ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

PATH LOSS PROPAGATION MODEL PREDICTION FOR GSM MOBILE NETWORK PLANNING IN KADUNA TOWN

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ABSTRACT

Accurate characterization of radio communication channel through key parameters and a mathematical model is important for predicting signal coverage, channel efficiency and capacity. Outdoor path loss propagation modeling plays a fundamental role in planning and designing of every radio communication link. The ultimate goal in this work is to develop a model that can help in planning better global system for mobile communication (GSM) network and to address complain of poor quality of service by the subscribers, within Kaduna town. Outdoor measurements were conducted to precision at 900MHz, the overall average path loss detected were; 93.70, 88.50, 98.27 and 103.15 dB for MTN, Glo, Airtel, and Etisalat networks, respectively. The differences may be attributed to the nature of the environment or the location or antenna heights of the respective base stations (BSs), or weather fluctuations. However, the variance of these average values lies between 10 to 20dB, which is within the acceptable range. The empirical model developed from Log-normal shadowing model, which has a unique advantage of accounting for shadowing effects that may be caused by varying degree of clutter between transmitter and receiver, may be used in planning and optimization of GSM service within Kaduna town.

KEYWORDS: Base Station, GSM, Path loss, Propagation models

INTRODUCTION

Global system for mobile communication (GSM) became the most active industry in our country Nigeria, since its inception in 2004. The number of service providers keeps on increasing, but the quality of services, provided is still low. Several factors may be attributed to the poor quality of service. Therefore, there is need to identify these factors and propose solutions, through research. A survey carried out in 2011, through interview with cross section of GSM subscribers within the investigation area, indicate that some of the difficulties they experienced are; frequent call drops, network busy, poor inter and intra connectivity, cross talk interference during conversation and signal fading, among others. Factors that affect GSM signal strength within an area may include; rainfall, snow, fog, reflection, diffraction, free space loss, vegetation and other geographical features [1][2].

Propagation path loss greatly impact on the quality of service of a mobile communication system. Accurate determination of propagation path loss leads to development of efficient design and operation of high quality and high capacity network [3]. There are many such different propagation path loss models developed over the past, to predict coverage. However, no matter how accurate such models are, cannot be generalized to different environments. In general, the suitability of such models differs for different environments. So the best bet is to perform site-specific measurements and develop a practical model suitable for a given area [4]. This work aimed at predicting propagation path loss model for four GSM service providers within Kaduna metropolis.

This work is also organized in the following manner; theoretical modeling of the propagation path loss, followed by empirical model prediction, then result, discussion and conclusions.

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SOME STANDARD PROPAGATION PATH LOSS MODELS

Planning is the key to implementing designs, and also setting up of wireless communication systems. A number of propagation models, both theoretical and empirical, are available to predict path loss over different types of terrain. However, this article discusses only Free space, Hata and Log-normal shadowing propagation models, among others.

Free-space Propagation Model

In free space, the wave is not reflected or absorbed. Ideal propagation implies equal radiation in all directions from the radiating source and propagation to an infinite distance with no degradation [5]. Free space attenuation increases as the frequency, f (in MHz) goes up for a given unit distance, d (in km). To calculate free space path loss (PL_{FS}), it is assumed that both transmitting and receiving antennas are isotropic and the following equation is used:

$$PL_{FS}(dB) = 32.5 + 20\log_{10}(d) + 20\log_{10}(f) \qquad (1)$$

Hata's Propagation Model

Hata model [5][6] is an empirical formulation of graphical path loss data provided by Okumura's Model. It gives prediction of the median path loss. The standard formula for urban area is:

$$P_{L(urban)}(dB) = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_b) - a(h_m) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) \qquad (2)$$

Where f_c is in MHz and within the range of 150MHz to 1500MHz, h_b is the Base Station (BS) effective transmitter antenna height in meter ranging from 30m to 200m, h_m is the effective mobile receiver antenna height in meter ranging from 1m to 10m, d is the distance between Base Station (BS) and Mobile Station (MS) in kilometers, $a(h_m)$ is the correction factor for effective MS antenna height which is a function of the size of the coverage area. For a small to medium size city, it is given by:

$$a(h_m) = (1.1\log_{10}(f_c) - 0.7)\,h_m - (1.56\log_{10}(f_c) - 0.8 \qquad (3)$$

To obtain the path loss in suburban area, equation (2) is therefore modified as

$$P_{L(suburban)}(dB) = P_{L(urban)} - 2(\log_{10}(\tfrac{f_c}{28}))^2 - 5.4 \qquad (4)$$

This prediction of Hata's model compares very closely with that of the original Okumura's model as long as the distance, d exceeds 1km. it is said to be suitable for macro cells, but not micro and Pico cells [4].

Log-Normal Shadowing Model

Generally, in terrestrial wireless communication environment, signal propagation may be characterized by such factors as path loss, shadowing and fading. Path loss has been explained as the attenuation effect on the signal as it propagates from the transmitter to the receiver. When the received signal strength gradually varies around its mean value, this phenomenon is called shadowing. While, on the other hand, fading describes the rapid fluctuation in the received signal strength due to multipath propagation.

A simple power law path loss model [5] was chosen for predicting the distance over which a reliable communication link can be established between two mobiles. A modified version of the power law path loss model is given as [6]:

$$P_L(di) = P_L(d_o) + 10n\log_{10}(d_i/d_o) + X_\delta \qquad (5)$$

Where,

$$n = \frac{P_L(d_i) - P_L(d_o)}{10\log_{10}(\frac{d_i}{d_o})} \qquad (6)$$

Where, X_δ is a Zero-Mean Gaussian distributed random variable (in dB) with standard deviation σ (in dB), which attempts to compensate for random shadowing effect that can result from clutter. Using linear regression analysis, the

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

path loss exponent, n, can be determine (in a mean square error sense) the difference between measured and predicted values of equation (5) to yield [4]:

$$n = \frac{\sum_{i=1}^{N}[P_{LM}(d_i) - P_{LP}(d_i)]}{\sum_{i=1}^{N} 10\log_{10}(d_i/d_o)} \quad (7)$$

Where P_{LM} (d_i) represent measured path loss and P_{LP} (d_i) represent predicted path loss at any distance d_i, N is the number of measured data or sample points. The standard deviation is equally minimized as:

$$\sigma = \sqrt{\frac{1}{N}\sum[P_{LM}(d_i) - P_{LP}(d_i)]^2} \quad (8)$$

Also, Received power P_r in (dBm), at any distance D from the transmitter, with transmit power P_t in (dBm) is given by:

$$P_r(dBm) = P_t(dBm) - P_L(dB) \quad (9)$$

INVESTIGATION AREA AND METHOD OF MEASUREMENT

Kaduna, the capital city of Kaduna state, North-western Nigeria is a typical urban city characterized by sites located near tall and moderate, closely built residential, commercials, factories, offices, etc, with communication towers and high density of both human and vehicle traffic. The measurement environment consist of GSM base stations operated by MTN, GlobaCom, Airtel and Etisalat at 900MHz with the average base station antenna height of 35m, transmitter power is within the average of 30w. A spectrum analyzer (AAronia AG HF 2025E Spectran), interfaced with a PC was used to measure the Received Signal Strength (RSS) in dBm, while meter wheel equipment was used for distance measurement.

The areas tested include; Kabala Costain, Haying Banki, Unguwan Mu'azu and Hayin Dan-mani, all within the metropolitan city. To ensure wider and applicability of the result, data was collected over different seasons of the year, considering climatic changes.

Result and Analysis

For path loss determination and to be able to derived and optimize an empirical model suitable and valid to the area under investigation, field experimental data of RSS were gathered. Table 1 shows the average values of the measured RSS and corresponding values of the measured and the predicted path losses for specific distances, 100m ≤ di ≤ 1000m obtained using equation (10):

$$P_L(d_i) = 10\log_{10}[\frac{P_t}{P_r}]\ (dB) \quad (10)$$

Recall, Path Loss Exponent indicates the rate at which path loss increase with distance. Path loss can therefore be estimated or predicted using data obtained from field measurements, which are substituted in to equation (11) [7]:

$$P_L(d_i) = P_L(d_o) + 10n\log_{10}(\frac{d_i}{d_o})\ (dB) \quad (11)$$

Where, $P_L(d_o)$ is the reference path loss measured at the reference distance d_o, n, is the path loss exponent (usually empirically determine by field measurement). It is important to select a free space reference distance that is appropriate for the propagation environment. In large coverage cellular systems, 1 km reference distance is commonly used whereas in microcellular systems, much smaller distances (such as 100m or 1m) are used [8]. The reference distance should always be in the far field of the antenna so that near field effect do not alter the reference path loss [7][8][9]. In this work we desire to chose d_o = 100 m as a reference. The path loss exponent n, then can be derived statistically through the application of linear regression analysis techniques by minimizing in a mean square sense, the difference between the measured and predicted path loss. Refer to equation (7), the expression $P_{LM}(di) - P_{LP}(di)$ is an error term with respect to n, and the sum of the mean squared error, e(n), is therefore expressed as:

$$e(n) = \sum_{i=1}^{N}[P_{LM}(d_i) - P_{LP}(d_i)]^2 \quad (12)$$

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

The value of n, which minimizes the Mean Square Error (MSE), is obtained by equating the derivative of equation (12) to zero, and solving for n:

$$\frac{\partial e(n)}{\partial n} = 0 \tag{13}$$

In Table 1, P_{LM} (di) is computed from equation (10) and P_{LP} (di) was computed from equation (11), using P_t = 30w and P_r = Antilog (RSS/10).

Table 1: Measured and Predicted Path losses

Distance (m)	Average RSS (dBm)	Measured P_{LM}(di)dB	Predicted P_{LP}(di) dB	$P_{LM}(d_i) - P_{LP}(d_i)$	$[P_{LM}(d_i) - P_{LP}(d_i)]^2$
100	−54	69	69	0	0
200	−58	73	$69 + 3.01n$	$4 - 3.01n$	$16 - 24.08n + 9.0601n^2$
300	−63	78	$69 + 4.77n$	$9 - 4.77n$	$81 - 85.86n + 22.7527n^2$
400	−65	80	$69 + 6.02n$	$11 - 6.02n$	$121 - 132.44n + 36.7529n^2$
500	−69	84	$69 + 6.99n$	$15 - 6.99n$	$225 - 209.70n + 48.8601n^2$
600	−75	90	$69 + 7.78n$	$21 - 7.78n$	$441 - 326.76n + 60.5284n^2$
700	−72	87	$69 + 8.45n$	$18 - 8.45n$	$324 - 304.20n + 71.4025n^2$
800	−80	95	$69 + 9.03n$	$26 - 9.03n$	$676 - 469.56n + 81.5409n^2$
900	−86	101	$69 + 9.54n$	$32 - 9.54n$	$1024 - 610.56n + 91.0116n^2$
1000	−95	110	$69 + 10.00n$	$41 - 10.00n$	$1681 - 820.00n + 100.0000n^2$

From Table 1, an expression for the MSE can be obtained using equation (12);

$e(n) = \sum_{i=1}^{N}[P_{LM}(d_i) - P_{LP}(d_i)]^2 = 521.5969n^2 - 2983.16n + 4589 = 0$ Applying equation (13);

$\frac{\partial e(n)}{\partial n} = 2(521.5969n) - 2983.16 = 0$

Hence, $n = \frac{2983.16}{1042.7938} = \mathbf{2.9}$

Therefore, the standard deviation, σ (dB), about a mean value, can be determine from equation (8):

$\sigma = \sqrt{\frac{1}{N}\sum[P_{LM}(d_i) - P_{LP}(d_i)]^2} = \sqrt{\frac{1}{10}[521.5969(2.9)^2 - 2983.16(2.9) + 4589]}$

$\therefore\ \sigma = \sqrt{32.2786} = \mathbf{5.68}$

Substituting for $P_L(d_o), n$ and adding σ to compensate for the error into equation (11), will lead to development of a modified Log-normal shadowing empirical model for the investigated area, given by;

$$P_L(d_i) = 69 + 10(2.9)\log_{10}(\frac{d_i}{d_o}) + 5.68\ (dB)$$

Therefore the resultant path loss model for Kaduna urban environment is;

$$P_L(d_i) = 75 + 29\log_{10}(\frac{d_i}{d_o})\ (dB)$$

$$P_L(d) = 75 + 29\log_{10}(D)\ (dB) \tag{14}$$

Furthermore, the measurement and analysis in this work leading to determination of $P_L(d_o), n\ and\ \sigma$ for the case of MTN has been repeated for the cases of Glo, Airtel and Etisalat under the same operating conditions. These values are as presented in Table 2.

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
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Table 2: Comparing Path loss Exponent, Standard Deviation and Reference Path loss

Parameter	MTN	Glo	Airtel	Etisalat
n	2.9	2.7	3.1	3.3
$\sigma(dB)$	5.68	5.79	5.93	6.50
$P_L(d_o)\ dB$	69	65	72	75

These values are substituted back into equation (11), and the modified Log-normal shadowing model for the respective networks becomes:

$$P_{L(MTN)}(d_i) = 69 + 10(2.9)\log_{10}(\frac{d_i}{d_o}) + 5.68\ (dB) \quad (15)$$

$$P_{L(Glo)}(d_i) = 65 + 10(2.7)\log_{10}(\frac{d_i}{d_o}) + 5.79\ (dB) \quad (16)$$

$$P_{L(Airtel)}(d_i) = 72 + 10(3.1)\log_{10}(\frac{d_i}{d_o}) + 5.93\ (dB) \quad (17)$$

$$P_{L(Etisalat)}(d_i) = 75 + 10(3.3)\log_{10}(\frac{d_i}{d_o}) + 6.50\ (dB) \quad (18)$$

Hence, equations (15) – (18) are used to generate the data of Table 3 which compares the measured path loss for the four GSM operators. Table 3 is further simulated as depicted in Figs. 1 and 2.

Table 3: Comparing Measured Path losses from the Proposed Model

Distance (m)	Path loss MTN	Path loss Glo	Path loss Airtel	Path loss Etisalat
100	74.68	70.79	77.93	81.90
200	83.41	78.92	87.26	91.43
300	88.52	83.67	92.72	97.25
400	92.14	87.05	96.59	101.37
500	94.95	89.66	99.60	104.57
600	97.25	91.80	102.05	107.18
700	99.19	93.61	104.13	109.39
800	100.87	95.17	105.93	111.30
900	102.35	96.55	107.51	112.99
1000	103.68	97.79	108.93	114.50
Overall average	**93.70**	**88.50**	**98.27**	**103.15**

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Scientific Journal Impact Factor: 3.449
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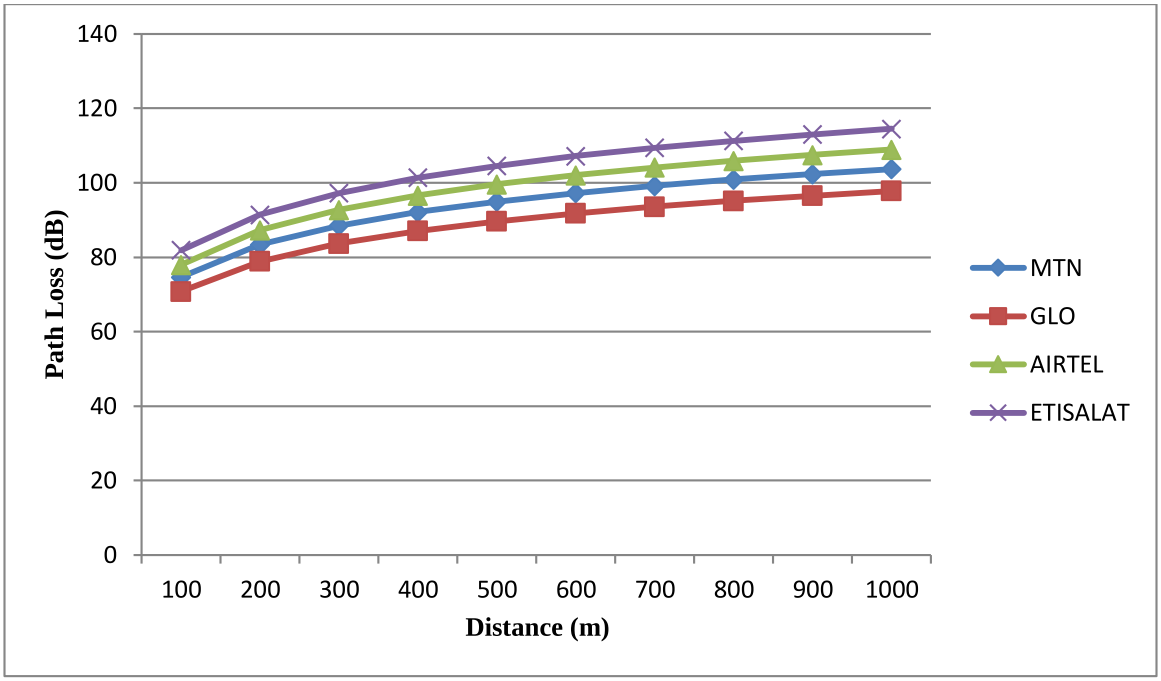

Figure 1: Measured path loss against distance

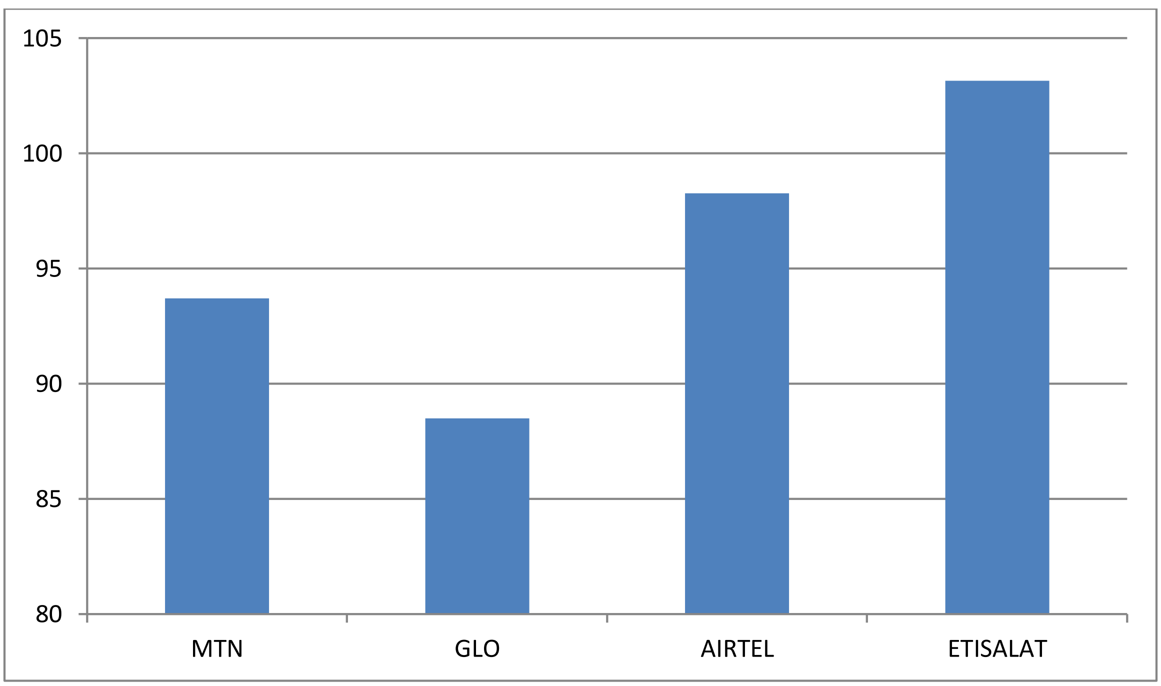

Figure 2: Average measured propagation path loss

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

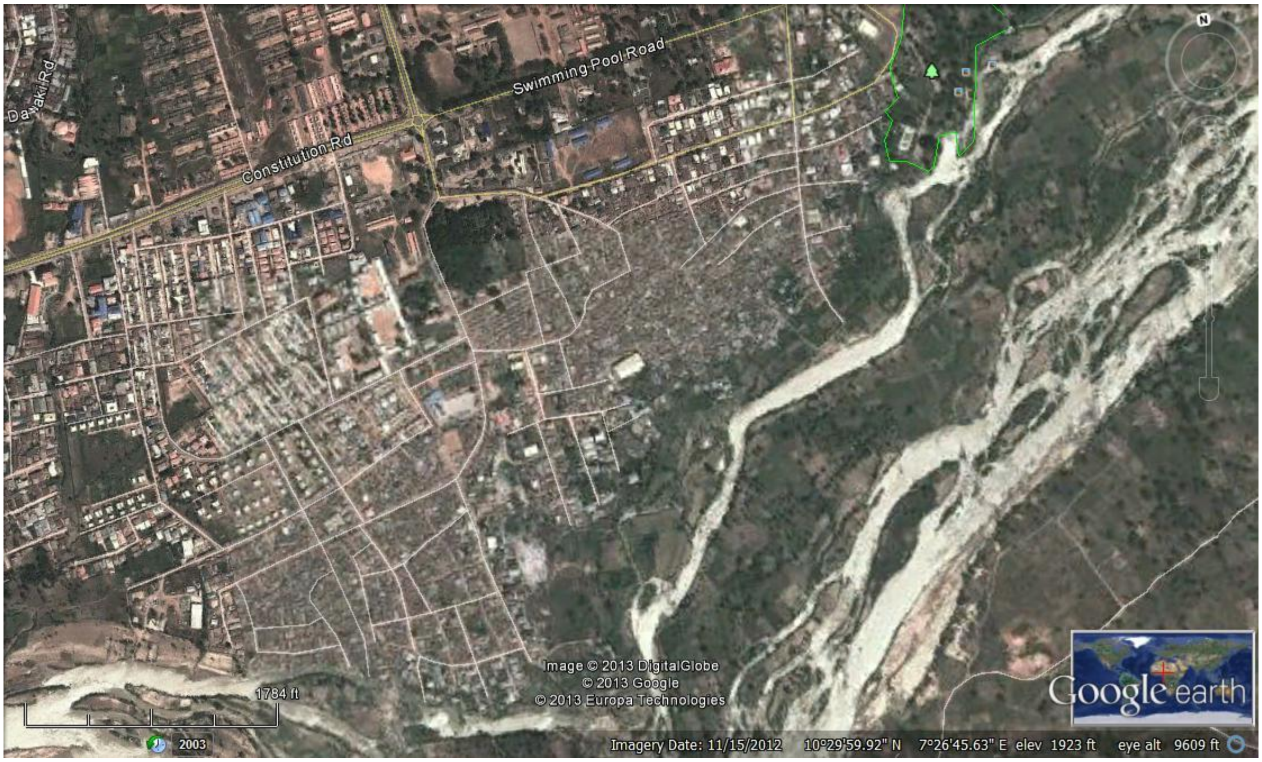

Figure 3: Google earth map showing measurement area at Kabala Costain

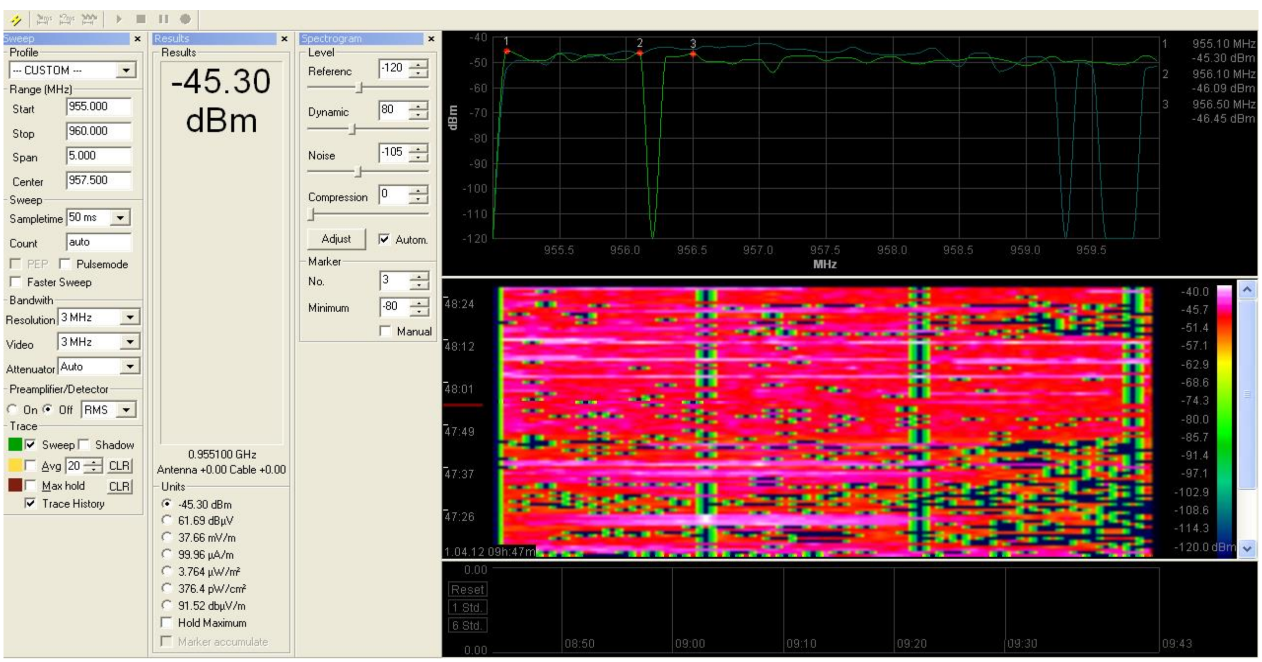

Figure 4: Some sample of measurement taken

ISSN: 2277-9655
Scientific Journal Impact Factor: 3.449
(ISRA), Impact Factor: 2.114

Fig. 1 presents the path loss against distance for all the four GSM operators. From the plot, result clearly shows that path loss for all the GSM operators increases at slightly different rates over the measured distance, although its values vary from each operator. This may be attributed to the location of the BS or height of the transmitting antenna and the compatibility of the environment, trees and other features in the investigation area. While Fig. 2 presents the overall average amount of propagation path loss measured for the GSM operators. Etisalat has the highest path loss greater than that of Airtel, MTN and Glo with 4.88dB, 9.45dB and 14.65dB respectively; over a maximum distance of 1km. Fig. 3 shows the Google earth map of one of the measured areas (Kabala Costain) and Fig. 4 is the print screen of the sampled measured data.

CONCLUSION

The ultimate goal in this work is to develop an empirical propagation model than can help in planning and optimizing global system for mobile communication (GSM) networks and to address complains of poor quality of GSM network services in Kaduna town, by the customers. The overall average path losses predicted were 93.70, 88.50, 98.27 and 103.15dB for MTN, Glo. The variance of these average values lies between 10 to 20 dB, which is within the acceptable range, since the acceptable range lies between $1 \leq P_L \leq 20dB$ [10]. It is therefore evident that the modified model developed from Log-normal shadowing model can help in GSM network planning and optimization of the investigated environment.

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