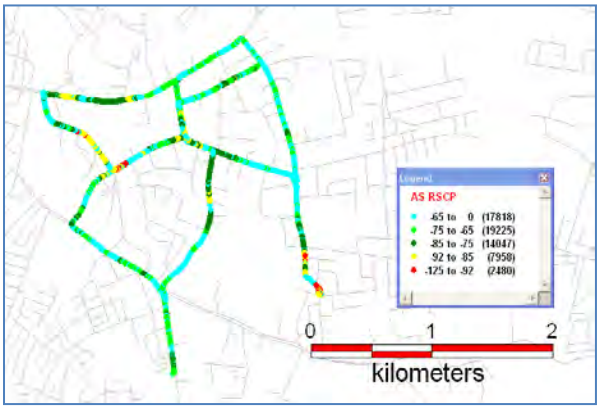

Figure 3b: MNO2 RSCP Plot Alagbaka Evening

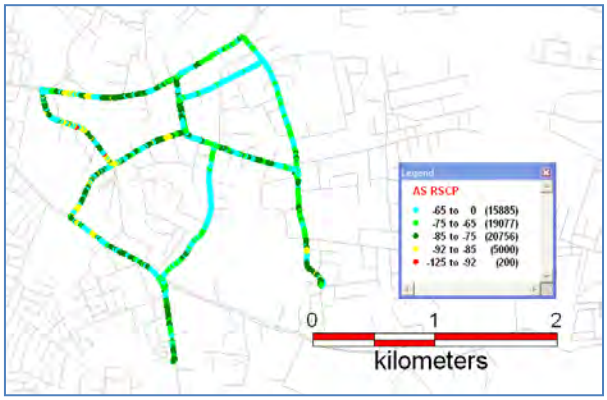

Figure 3c: MNO3 RSCP Plot Alagbaka Evening

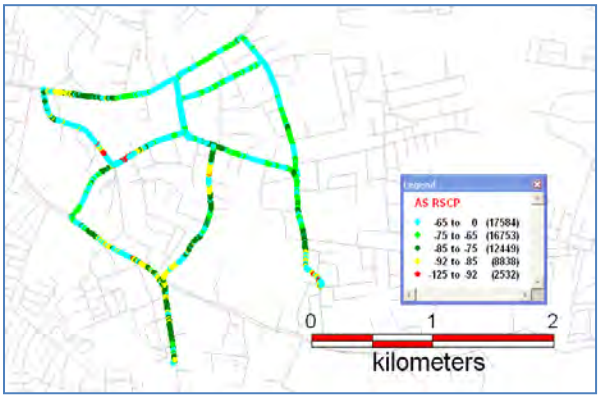

Figure 3d: MNO4 RSCP Plot Alagbaka Evening

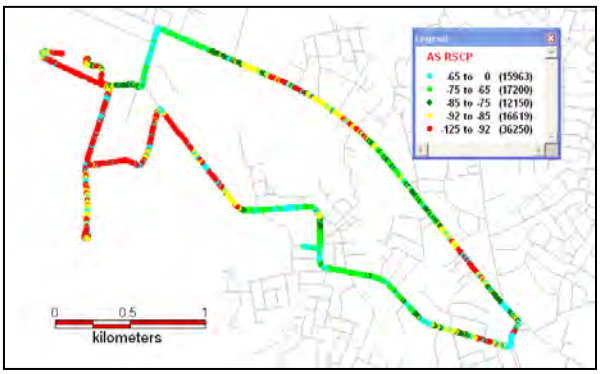

Figure 4a: MNO1 RSCP Plot FUTA Morning

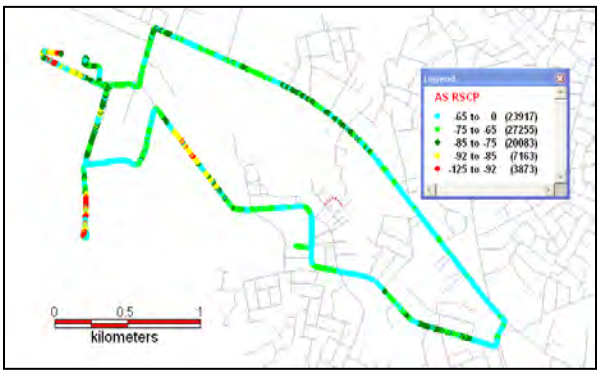

Figure 4b: MNO2 RSCP Plot FUTA Morning

Figure 4c: MNO3 RSCP Plot FUTA Morning

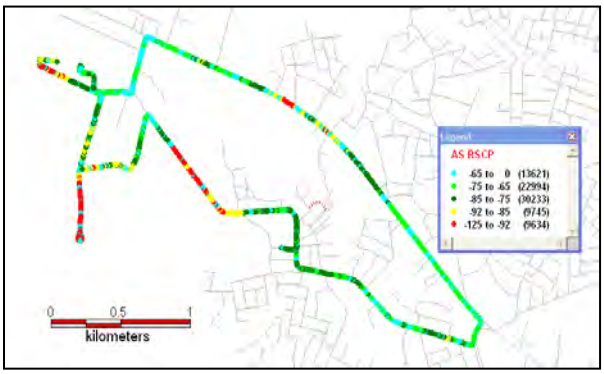

Figure 4d: MNO4 RSCP Plot FUTA Morning

Figure 5a: MNO1 RSCP Plot FUTA Afternoon

Figure 5b: MNO2 RSCP Plot FUTA Afternoon

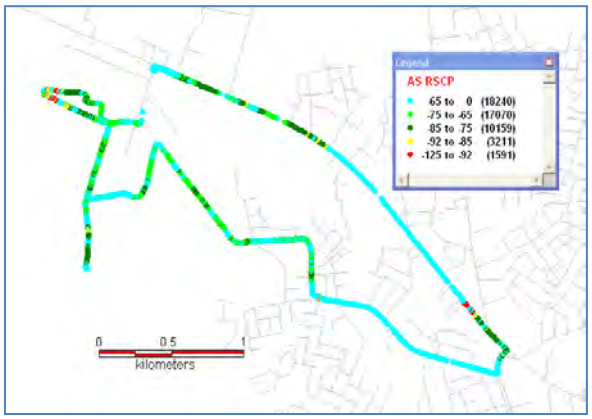

Figure 5c: MNO3 RSCP Plot FUTA Afternoon

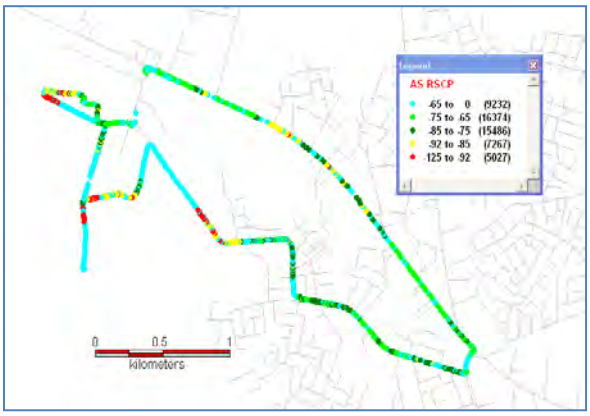

Figure 5d: MNO4 RSCP Plot FUTA Afternoon

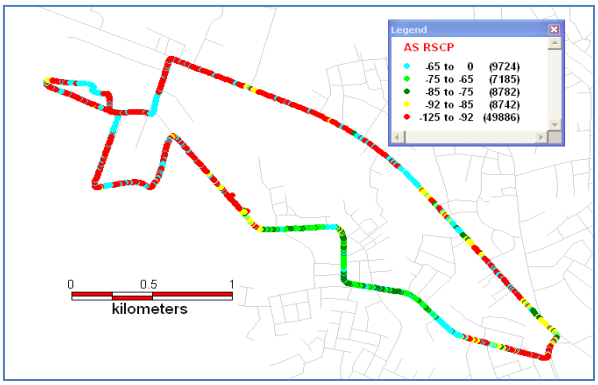

Figure 6a: MNO1 RSCP Plot FUTA Evening

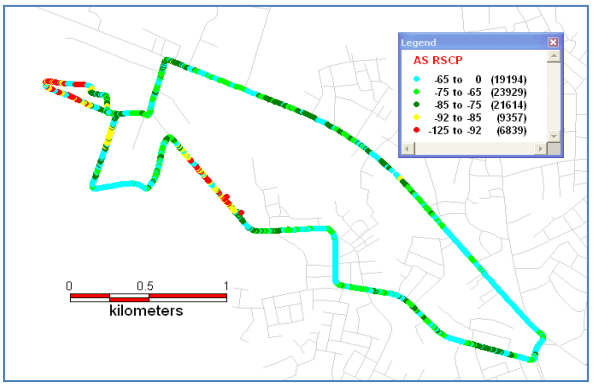

Figure 6b: MNO2 RSCP Plot FUTA Evening

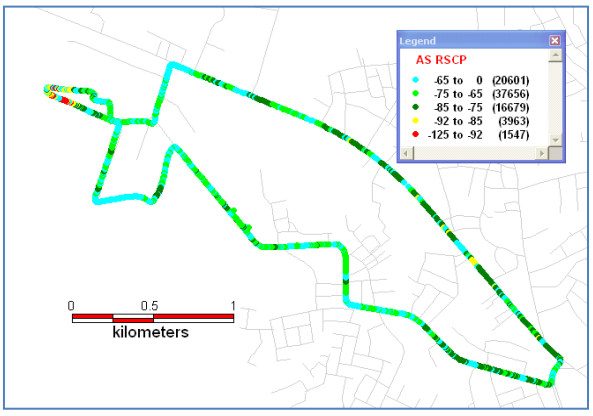

Figure 6c: MNO3 RSCP Plot FUTA Evening

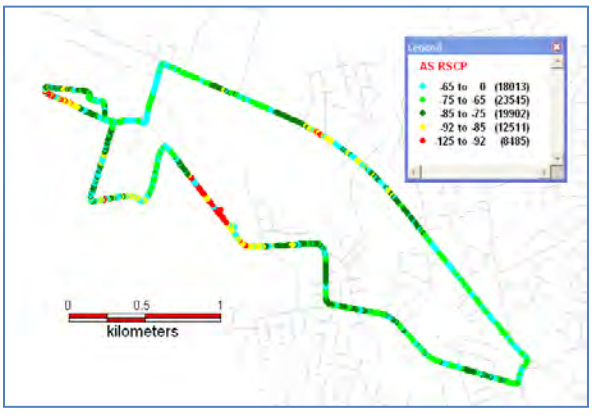

Figure 6d: MNO4 RSCP Plot FUTA Evening

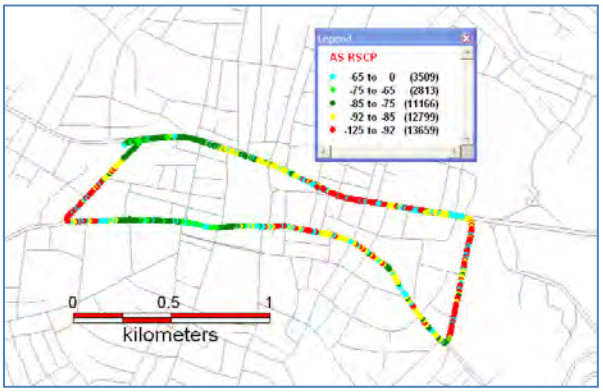

Figure 7a: MNO1 RSCP Plot Oja-Arakale Morning

Figure 7b: MNO2 RSCP Plot Oja-Arakale Morning

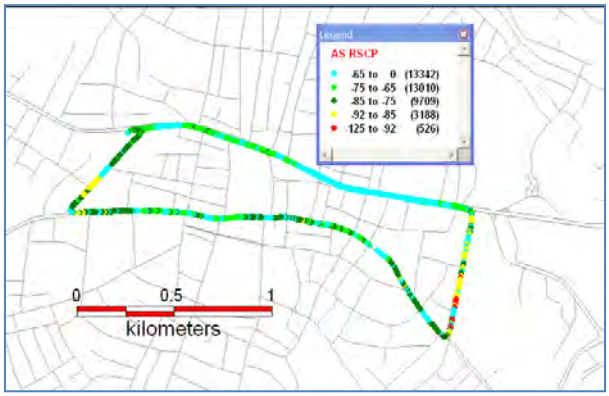

Figure 7c: MNO3 RSCP Plot Oja-Arakale Morning

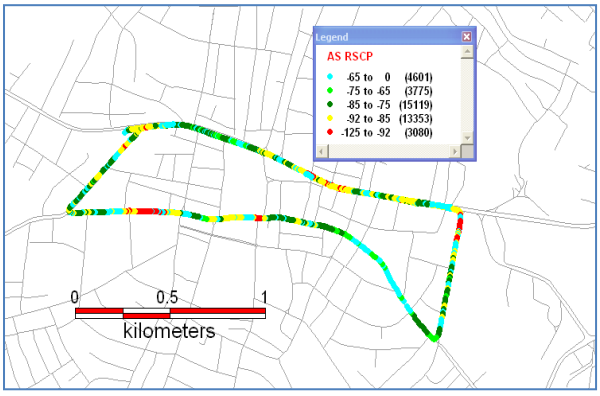

Figure 7d: MNO4 RSCP Plot Oja-Arakale Morning

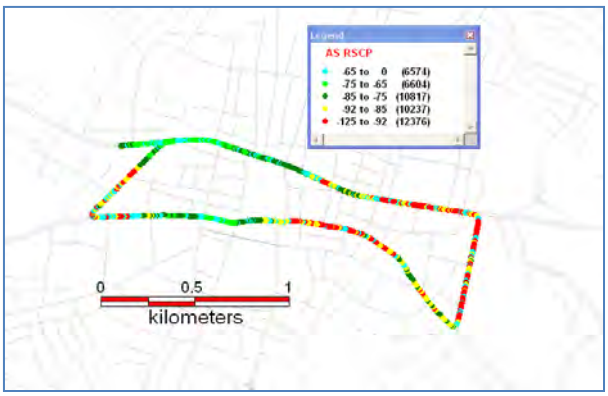

Figure 8a: MNO1 RSCP Plot Oja-Arakale Afternoon

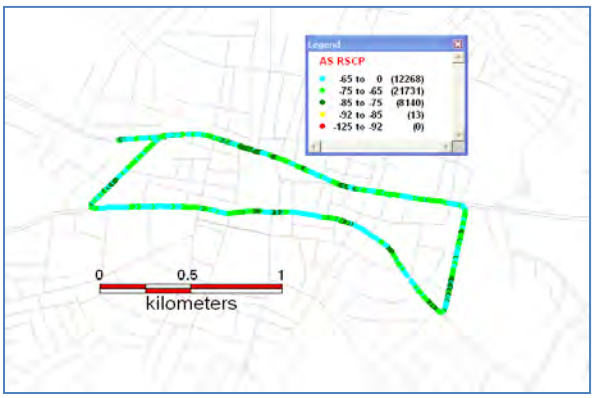

Figure 8b: MNO2 RSCP Plot Oja-Arakale Afternoon

Figure 8c: MNO3 RSCP Plot Oja-Arakale Afternoon

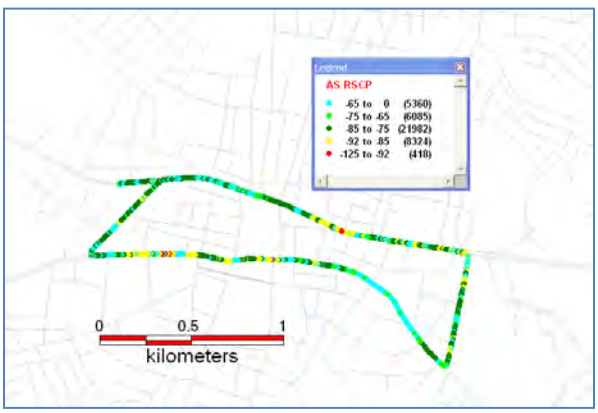

Figure 8d: MNO4 RSCP Plot Oja-Arakale Afternoon

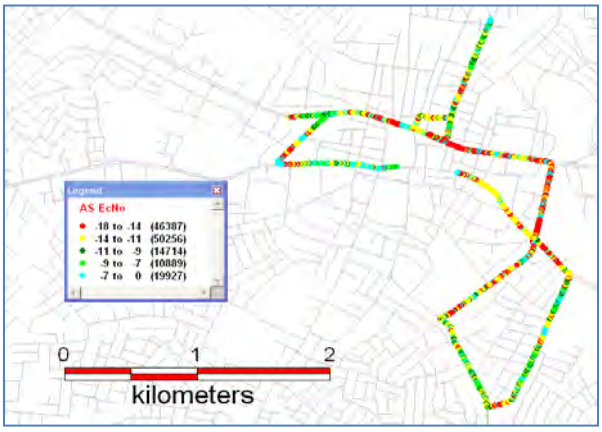

Figure 9a: MNO1 RSCP Plot Oja-Arakale Evening

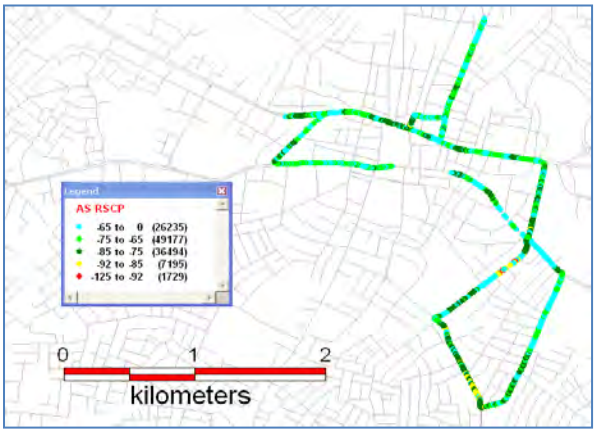

Figure 9b: MNO2 RSCP Plot Oja-Arakale Evening

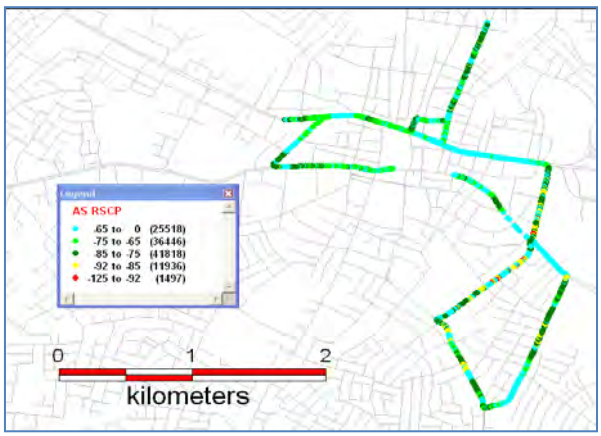

Figure 9c: MNO3 RSCP Plot Oja-Arakale Evening

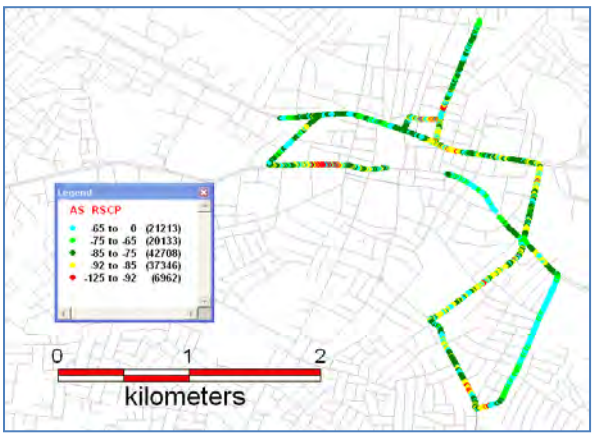

Figure 19d: MNO4 RSCP Plot Oja-Arakale Evening

A2. RSCP measurements

For Table A1 – A6, "Morn", "After" and "Even" stands for Morning, Afternoon and Evening

Table A1: Number of measurements against RSCP range at the Alagbaka area

	MNO1			MNO2			MNO3			MNO4		
RSCP (dbm)	Morn	After	Even	Morn	After	Even	Morn	After	Even	Morn	After	Even
> -110 to -92	28490	29175	32720	271	1320	2480	94	17	200	2148	2027	2532
> -92 to -85	11518	11472	18294	2985	3058	7958	3455	3590	5000	8687	8768	8838
> -85 to -75	8817	10405	11514	12262	12202	14047	16390	18319	20756	14340	11222	12449
> -75 to -65	4889	5242	5341	17926	18641	19225	12732	15345	19077	14357	16278	16753
> -65 to 0	4272	4281	6538	13584	15362	17818	9282	12603	15885	11521	14317	17584
% RSCP > = 92dbm	50.89	51.83	56.2	99.42	97.39	95.96	99.77	99.96	99.67	95.79	96.14	95.64

Table A2: Number of measurements against EcNo range at the Alagbaka area

	MNO1			MNO2			MNO3			MNO4		
	Morn	After	Even	Morn	After	Even	Morn	After	Even	Morn	After	Even
> -18 to -14	15951	14247	21144	5773	5420	8695	8580	7076	8580	1251	1498	1238
> -14 to -11	20414	26574	24722	12797	14855	11004	20253	18506	20253	7118	6089	3908
> -11 to -9	7987	6731	10273	10325	11143	12789	10292	8614	10292	9551	6310	5666
> -9 to -7	5576	4332	7184	6910	6819	1116	4950	4001	4950	7635	8088	9399
> -7 to 0	6422	7225	9591	9579	9825	14037	14648	9711	14648	25469	30672	37879
% EcNo Samples>=14 db	71.69	75.89	71	87.29	88.72	81.74	82.29	85.23	83.38	97.54	97.15	83.38

Table A3: Number of measurements against RSCP range at FUTA area

	MNO1			MNO2			MNO3			MNO4		
RSCP (dbm)	Morn	After	Even	Morn	After	Even	Morn	After	Even	Morn	After	Even
> -110 to -92	36250	23302	49886	3873	2993	6839	3743	1591	1547	9634	5027	8485
> -92 to -85	16619	6477	8742	7163	5789	9357	4687	3211	3963	9745	7267	12511
> -85 to -75	12150	10846	8782	20083	12930	21614	22731	10159	16679	30233	15486	19902
> -75 to -65	17200	11634	7185	27255	19498	23929	30404	17070	37656	22294	16374	23545
> -65 to 0	15963	10617	9724	23917	16546	19194	20604	18240	20601	13621	9232	18013
% RSCP > = 92dbm	63.07	62.93	40.83	95.29	94.81	91.54	95.44	96.83	98.07	88.73	90.58	89.7

Table A4: Number of measurements against EcNo range at FUTA area

	MNO1			MNO2			MNO3			MNO4		
	Morn	After	Even	Morn	After	Even	Morn	After	Even	Morn	After	Even
> -18 to -14	2889	14347	24067	15838	6285	13730	7312	3618	7490	296	1410	440
> -14 to -11	28731	17949	24022	36059	16836	3072	24236	12029	28849	15715	5924	7403
> -11 to -9	15280	8045	8970	14114	13217	16267	29435	13629	27199	10109	6743	13821
> -9 to -7	9663	5776	3609	4572	8049	7299	10547	8199	6779	9137	7827	14694
> -7 to 0	10337	13064	10001	9849	13000	11509	9786	11824	9284	50970	31164	46098
% EcNo Samples> =14db	68.91	75.75	65.94	80.3	89.2	73.53	91	92.66	90.59	99.65	97.34	99.46

Table A5: Number of measurements against RSCP range at Oja- Arakale area

	MNO1			MNO2			MNO3			MNO4		
RSCP (dbm)	Morn	After	Even	Morn	After	Even	Morn	After	Even	Morn	After	Even
> -110 to -92	13659	12376	49886	0	0	1729	526	83	1497	3080	3080	6962
> -92 to -85	12799	10237	9716	333	13	7195	3188	1973	11936	13353	13353	37346
> -85 to -75	11166	10817	27427	7610	8140	36494	9709	11520	41818	15119	15119	42708
> -75 to -65	2813	6604	38681	18896	21731	49177	13010	13567	36446	3775	3775	20133
> -65 to 0	3509	6574	54844	12943	12268	26235	13342	14104	15518	4601	4601	21213
% RSCP > = 92dbm	68.91	73.44	72.37	100	100	98.56	98.67	97.76	98.72	92.28	98.95	94.57

Table A6: Number of measurements against EcNo range at Oja- Arakale area

	MNO1			MNO2			MNO3			MNO4		
EcNo Sample (db)	Morn	After	Even	Morn	After	Even	Morn	After	Even	Morn	After	Even
> -18 to -14	15086	15672	46387	8170	10922	27988	6974	8461	25026	1066	288	7858
> -14 to -11	14376	17502	50256	16110	16216	38656	17983	20135	59285	6449	6965	43292
> -11 to -9	3429	3147	14714	8429	9432	24995	7056	5558	15405	8117	9176	19020
> -9 to -7	4561	3646	10889	2225	684	11511	2210	2289	2501	9173	9811	19569
> -7 to 0	5991	6547	19927	4259	4210	14736	4782	4482	12302	15106	15929	39193
% EcNo Samples>=14db	65.27	66.3	67.37	79.15	73.65	76.25	82.12	79.32	78.14	97.32	99.31	93.9

A3. KPI measurements

Table A7: KPI measurements for Oja-Arakale area test route

	Morning				Afternoon				Evening			
Variables	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4	MNO 1	MNO2	MNO3	MNO4
Call attempts	20	27	26	24	20	27	30	26	64	77	83	79
Call set up	20	27	24	24	20	27	25	26	63	76	69	78
Drop calls	0	0	0	0	0	0	0	0	0	0	1	0

	Morning				Afternoon				Evening			
Variables	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4
Blocked Calls	0	0	2	0	0	0	5	0	1	1	14	1
RRC Established	8	27	26	30	8	27	30	33	22	80	83	99
RRC Connection Abnormal Release	0	0	0	0	0	0	0	0	4	0	0	0
% Retainability	100	100	100	100	100	100	100	100	100	100	98.55	100
CSSR	100	100	92.31	100	100	100	83.33	100	98.44	98.7	83.13	98.13
% Dropped Calls	0	0	0	0	0	0	0	0	0	0	1.45	0
SHO Success Rate	100	100	100	100	100	100	100	100	100	100	100	100
RRC Connection	100	100	100	100	100	100	100	100	84.62	100	100	100

Table A8: KPI measurements for Alagbaka area test route

	Morning				Afternoon				Evening			
	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4
Call attempts	33	40	42	57	28	36	35	33	26	33	28	32
Call set up	32	39	37	33	28	35	31	33	26	33	26	32
Drop calls	0	1	0	0	0	1	0	0	0	3	0	0
Blocked Calls	1	1	5	24	0	1	4	0	0	0	4	0
RRC Established	9	45	41	63	14	45	36	35	10	39	28	38
RRC Connection Abnormal Release	0	1	0	46	0	3	0	0	0	0	0	0
% Retainability	100	97.44	100	100	100	97.14	100	100	100	90.91	100	100
CSSR	96.97	97.5	88.1	57.89	100	97.32	88.57	100	100	100	92.86	100
% Dropped Calls	0	2.56	0	0	0	2.86	0	0	0	9.09	0	0
SHO Success Rate	100	100	100	100	100	100	100	100	100	100	100	100
RRC Connection	100	97.83	100	57.8	100	93.76	100	100	100	100	100	100

Table A9: KPI measurements for FUTA area test route

	Morning				Afternoon				Evening			
	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4	MNO1	MNO2	MNO3	MNO4
Call attempts	42	47	42	44	43	56	61	55	36	56	55	51
Call set up	15	46	38	44	38	54	52	55	33	54	50	51
Drop calls	1	0	0	0	0	0	0	0	1	0	0	0
Blocked Calls	27	2	4	4	5	2	9	0	3	2	5	0
RRC Established	35	47	42	44	24	55	61	75	24	55	58	62
RRC Connection Abnormal Release	10	0	0	0	4	0	0	0	7	0	0	0
% Retainability	93.33	100	100	100	100	100	100	100	96.97	100	100	100
CSSR	35.71	97.87	90.48	100	88.37	96.43	85.25	100	91.67	96.43	90.91	100
% Dropped Calls	6.67	0	0	0	0	0	0	0	3.03	0	1.45	0
SHO Success Rate	100	100	100	100	100	100	100	100	100	100	100	100
RRC Connection	77.78	100	100	100	85.71	100	100	100	72.42	100	100	100