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# Measurement-based Statistical Method for Estimating and Verifying Signal Coverage and Coverage Probability in Urban Microcells

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***Abstract: Customer's complaints and concerns about radio signal coverage at their home are important trigger to performance relevant drive test in the relevant area to observe the coverage quality. In this paper, statistical approach has been employed to assess the quality of the radio coverage and outage probability based on measured radio signals in an established UMTS network, operational in Ikoyi, a typical urban microcell in Nigerian environment. The results shows that the quality of radio signals at the cell edge is very poor in locations 2 and 4, as they recorded poor coverage probability performance of 89.25% and 81.72% and high outage probability performance of 10.74% and 18.28% respectively. It is also observed that the smaller the fade margin, the higher the outage probability and the lower the coverage reliability. This implies that the smaller the fade margin, the smaller the received signal strength at the MS and the more likely outage events. Hence, sufficient signal strength is needed at the mobile terminals at locations 2 and 4 in order to achieve the outage probability and coverage reliability required to effectively operate cellular communication networks.***

***Keywords: Radio signal coverage, fade margin, coverage probability reliability, outage probability performance, urban microcell***

## I. INTRODUCTION

In recent years, the acceptance and usage of smart phones and other personal mobile devices have become more widespread, which requires the cellular communication networks to provide high quality connections with good coverage.

The fundamental concept of modern wireless communication networks is a cell. A cell can defined as geographic area within which mobile users can communicate with a particular base station (BS) (see figure 1). The BS of the cell is the physical location of some of the equipment needed to operate the wireless network, such as antennas, GPS timing systems, cell towers, etc. The idea of cellular layout is to allow efficient use of bandwidth: in GSM systems, for instance, each cell is allocated a group of frequency bands which is completely different from the group allocated to the neighboring cells [1]. The combinations of these cells is what provide a radio coverage over a large geographical area of the entire network

The coverage area of each cell varies in sizes - macro, micro, pico, femto, nano and umbrella cells; each which are usually implemented according to different environment and configuration. Macro cells can be regarded as cells where the BS antenna is installed on a mast or a building above average rooftop level [2].The BS range of a macro cell is generally 100 meters to some few kilometers. Micro cells are cells whose antenna height is under average rooftop level; the BS range of a micro cell is generally 100 meters to 1000 meters and they are typically used in urban areas. Pico cells are small cells whose BS range of a Pico cells are generally less than 100 meters; they are mainly used indoors and airports. Femto cells are cells designed for use in homes, office areas or small business environments; the BS range typically covers small areas of tens of meters. Nano cells are cells usually mounted on walls, in vehicles or outdoor weatherproof enclosure. Umbrella cells are used to cover shadowed regions of smaller cells and fill in gaps in coverage between those cells [2].

The minimum Quality of Service (QoS) within a cell is achieved when the received signal power has a certain level in at least 90%-95% of the coverage area, and this QoS parameter is referred to as the coverage reliability [3]. The coverage area of a cell is simply the area where the radiated signal is covered or does not fall under the receiver sensitivity of the mobiles. A MS is said to be in coverage, if the signal at the mobile terminal from the BS is sufficient to place and maintain a call. The receiver sensitivity is given by the minimum signal level where a mobile station (MS) is still able to operate effectively.

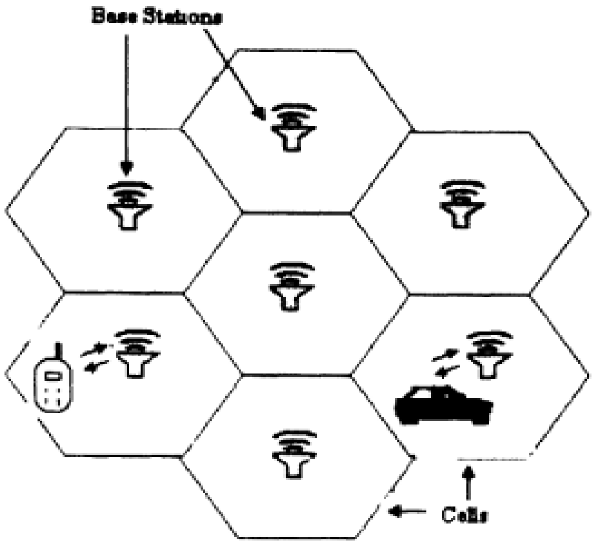


**Figure 4: A typical cellular scenario ([4])**

The most used measures of the coverage reliability in cellular networks are cell edge reliability and cell area reliability [5]. Cell edge reliability refers to the probability that the RF signal strength measured on a circular contour at the cell edge will meet or exceed a desired quality threshold. Whereas, cell area reliability is the probability that RF signal will meet or exceed the quality threshold after integrating the contour probability over the entire area of the cell (i.e., across all of the contours of the cell, including the cell edge). Thus, Signal strength level measurements at the mobile terminal must be taken into consideration while designing a new network or optimizing an existing network in order to provide an efficient and reliable coverage area.

In this paper, frequency-based statistical analysis approach was employed to assess the quality of the radio coverage and outage probability based on measured radio signals in an established UMTS network, deployed in a typical urban microcell in Nigerian environment.

## II. PROBLEM STATEMENT

Generally, in wireless communication networks, the transmission environment can vary greatly as conditions evolve over time. This leads to the variation in the received radio signals caused by propagation factors, not only due to changes in the distance between the transmitter and the receiver, but also to shadowing and multipath fading. Shadowing occurs when a topographical elements and other structures such as tall buildings and tress in the transmission path between the transmitter and receiver obscures the main signal path between the transmitter and the receiver. Such topographical elements attenuate signal power through absorption, reflection, scattering, and diffraction; when the attenuation is very strong, the signal is drop.

The increasing rate of call drops, especially in urban and metro areas, can also be attributed to these propagation factors on signal behavior such as reflections and multipath, diffraction and shadowing, building and vehicle penetration, propagation of signal over water, propagation of signal over vegetation (foliage loss) and fading of the signal. In [7], more than 50% of the reasons for dropped calls/network failures in a cell, especially in urban and metro areas, have be attributed to these propagation factors.

Specifically, Operator A whose Telecom network was used as a case study in this paper is one independent, middle range communication company that has been providing wireless mobile service from more than14 years. It is one of nation’s leading Telecom Company which was lunched with a reputation of providing good and efficient service. Specifically, Operator A launched GSM/UMTS mobile services in May, 1999 for the first time in Nigeria. The operator’s network is expanded all over the country and it covers almost all the major cities as well as suburban and rural areas. The customers‟ rate of subscription to Operator’s A telecom network is almost greater than a double every year. With the increase of the subscriber base, customers‟ complain has also increased. Poor network coverage, frequent call drop and unsatisfactory customer care support are the common issues faced by the subscribers [6], [7]. As a result, customer's dissatisfaction is increasing and complains against the network are also increasing, which in turn leads to low customers loyalty and high churn rate. In fact, presently, Operator A is having a public pressure to fulfill the demand of a prepaid mobile which is popular throughout the country.

Thus, customer's complaints and concerns about radio signal coverage at their home are important trigger to performance relevant drive test in the relevant area to observe the coverage quality. Information about radio coverage is essential for network planning, network optimization and radio resource parameter optimization, as well as backend network management activities, such as network dimensioning, PAPEX/OPEX planning and marketing [8].

Moreover, it is very for very important for telecom operators to be aware of the radio coverage and quality their networks provide for effective for network planning and performance optimization. This can only be achieved by carrying out drive test periodically in order to update their understanding of the radio coverage levels their networks provide. This kind of drive test is also performed on a regular basis by a third party (the end users) in particular, for benchmarking telecom operators.

However, how to carry out such a periodic drive test in urban terrain where there are always vehicular traffic jams, with busy streets all day long is the real challenge.

## III. MATERIALS AND METHODS

### A. *Theoretical Framework*

Providing adequate signal coverage of the target area or at the cell edge is of paramount importance for proper functioning of wireless cellular networks.

In typical cellular network environments, the variations in the received signal strength as measured at different receivers' locations from the same transmitter are random and independent due to obstacles between the transmitter and receiver that attenuate signal power through absorption, reflection, scattering, and diffraction.This type of variation in the signal strength is called shadowing and is usually formulated as log-normally distributed over the ensemble of typical locals [9]. Shadowing creates holes in coverage areas and results in poor coverage and poor service quality in different places. When the attenuation is strong, the signal is blocked.The log-normal received signal strength, *Pr* at distance *d* from the transmitter can be described by [10]:

$$P(r) = P_0 - 10\beta \log\left(\frac{d}{d_0}\right) + Xr \quad (1)$$

where $P_0$ is the reference power measured at a distance of d, do is the reference distance, ß is the path-loss exponent, and *Xr* represents a normal random variable with zero mean and standard deviation, σ.

The probability density function (PDF) of the received signal's envelope affected by shadowing follows lognormal distribution that can be written in the following mathematical form [11]:

$$P(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)2}{2\sigma 2}\right) \quad (2)$$

where μ and σ are mean and standard deviation of the shadowed component of the received signal, respectively. Typically, σ in dB ranges from 4 dB to 12 dB in outdoor environments [12], and $x$ is the signal strength measured value. The probability that $x$ exceeds the threshold, $x_o$ at a given radius r is given by

$$P_o(r) = P[x \geq x_o] = \int_{xo}^{\infty} p(x)dx \quad (3)$$

By integrating the probability density function from $x_o$ to ∞, the edge reliability results is

$$P_o(r) = \frac{1}{2}\left(1 + erfc\left(\frac{\mu - x_o}{\sigma\sqrt{2}}\right)\right) \quad (4)$$

where $\mathrm{FM} = \mu - x_o$ defines the fade margin and r is the cell radius.Here, FM is excess or additional margin for compensating signal variation levels at the receiver due to shadowing fading. This is to maintain the signal strength level above the target level at the input of the receiver according to the reliability required from the system.Equation (4) expresses cell edge reliability and it is defined as the probability that the received signal strength measured on a circular contour at the cell edge will exceed or meet a desired quality threshold.

### B. *Outage Probability Model*

Outage probability is another important parameter for performance evaluation of cellular communication networks. An outage occurs when the signal fading component is larger than FM. The outage probability of the cell is defined as the percentage of area within the cell that does not meet its minimum signal strength requirement, $x_o$ and it is expressed as [13]:

$$P_{out}\left(\frac{FM}{\sigma}\right) = \frac{1}{2}\left(erfc\left(\frac{FM}{\sqrt{2}\sigma}\right)\right) \quad (5)$$

Equation (4) is related to equation (5) by:

$$P_{out}\left(\frac{FM}{\sigma}\right) = 1 - P_o(r) \quad (6)$$

### *C. Study Locations, Measurement and Methods*

The quality of communication links is a function of many variables including location, distance, direction and time [14][15]. Here, seven cell site locations, namely location 1, 2, 3, 4, 5, 6 and 7 were randomly chosen for this study and depended on the accessibility of the testing to a particular location.

### *D. Investigated Environment*

This research was carried out in Ikoyi, Lagos Nigeria. Ikoyi lies to the northeast of Obalende and adjoins Lagos Island to the West, and the edge of the Lagos Lagoon; its geographical coordinates are within latitude $6^o$ 27' 11" North, longitude $3^o$ 26' 8" East. Ikoyi is often regarded as the most affluent neighborhood of Lagos, with most sumptuous residential facilities in Nigeria. It is also thought to have the most expensive real estate on the entire African continent. So, Ikoyi was chosen to represent a typical urban region which consists of blocks densely high rise commercial buildings/human made structures. Ten main radio BSs are used to cover main parts of this area. The coverage and quality test perform is limited to outdoor environment. The areas the drive test covers are along the main strength roads of the studied area.

Past study reveals that determining the propagation of a city requires taking measurement at various high and low environment or taking exhaustive measurement round the city to cover all the possible terrain conditions [16-18]. In this study, the focus is on the first approach.

### *E. Measurement Campaign*

Measurements were conducted with Drive test tools that could generate calls automatically and uniformly within the cellular network of study.The testing process started with selection of the cell site locations of the network where the tests need to be performed, and the drive testing path. In this study, Drive test was performed to assess signal strength levels from a moving subscribers' point of view. The tools consisted of a Vehicle, Test terminal, Test cable, Laptop, Mobile handset, Power inverter, Socket, Compass, Global Positioning System GPS, and MapInfo digital maps. The Mobile handset and the laptop were equipped with TEMS Drive Test software for data collection.The compass helps to determine the various azimuth angles of the BS transmitters. Average height of BS antenna is about 30 – 45 meters above ground level, with comparatively same transmit power. In all the study locations, BS was equipped three sectored antennas with inbuilt features, which enables them to radiate in three directions at 1800MHz. Location of the BS antenna was a parameter for site selection.

With the aid of testing Sony Ericson mobile handset running on the TEMS software mode, calls were initiated at each test point until it is established and the RxLev (receivedlevel) based on field strengthinformation displayed on the MSterminal were read along the selected routes which cover main roads, public access and hot spot areas. The RXLev is the parameter that determines the received signal strength (RSS) at the MS terminal and it is one of the most significant radio signal parameters of radio coverage that can be measured forUMTSperformance verification and evaluation (see table 1). Seven locations, namely location 1, 2, 3, 4, 5, 6 and 7 were randomly chosen for this study and depended on the accessibility of the testing to a particular location. At each data location, the testing vehicle was displaced slowly at a distance of 5m-10m before data being collected. By moving the testing vehicle slowly between 5m-10m, the fast fading effect is eliminated from the collected data [19]; meaning that the collected measured data only show signal attenuation loss and shadow fading components. All measurements were taken in the mobile active mode and in three sectors of each base station. This was to ensure that the mobile phone was in constant touch with the base station.

## IV. RESULTS AND DISCUSSION

For better evaluation of measured data, frequency table 2 was produced according to the classified signal ranges as in table 1. Also, using these tables, measured signal data range between medium-good is considered acceptable while signal range between weak-insufficient is considered unacceptable for all the study locations, with the analysis given in fig.2.As can be seen in figure 3, Locations 1, 3, 4, 5, 6, 7 recorded 100% acceptable radio signals. On the other hand, locations 4 and 2 recorded the worst unacceptable signal performance of 79% and 93% respectively.

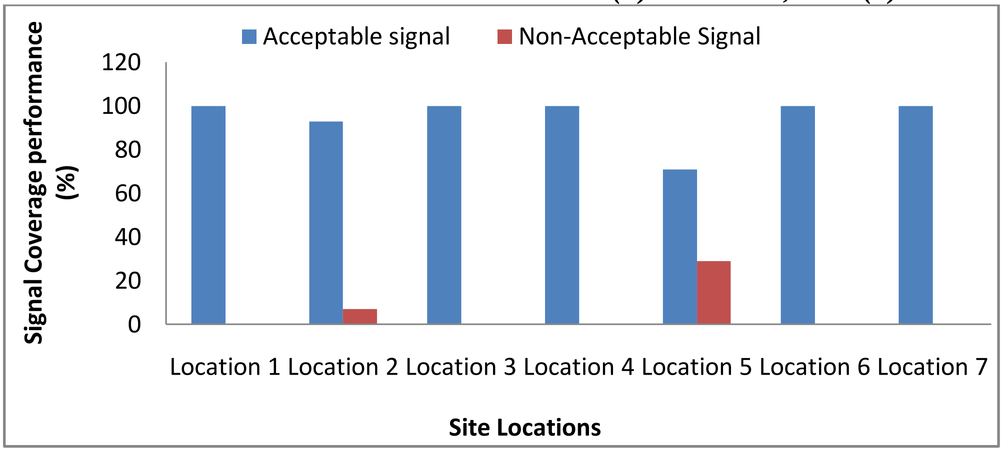


**Figure 2: A summary of signal performance using frequency tables**

**Table 1: Legend of Received Signal Strength (RSS) at the MS terminal (source: [20])**

| Signal Strength Value | Signal Strength range (dBm) | Classification (Coverage) |
|---|---|---|
| 0…6,99 | 101 or lower | Insufficient |
| 7…11,99 | -100 ... -91 | Weak |
| 12…16,99 | 90… -81 | medium |
| 17…31,99 | -80 or higher | Good |
| 99 | - | Unknown |

**Table 2: Classification by Frequency tables**

| | Location 1 | | Location 2 | | Location 3 | | Location 5 | | Location 6 | | Location 6 | | Location 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Valid | Freq | % | Freq | % | Freq | % | Freq | % | Freq | % | Freq | % | Freq | % |
| Good | 83 | 73 | 72 | 53 | 32 | 30 | 8 | 6 | 105 | 91 | 116 | 98 | 87 | 85 |
| medium | 29 | 27 | 46 | 40 | 72 | 70 | 81 | 65 | 11 | 10 | 5 | 2 | 16 | 1 |
| Weak | 0 | 0 | 8 | 7 | 0 | 0 | 35 | 29 | 0 | 0 | 0 | 0 | 0 | 0 |

Descriptive statistics histograms of measured signal coverage data with fitted lognormal or Gaussian distribution in each study locations is shown Figs.3-9 and summarized in table 3. In evaluating the minimum field strength, a value of -95 dBm was observed in locations 2 and 4 which are lower than the reference of -92 dBm for perfect reception at the end user mobile terminal. Notice the variation of field strength per measurement point and this can be attributed to shadow fading and attenuation present around the test sites.

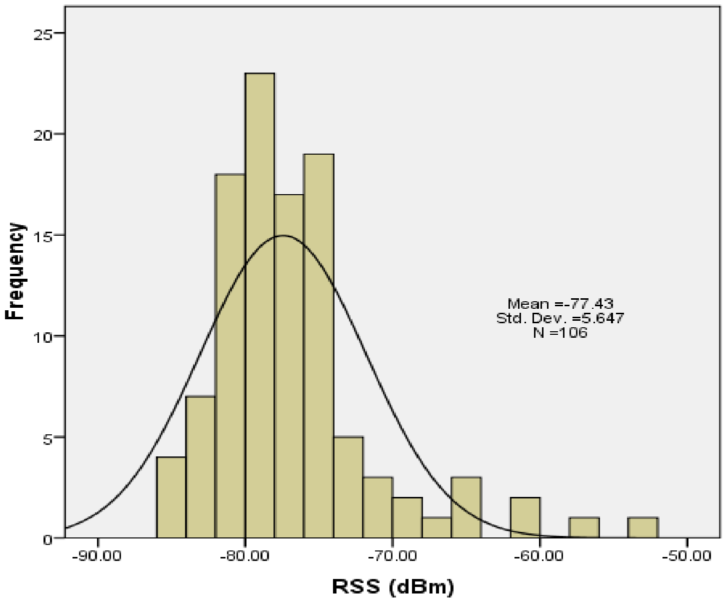


**Fig.3: Histogram of observed RSS (dBm) versus normal distribution with μ =-77.43 and σ =5.65 in location1**

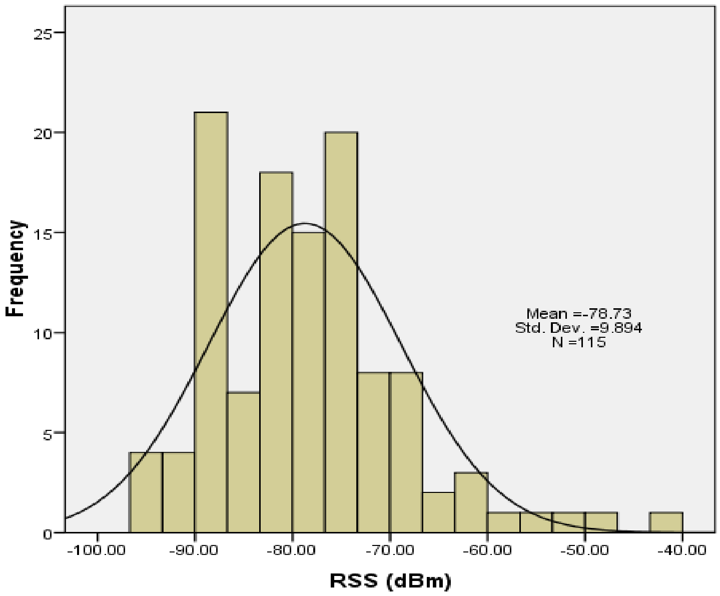


**Fig. 4: Histogram of observed RSS (dBm) versus normal distribution with μ =-78.73 and σ =9.89 in location 2**

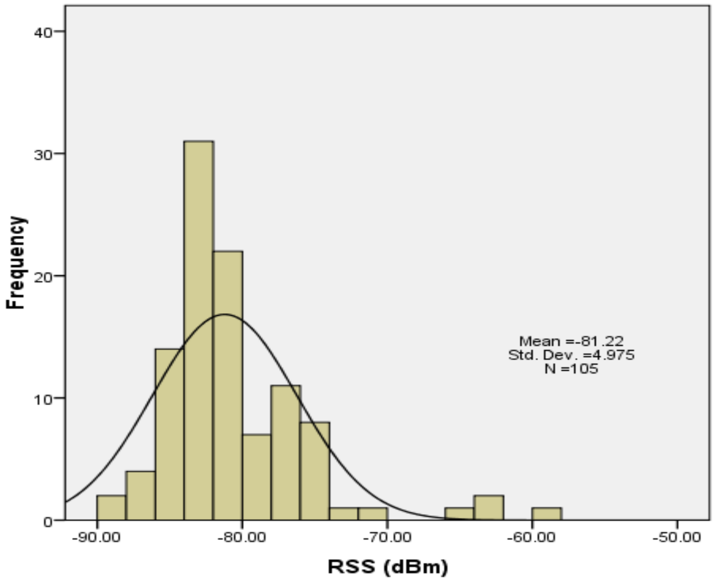


**Fig.5: Histogram of observed RSS (dBm) versus normal distribution with μ =-81.22 and σ =4.97 in location 3**

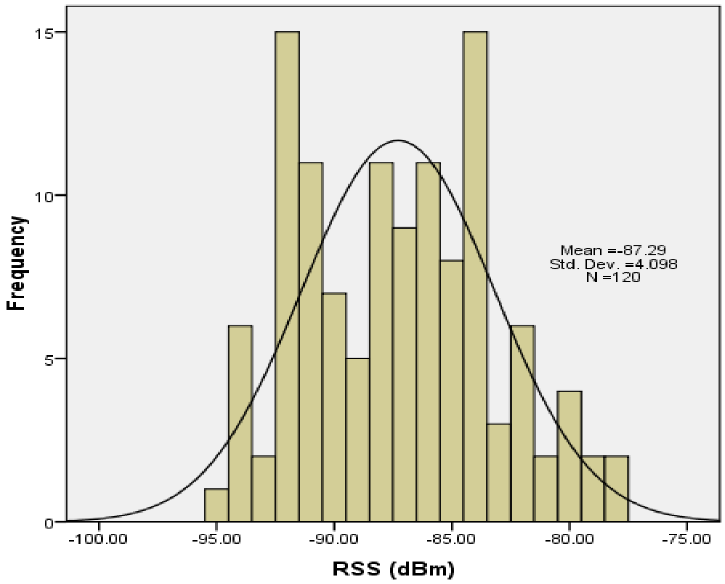


**Fig. 6: Histogram of observed RSS (dBm) versus normal distribution with μ =-87.29 and σ = 4.09 in location 4**

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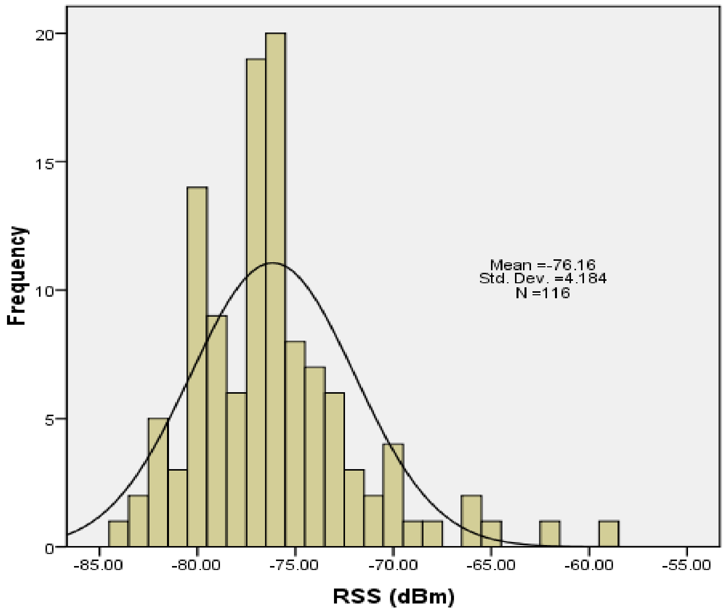


**Fig. 7: Histogram of observed RSS (dBm) versus normal distribution with μ =-76.16 and σ =4.18 in location 5**

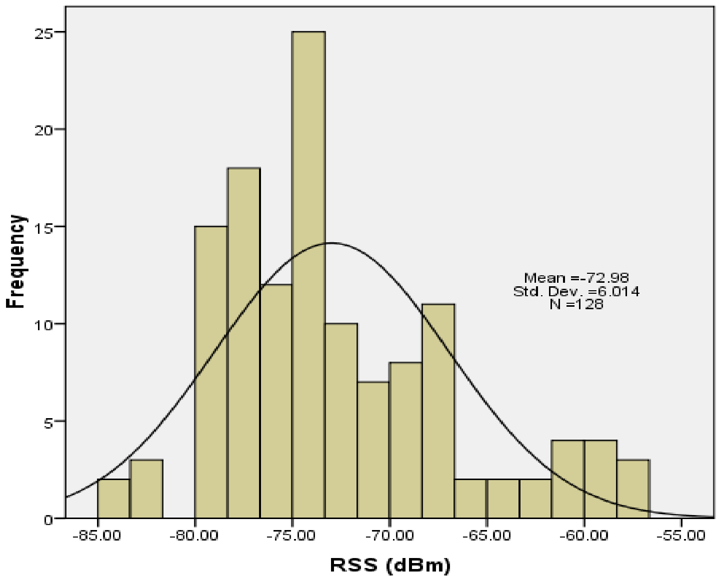


**Fig.8: Histogram of observed RSS (dBm) versus normal distribution with μ =-72.96 and σ = 6.01 in location 6**

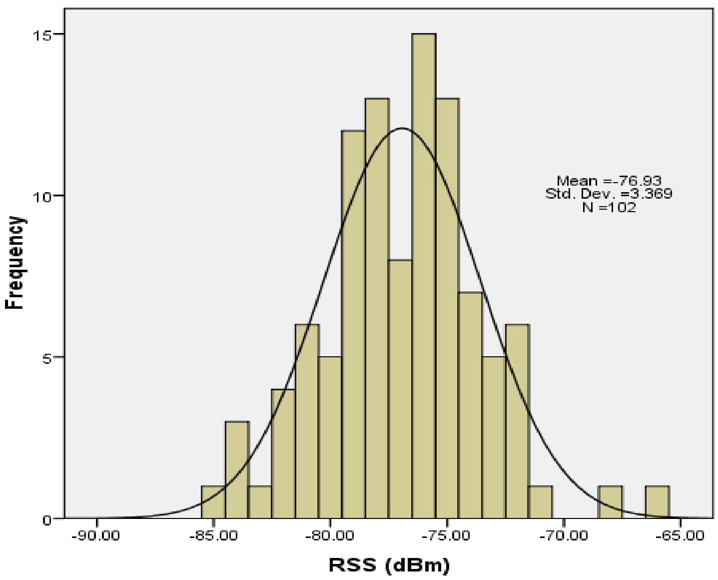


**Fig.9: Histogram of observed RSS (dBm) versus normal distribution with μ =-76.93 and σ =3.36 in location 7**

 

The data for the study as captured at different locations designated as location 1, location 2…location 7. Shown in table 2are calculated mean, the minimum and the maximum signal strength levels at each location. The results in table shows that, mean signal strengths in each investigated locations are above the reference level of -93dBm for perfect reception, except in locations 2 and 4.

Standard deviations, fade margin, coverage reliability and outage probability were calculated and presented in table 3. It is observed that the standard deviation is ranged between 3.37 dB and 9.89 dB. Figure 10 depicts a plot of standard deviation with mean signal levels at each measurement locations. It basically represents how the signal strength level values spread (log-normally distributed around the mean value) in each measurement locations. So, the standard deviation would vary by clutter type in different signal propagation environment. Assuming a dense urban terrain, clutter type would more often than not have a higher standard deviation levels than the suburban or open clutter types. This is due to the highly obstructive properties encountered in an urban environment that in turn will produce higher standard deviation to mean signal strengths than that experienced in anopen area.

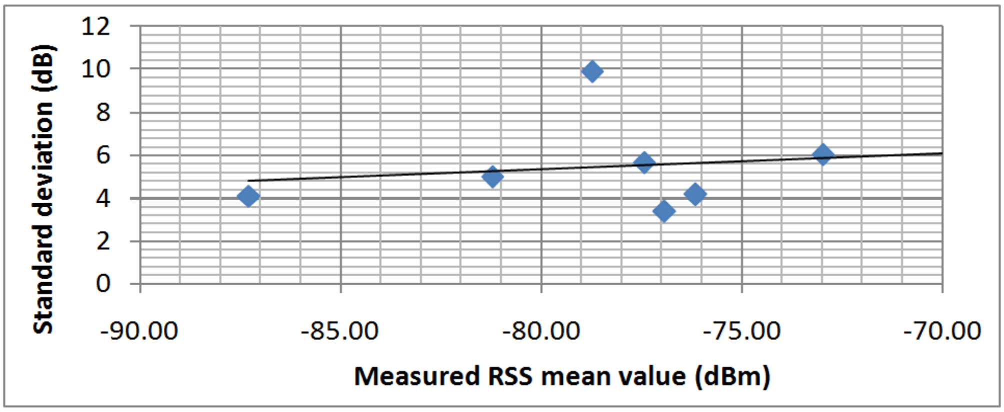


**Fig.10: Standard deviation as function of mean signal strength**

An outage probability of ≤ 5% and coverage probability of ≥ 90%-95% is usually allowed in wireless networks. Table 3 shows the results of the coverage probability and outage probability for the various cell locations considered in this paper. It is evident in table 4 that the quality of radio signals of mobiles at the cell edgeis very poor in locations 2 and 4, as they recorded poor coverage probability performanceof 89.25% and 81.72% and hence high outage probability performance of 10.74% and 18.28% respectively.It is also observed in table 3that the smaller the fade margin, the higher the outage probability and the lower the coverage reliability(see figure 11). This implies that the smaller the fade margin, the smaller the received signal strength at the MS and the more likely outage events.Hence, sufficient signal strength is needed at the mobile terminal in order to achieve the outage probability and coverage reliability required to effectively operate cellular communication networks. In other words, the MS must have a good signal level to access the network. Therefore, for effective network design, the knowledge of these parameters is needful to aid system designers in link budget calculation. This type ofknowledge can also help to guide the network designersto determine the required fading margin

**Table 3: Received Signal Strength Statistics in each Study Locations**

| Parameter | Location 1 | Location 2 | Location 3 | Location 4 | Location 5 | Location 6 | Location 7 |
|---|---|---|---|---|---|---|---|
| Mean received signal strength (dBm) | -77.43 | -78.73 | -81.22 | -87.29 | -76.16 | -72.98 | -76.93 |
| Minimum received signal strength (dBm) | -86.0 | -95.0 | -89.0 | -95.0 | -84.0 | -84.0 | -85.0 |
| Maximum received signal strength (dBm) | -54.0 | -43.0 | -60.0 | -78.0 | -59.0 | -57.0 | -66.0 |
| N | 106 | 115 | 105 | 120 | 116 | 128 | 102 |

**Table 4: Coverage Reliability/ Outage Probability Parameters in each Study Locations**

| Parameter | Location 1 | Location 2 | Location 3 | Location 4 | Location 5 | Location 6 | Location 7 |
|---|---|---|---|---|---|---|---|
| Standard. Deviation | 5.65 | 9.89 | 4.97 | 4.10 | 4.18 | 6.01 | 3.37 |
| Fade Margin | 13.57 | 12.27 | 9.78 | 3.71 | 14.84 | 18.02 | 14.07 |

 

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cell edge Reliability | 0.99 | 0.89 | 0.97 | 0.81 | 0.99 | 0.99 | 0.99 |
| Outage Probability | 8.14E-03 | 1.07E-01 | 2.46 E-02 | 1.18 E-01 | 1.94 E-04 | 1.37 E-03 | 1.49E-05 |

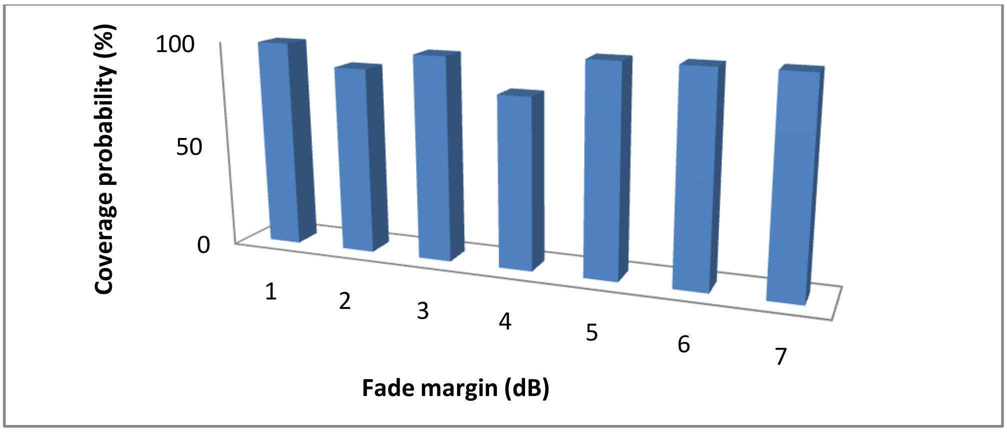


**Fig.12: Coverage Probability versus fade margin**

## V. CONCLUSION

Network coverage problems remain one of important issues for the mobile cellular communication service providers. The study was carried out to identify some problematic BS site locations using statistical descriptive analysis in an established UMTS network, operational in Ikoyi area of Lagos State, Nigerian The results shows that the quality of radio signals at the cell edge in locations 2 and 4 is weak, as they recorded poor coverage probability performance of 89.25% and 81.72% and high outage probability performance of 10.74% and 18.28% respectively. It is also observed that the smaller the fade margin, the higher the outage probability and the lower the coverage reliability. These are locations within the coverage area or at the outskirts of the coverage area where the propagated signal is not good enough for perfect reception at the mobile terminal. Therefore, the GSM network operator should take action to deploy new cell or adjust the antenna tilts/azimuth of existing cells, among others things for adequate reception signal coverage at the mobile terminals in the specific cell locations.

In future work, we will look out to evaluate the entire cell area reliability, which is is often more useful than edge reliability.

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