Original Research Article

Measurement and Performance Analysis of Signal-to-Interference Ratio in Wireless Networks

Abstract

To evaluate the reliability and quality of signal of UMTS radio access technology of three cellular networks (MTN, 9mobile and Airtel network) over two cities in Nigeria, an intensive drive test measurement was conducted, taking into consideration, signal-to-interference ratio (Ec/Io) as the key performance indicator under study. A total of 10958, 11075 and 11109 Ec/Io measurements were obtained for MTN, 9mobile and Airtel network. These measured data were subjected to statistical analysis in the form of bar charts, quality plots and calculations of measures of central tendency and dispersion. Result shows that 59.64%, 50.45% and 17.02% of the drive test route for Airtel, 9mobile and MTN network had good signal quality and met with the Nigerian telecommunication regulatory benchmark of at least -9dB for Ec/Io. Also, 40.36%, 49.55% and 82.98% of the drive test area for Airtel, 9mobile and MTN network fell below the regulatory benchmark and subscribers in this region experienced dropped calls, blocked calls, handover failures and degraded signal quality due to interference. Airtel network was adjudged the best network while the worst network was MTN network. The result provided by this article will help radio network engineers operating in Calabar South and Calabar Municipality, to efficiently reuse limited frequencies, avoid interferences, optimize handover and adjust transmitted power level. The mobile network operators are advised to build new base stations and visit the existing ones regularly for optimization.

Keywords: Interference, signal-to-interference ratio, UMTS radio access, wireless networks, signal quality

Introduction

For successful communication of signals across any communication link, the signal strength of the transmitter must be stronger than the background noise. The receiver, interested in one signal, may simultaneously detect undesired signals from multiple transmitters. These unwanted signals form a type of noise usually called interference [1-2].

Signal-to-interference ratio (Ec/Io) sometimes called carrier-to-interference ratio, is the communication bottleneck and an important metric of link quality for any receiver and transmitter pair in UMTS networks [3]. It is the ratio of the received energy per chip (Ec) to the interference level (Io), measured in decibel (dB) [4] and defined within the common pilot channel (CPICH) which is measured before the despreading of the received signal [5]. It is technically used to measure equipment capability in UMTS networks [4]. It is a predominant criterion for optimal allocation and management of radio resources in UMTS networks [3] and an algorithm for power control and handoff which requires fast and accurate Ec/Io measurement [6].

Interference limits the performance of cellular networks [7-8], degrades the quality of transmission for voice and data services by introducing bit errors in the received signal [9] and reduces the coverage and capacity of a network [10-13]. The value of Ec/Io varies such that if the value gets low, subscribers experience dropped and blocked calls [14]. The higher the number of users on the network, the higher the interference level and the smaller the cell radius [15]. Interference have stirred the migration of wireless networks from one technology to another [16-18].

In cellular networks, a specific spectrum (frequency allocation) is assigned to base stations to transmit and receive signals within a small geographic area called a cell. This is done to avoid the anomaly of having different services being transmitted at the same frequency thus, permitting easy and manageable analysis of the cellular system [19]. Also, other than interference due to radio frequency (RF) leakages, harmonics or frequency drifts, cell sites are subjected to interferences generated from improper connectivity of RF devices such as antennas, connectors and cables [20].

Two types of interference are considered in cellular networks; co-channel interference and adjacent channel interference. Co-channel interference is due to frequency reuse. This implies reusing the same set of frequency between base stations at relatively short distances from each other [21]. Factors such as reuse distance, antenna type, directionality, antenna height, site position and carrier transmit power, influence co-channel interference between cells. To mitigate this, the cells are separated by a minimum distance to provide sufficient isolation due to propagation or by reducing the footprint of the cell.

Adjacent channel interference is a consequence of signals from neighbouring frequencies interfering with the desired signal of another channel [22]. Imperfect receiver filters which allow nearby frequencies to leak into the passband and improper channel assignment causes adjacent channel interference. This type of interference can be minimized through careful filtering and by keeping the frequency of separation between each channel in a given cell as large as possible [19]. Other techniques are using modulation schemes which have low out-of-band radiation, using proper channel interleaving by assigning adjacent channels to different cells, avoiding the usage of adjacent channels in adjacent cells and separating the uplink and downlink property by time division duplex or frequency division duplex [23].

Several researches on Ec/Io have been conducted overtime. The authors in [24] worked on modeling the destructive effect of interference on mobile networks using the 3G standard. The spectra of the 3G signal without impact, as well as in the presence of destructive effects were estimated. It was concluded that interference impedes the transmission of messages. The authors in [25] investigated interference management for 5G cellular network constructions. They proposed fractional frequency reuse and soft frequency reuse to overcome interference and make good use of ultra-reliable network. The authors in [26] modeled co-channel interference in the THz band. The results played a meaningful role in the practical implementation and was easily extended for advanced performance analysis for THz communication systems. The authors in [27] analyzed the performance of uplink fractional frequency reuse (FFR) using worst case Ec/Io. The effect of power control exponents on FFR schemes were also studied. FFR reuse yielded the highest Ec/Io. It was also noticed that power control exponent do not affect strict FFR but reduces Ec/Io and the inner radius. The authors in [28] proposed a multi-cell interference management; a distributed power control method with the goal of improving the user supporting ratio of each cell. A notable performance gain was achieved by the proposed scheme. In [29], the authors applied frequency reuse technique for the management of interference in two mobile networks using a software, Monte-Carlo, for simulation. The obtained signal to interference ratio was above the protection criteria, depicting minimal rate of interference occurrence between the two radio stations.

In this article, we are investigating the performance of three wireless networks operating in Calabar South and Calabar Municipality, Nigeria, based on Ec/Io data obtained after an intensive drive test measurement. The obtained data are subjected to statistical analysis and compared with the performance benchmark of at least -9dB [30-31] stipulated by the telecommunication regulatory authority in Nigeria, the Nigerian Communication Commission (NCC). The remaining part of this article is divided into three parts; first, we shall discuss the method at which this research was carried out, followed by the display and discussion of results and finally go into a conclusion.

Materials and Method

The research sets to investigate the Ec/Io of three major mobile networks operating in Calabar South and Calabar Municipality and to further make comparative analyses, so as to deduce which network performs best, based on the NCC benchmark of at least – 9dB. The cellular networks investigated are MTN, Airtel and 9Mobile. Materials used to carry out this study are; a Garmin Global Positioning System (GPS), three TEMS mobile phones, three SIM cards, a TEMS investigation software, a laptop, a USB hub, a car inverter and a car. The SIM cards were slotted into the TEMS phones while the TEMS investigation software was installed in a windows 10 operating system laptop. The TEMS phones were powered by connecting them to the USB hub which is plugged to the laptop. The GPS, which is also powered by the laptop, gives the location for the drive test.

An extensive drive test measurement was conducted and Ec/Io data were collected over base stations in Calabar South and Calabar Municipality. The collected data were analyzed in the form of quality plots using the TEMS discovery software. Furthermore, bar charts, measures of central tendency and dispersion (mean, mode, standard deviations, standard errors of mean, kurtosis and skewness) were calculated with the use of an excel spreadsheet for a better description and understanding of Ec/Io data trends in the areas under study.

Results and Discussion

An intensive measurement was conducted to evaluate the performance of three cellular networks transmitting UMTS radio access signals over two cities in Nigeria based on generated Ec/Io data through drive test. During the measurement campaign, a total of 10958, 11075 and 11109 Ec/Io signals were obtained for MTN, 9mobile and Airtel network. These generated data were subjected to statistical analysis whose summary is given in table 1. Bar charts of mean and mode of the three networks under study are obtained in figure 1 and 2. Figure 3 to 8 are bar charts comparing the Ec/Io of the networks at various thresholds and finally, quality plots of the networks based on the drive test route are shown in Figure 9, 10 and 11 for Airtel, MTN and 9mobile network.

Table 1: Summary of Measures of Central Tendency and Dispersion

Mobile Networks	MTN	9Mobile	Airtel
Mean (dB)	-12.58	-9.35	-8.30
Mode (dB)	-13.88	-8.00	-7.45
Minimum (dB)	-24.50	-24.50	-24.50
Maximum (dB)	-1.23	0	-2.08
Kurtosis	0.12	1.43	0.09
Skewness	0.25	-0.85	-0.45
Population Std. dev (dB)	3.61	3.72	3.18
Std. error of mean (dB^2)	0.03	0.04	0.03

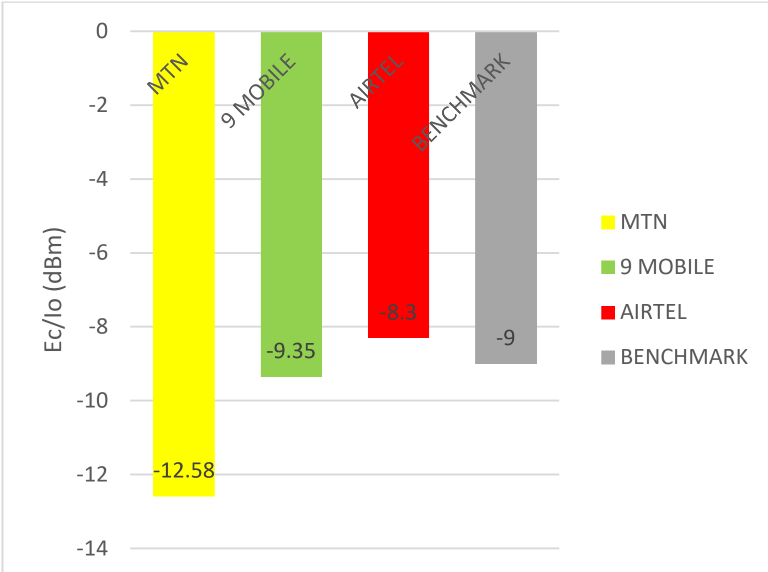

Figure 1: Mean values of Ec/Io for the networks under study

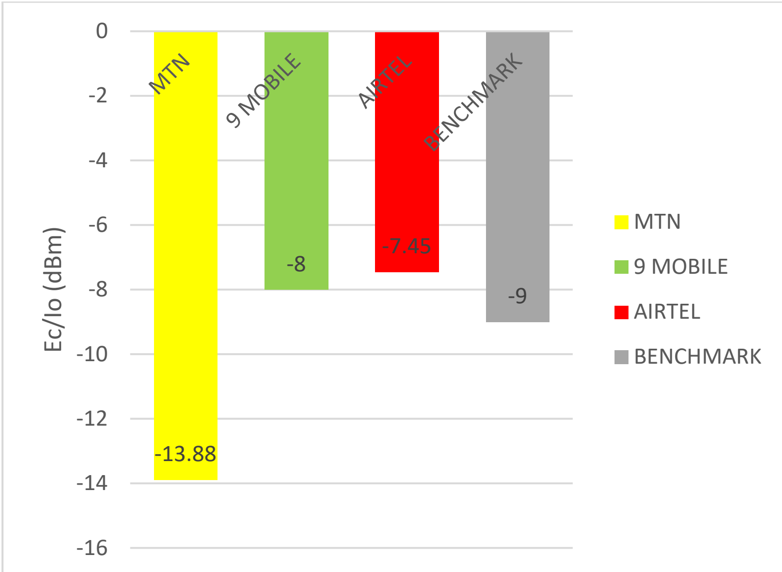

Figure 2: Most occuring values of Ec/Io for the networks under study

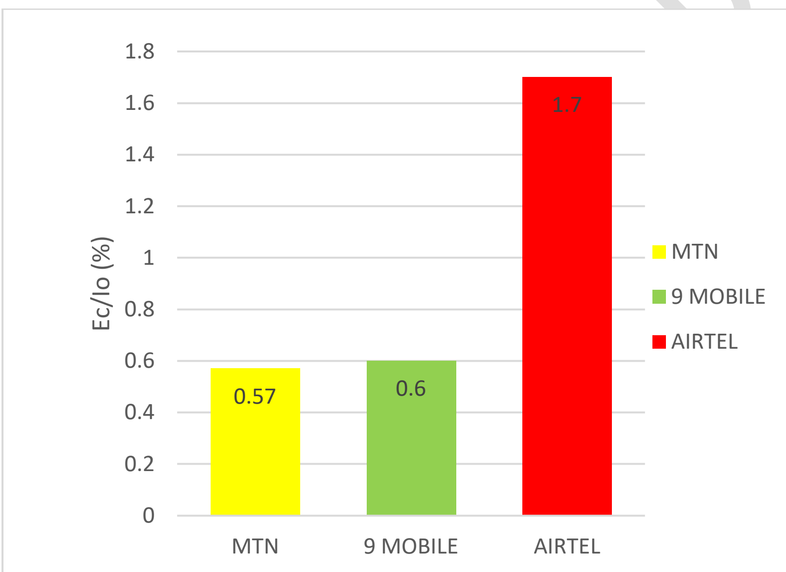

Figure 3: Percentage of Ec/Io at -3dB to 0dB for the networks under study

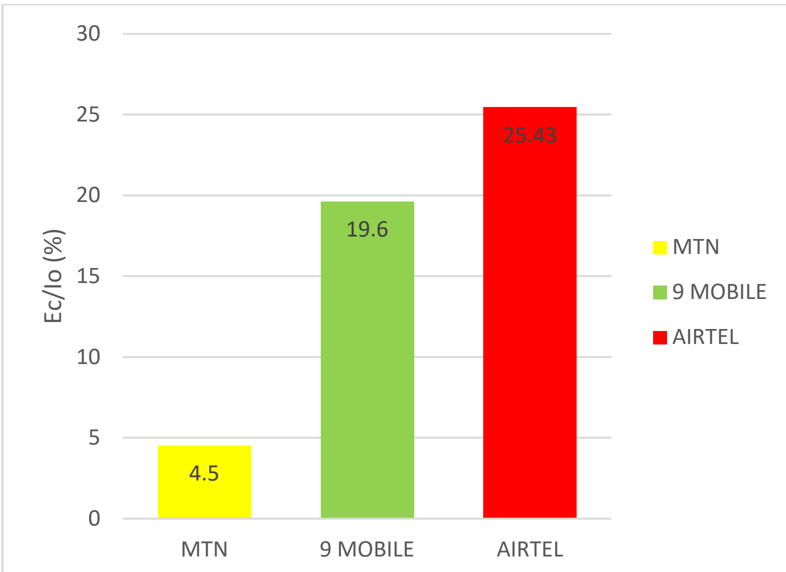

Figure 4: Percentage of Ec/Io at -6dB to -3dB for the networks under study

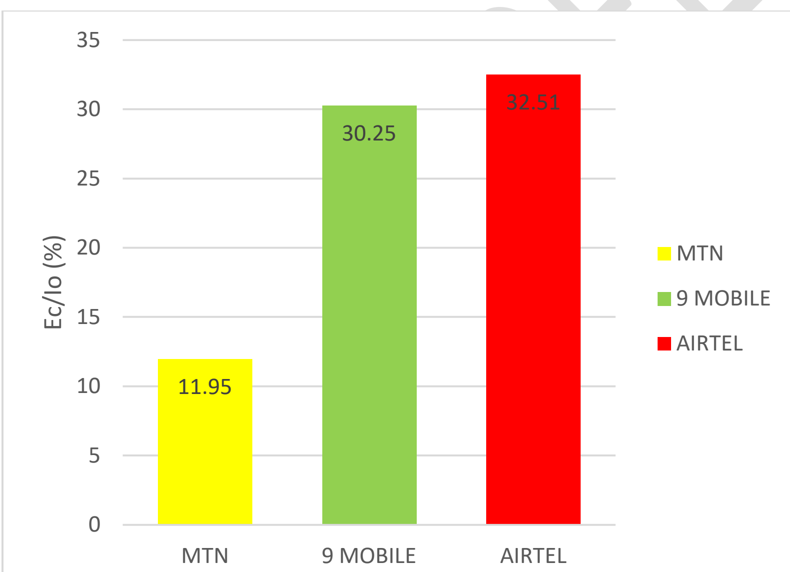

Figure 5: Percentage of Ec/Io at -9dB to -6dB for the networks under study

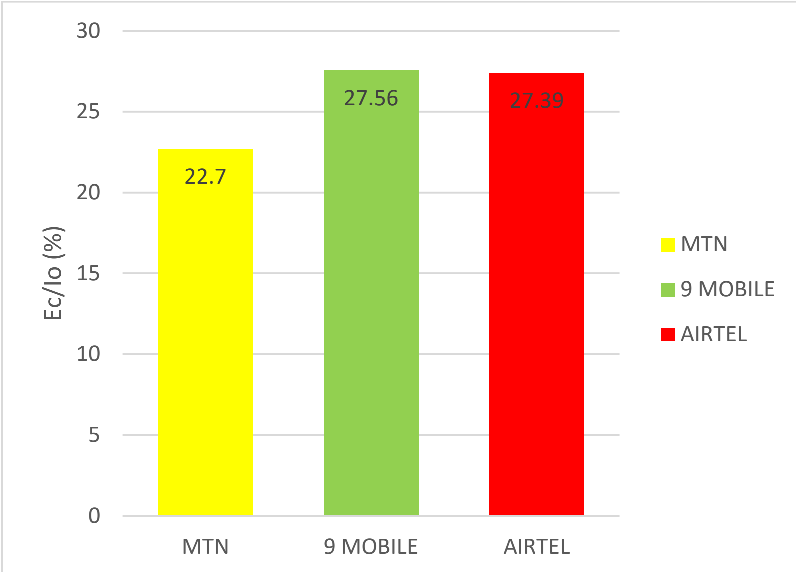

Figure 6: Percentage of Ec/Io at -12dB to -9dB for the networks under study

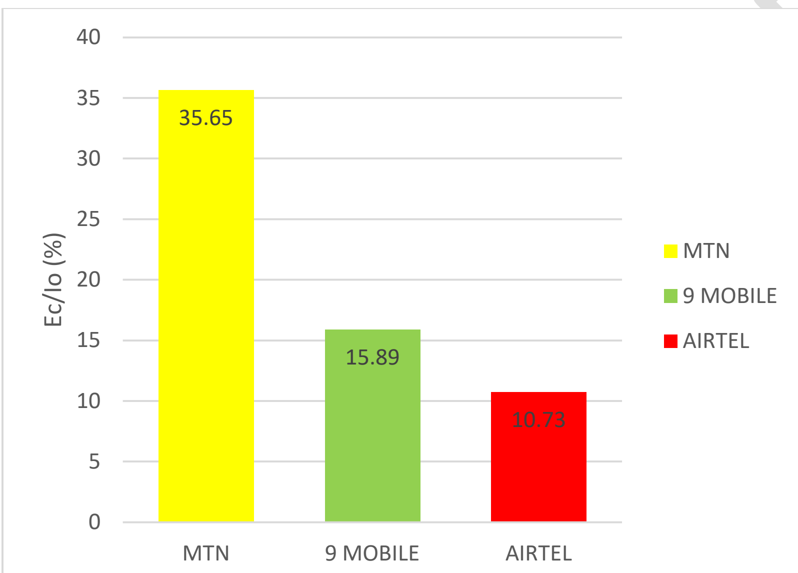

Figure 7: Percentage of Ec/Io at -15dB to -12dB for the networks under study

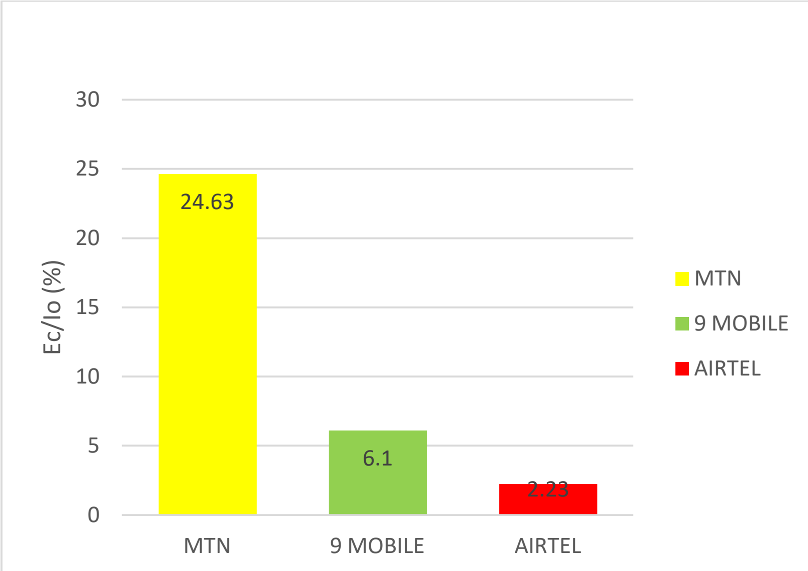

Figure 8: Percentage of Ec/Io at -40dB to -15dB for the networks under study

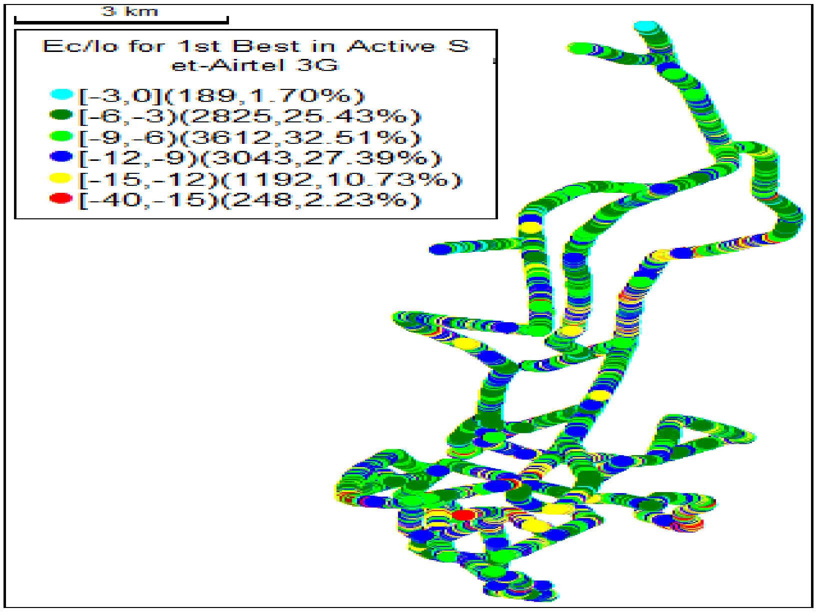

Figure 9: Received Signal Quality plots of Ec/Io for Airtel Network

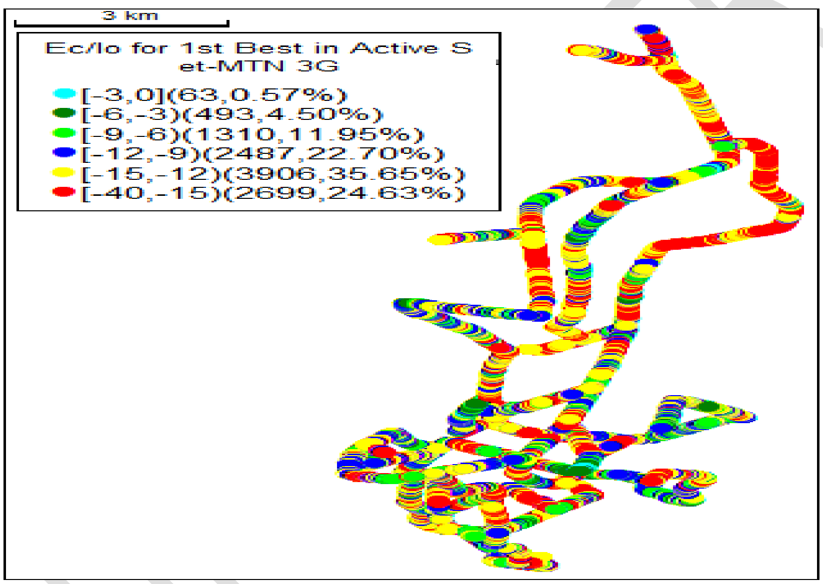

Figure 10: Received Signal Quality plots of Ec/Io for MTN Network

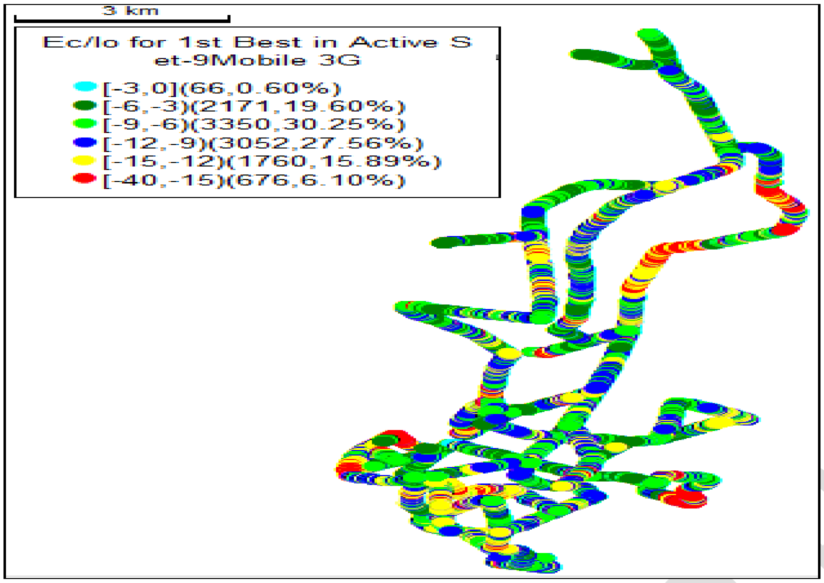

Figure 11: Received Signal Quality plots of Ec/Io for Airtel Network

In this study, mean values of -12.58dB, -9.35dB and -8.30 were obtained for MTN, 9mobile and Airtel network as shown in table 1. Comparing these values with the NCC benchmark of at least -9dB, only Airtel network had mean value within the required benchmark. To check the dispersion of the distribution around the mean, standard deviation values of 3.61, 3.72 and 3.18 were obtained as shown in table 1. This means that 68% of the measured data were ±3.61dB away from the mean value of MTN network, ±3.72dB away from the mean value of 9mobile network and ±3.18dB away from the mean value of Airtel network. Furthermore, 95% of the measured data were ±7.22dB away from the mean value of MTN network, ±7.44dB away from the mean value of 9mobile network and ±6.36dB away from the mean value of Airtel network. Finally, 99.7% of the measured data were ±10.83dB away from the mean value of MTN network, ±11.16dB away from the mean value of 9mobile network and ±9.54dB away from the mean value of Airtel network. This means that 65% of the measured data fell in the range -16.19dB to -8.97dB, -13.07dB to -5.63dB, -11.48dB to -5.12dB for MTN, 9mobile and Airtel network, 95% of the measured data fell in the range -19.80dB to -5.36dB, -16.79dB to -1.91dB, -14.66dB to -1.94dB for MTN, 9mobile and Airtel network while 99.7% of the measured data were in the range -23.41dB to -1.75dB, -20.51dB to 0dB, -17.84dB to 0dB for MTN, 9mobile and Airtel network.

In figure 2, the most occurring Ec/Io signal was measured to be -13.88dB for MTN network, -8dB for 9mobile network and -7.45dB for Airtel network. From the given data, it could be depicted that Airtel had the best Ec/Io value, followed by 9mobile network and the worst coming from MTN network. Also, in this scenario, MTN network did not meet with the regulatory standard of at least -9dB.

Figure 3 gives a picture of data values in the range -3dB to 0dB for the three networks. 0.57%, 0.60% and 1.70% of the measured data fell into this category for MTN, 9mobile and Airtel network. This means that only 63, 66 and 189 samples in the 10958, 11075 and 11109 distributions were in this category. In this region, network quality was excellent and the subscribers were remarkably satisfied In the Ec/Io plot, this region is denoted by a cyan colour, as shown in figure 9 to 11.

In figure 4, data values in the range -6dB to -3dB is displayed for the three networks investigated. 493, 2171, 2825 samples of the distribution, depicting 4.5%, 19.6% and 25.43% of 10958, 11075, and 11109 measured data for MTN, 9mobile and Airtel network. In the Ec/Io plots of figure 9 to 11, this region is denoted in dark green. The subscribers are very satisfied since the signal quality is very good.

In figure 5, MTN, 9mobile and Airtel network had data values 1310, 3350 and 3612 in the -9dB to -6dB range, representing 11.95%, 30.25% and 32.51% of the distribution respectively. In the Ec/Io plot, this region is denoted in light-green colour and subscribers were satisfied because they had good signal quality.

In figures 6 and 7, data samples in the ranges -12dB to -9dB and -15dB to -12dB are presented with 22.7%, 27.56%, 27.39% and 35.65%, 15.89%, 10.73% data samples, representing 2487, 3052, 3043 and 3906, 1760, 1192 of the entire distribution for MTN, 9mobile and Airtel network. These regions in the Ec/Io plots are denoted in blue and yellow colour. In this region, subscribers are dissatisfied as it is characterized by fair coverage with moderate interference. In figure 8, data samples 2699, 676 and 248 representing 24.63%, 6.10% and 2.23% of the entire data for MTN, 9mobile and Airtel network is presented. This region is denoted by a red colour and the subscribers are very dissatisfied as a result of very high interference due to poor signal quality.

In considering the shape of the distribution, we calculated skewness and kurtosis for the distribution. MTN, 9mobile and Airtel network were seen to have excess kurtosis of 0.12, 1.43 and 0.09. This shows that the data distribution in MTN and Airtel network were slightly leptokurtic while that of 9mobile network was moderately leptokurtic. Again, MTN, 9mobile and Airtel network had skewness values 0.25, -0.85 and -0.45. This means that the data distribution for MTN network was approximately symmetric while data distribution for 9mobile and Airtel network were moderately skewed.

Finally, to estimate the efficiency, accuracy and consistency of the measured data, standard error of the various data were calculated. Low values of 0.03, 0.04 and 0.04 were obtained, showing that the data used in this study were precise and not falsified.

Conclusion

Performance evaluation of UMTS radio access signals over two cities in Nigeria has been conducted, taking the Ec/Io as the key performance indicator in consideration. Result shows that 59.64%, 50.45% and 17.02% of the drive test route for Airtel, 9mobile and MTN network had good signal quality and met with the Nigerian telecommunication regulatory benchmark of at least -9dB for Ec/Io. Also, 40.36%, 49.55% and 82.98% of the drive test area for Airtel, 9mobile and MTN network fell below the regulatory benchmark. Though Airtel is adjudged the best, followed by 9mobile network, MTN network was adjudged being the worst. Drive test samples and quality plots in the drive test route shows that during this period of study, the signal qualities, in general, were poor in major routes of both cities as the subscribers experienced dropped calls, blocked calls, handover failures and poor data services due to interference. The mobile network operators are advised to build new base stations and visit the existing ones for optimization of their networks.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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