International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 10 Issue 7 Series II || July 2021 || PP 47-55

Outdoor Environment Gsm Network Path loss Measurements and Forecasting at Nsukka Urban Using Regression Analysis Model

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ABSTRACT: *Currently, the growth of mobile communication subscribers in the country is at an alarming rate without a corresponding increase in network performance. This necessitated the call for a high-quality network to serve the customers better. There exist already different models proposed for different types of terrain to predict path loss, but none of these models adapt effectively to the environment for which it was not developed for. These models have been developed in other places but to the best of our knowledge and at the time of this research, no author has done so in Nsuuka urban. In this work, Regression analysis was used to model and forecast path loss for a global system for mobile communication (GSM) networks at Nsukka urban. The received signal strength of the GSM network operating at 1800 MHz obtained in the field was used to model the path loss. The projected path loss model was executed using the R programming language 3.6.3 version. The regression model to forecast GSM network path loss at various transmitter-receiver distances in the area is given in(31).The predicted model has limited prediction errors and it outperforms other standard empirical path loss models compared.*

KEYWORDS -*Base stations, Electromagnetic wave, GSM, path loss, received signal strength*

Date of Submission: 18-07-2021 Date of Acceptance: 03-08-2021

I. INTRODUCTION

There is usually signal level attenuation in an environment during radio wave propagation resulting from the interaction between the radio wave and the environment thereby limiting the coverage areas [1]. In network planning, path loss prediction for the coverage area, frequency assignment, and degree of interference is the most concern for network engineers during this planning process [2]. Therefore, a more formidable path loss model capable of predicting signal attenuation in every environment is required to address the recent challenges faced by GSM service providers in the country.Hence, to actualize this aim, signal strength field measurement for live data must be adopted to provide an efficient and dependable coverage area. In planning and designing a wireless network, the network engineers either make use of an existing propagation model or develop their prediction model for the area [3].

There are challenges in which customers encounter while making use of their mobile phones which include continual dropped calls, poor network inter and intra connectivity, echoes, network busy, and network bottleneck. These confrontations in the network have been a very big problem to Nigeria's telecommunication industry to handle. Mobile telecommunication networks (MTN) adopted so many strategies to overcome the challenges [4]. All these problems are associated with improper analysis and inadequate measurements before implementation of a network in a particular area. The propagation environment contributes immensely in determining the behavior of the wireless network in a given area [5]. The signal levels of networks are usually attenuated during signal propagation by the interaction between the wave and environment which results in insufficient coverage by the network.

As the number of GSM subscribers in the country increases, there is a need for more base stations with appropriate path loss model prediction as a measure to resolve some of the poor network performance. Hence, comprehensive information of physical radio channels in an area is very important for an efficient and reliable cellular design using the network signal strength obtained from field measurement as a source of data for the propagation model. The performance of a wireless communication system in any environment depends fundamentally on the design and transmission strategy of the network [6], in which the environment plays a key role in the performance and reliability of the network. Hence, it has become absolutely important to model different environments to accurately forecast path loss to improve the quality of the network in the area.

In this paper, a new path loss model was developed using statistical principles to account for signal attenuation in GSM networks in Nsukka urban to remedy the challenges the network is currently facing in the area. To achieve this aim, field measurements for real live data were carried out on GSM signal strength and path loss which were employed in the development of the model. The model will be useful for the design and deployment of future mobile wireless communication and also help to correct some of the anomalies associated with the present GSM networks in the area.

The power received in a wireless communication system is largely less than the original transmitted power because the electromagnetic wave is subjected to various propagation mechanisms as the wave signals propagate through space. The power reduction is heavily influenced by environmental factors [7]. In any particular environment, three main propagation mechanisms regulate radio propagation which includes reflection, diffraction, and scattering [8] as demonstrated in Fig. 1.

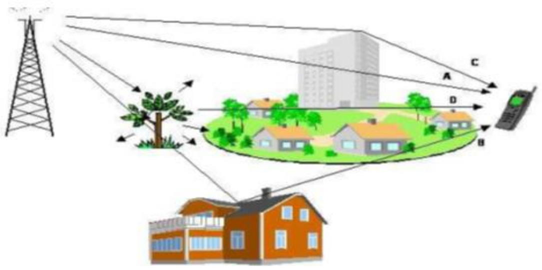

Fig. 1. Principles govern the electromagnetic wave propagation mechanism [9].

In Fig.1, "A" represents free space, "B" is reflection, "C" symbolizes diffraction, while "D" is scattering.

The principles governing the electromagnetic wave propagation mechanism in an environment are as follows.

1. REFLECTION

This occurs when obstacles of larger dimensions than the wavelength of a propagating wave obstruct the path of the propagating electromagnetic wave thereby reducing the signal strength of the wave. The reflections from the surface of the earth and other man-made structures produce reflected waves that may interfere at the receiver section as demonstrated above.

2. DIFFRACTION

In wireless networks, diffraction occurs as a result of obstruction by a sharp edge surface between the transmitter and the receiver. This is also referred to as the diversion of electromagnetic wave signals which happen when the signal bumps the edge of an obstacle. The angle of the incident, the amplitude, the geometry of the object, and the phase of the signal are responsible for the diffraction of an electromagnetic wave.

3. SCATTERING

Scattering occurs when the medium through which the wave is traveling contains objects which are much smaller than the wavelength of the electromagnetic wave. It also refers to any process by which wave propagation is altered by a particle or group of particles thereby causing the signal energy to spread out in all directions.

II. REVIEW OF PATH LOSS MODELS

There are different models proposed for different types of terrain to predict path loss, but none of these models can work perfectively in an environment in which it was not built for [10]. These models are commonly categorized into three main types which include empirical, deterministic, and stochastic models. Empirical models are kind of model that predict new models using an existing equation which is based on inspection and measurements alone. Deterministic models apply the principles governing electromagnetic wave propagation in determining the received signal power at a particular location while stochastic models mock up the surroundings as a sequence of indiscriminate variables.

1. FREE SPACE PATH LOSS MODEL (FSPL)

When there is no reflection or absorption of a propagating wave in an environment the propagating wave is said to be operating in free space [11]. The model is used to forecast the received signal strength when there is no obstruction in the communication channel. An ideal propagation is assumed in a free space propagation model with an isotropic antenna radiating energy uniformly in all paths to an unrestricted distance. The power received in free space receiver antenna is expressed as [12]:

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2} \quad (1)$$

Where P_t is the power transmitted, P_r is the obtained power, d represents separation distance, G_t symbolizes the transmitter antenna gain, G_r is the receiver antenna gain, while λ is the wavelength. The quantity of P_t and P_r should be stated in the same unit while G_t and G_r are dimensionless quantities. The effective power broad-casted from the source is different from the obtained power. The disparity between the two powers is termed path loss which is heavily influenced by so many factors. Path loss is measured in decibel (dB) and also calculated as [12], [13]:

$$P_{\text{loss}}(\text{dB}) = (p_t) - (p_r) = 10\log_{10}\left(\frac{p_t}{p_r}\right) \tag{2}$$

Therefore, when the value of (1) is substituted into (2), the path loss becomes:

$$P\text{loss}(\text{dB}) = -10\log_{10}\left[\frac{GtGr\lambda^2}{(4\pi d)^2}\right] \tag{3}$$

But, G_t=G_r=1 for Omnidirectional and unity gain antenna, replacing the values of G_t and G_r in (3) the path loss becomes:

$$P\text{loss}(\text{dB}) = -10\log_{10}\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \tag{4}$$

After simplifying (4), the path loss value will be represented as:

$$P_{\text{loss}}(\text{dB}) = 20\log_{10}(4\pi) + 20\log_{10}(d) - 20\log_{10}(\lambda) \tag{5}$$

In which λ symbolizes the wavelength measured in kilometer. But the frequency of operation (f) is measured in megahertz; as a result, the wavelength is given as:

$$\lambda = \frac{0.3}{f} \tag{6}$$

If the value of (6) is substituted into (5) and simplified, the free space path loss becomes:

$$P_{loss}(dB) = 32.5 + 20\log_{10}(d) + 20\log_{10}(f) \tag{7}$$

Where, f=Frequency [MHz], d= Distance between transmitter and receiver [km]

2. HATA MODEL

This is a model developed by Hata which is valid from 150MHz to 1500MHz frequencies [14]. It is an empirical formulation of the graphical path loss data provided by Okumura. This model is one of the most used models for signal prediction in urban areas which is based on measured data without any analytical explanation [15]. The model predicted path loss for different types of environments. The average path loss expression for urban (LpU), suburban (LpSU), and open country (LpOC) areas are expressed as [16]:

$$L_P\text{U} = 69.55 + 26.16\log_{10}(\text{f}) - 13.82\log_{10}(\text{h}_\text{b}) - \text{a}(\text{h}_\text{m}) + (44.9 - 6.55\log_{10}(\text{h}_\text{b}))\log_{10}(\text{d}) \tag{8}$$

$$\text{a}(\text{h}_\text{m}) = (1.1\log_{10}(\text{f}) - 0.7)\text{h}_\text{m} - (1.56\log_{10}(\text{f}) - 0.8) \tag{9}$$

$$L_P\text{SU} = \text{L}_P\text{U} - 2(\log_{10}(\frac{\text{f}}{28}))^2 - 5.4 \tag{10}$$

$$L_P\text{OC} = \text{L}_P\text{U} - 4.78(\log_{10}(\frac{\text{f}}{28}))^2 - 18.33\log_{10}(\text{f}) - 40.94 \tag{11}$$

Where;

f = frequency (in MHz) from 150 MHz to 1500 MHz, d = distance (in km) between transmitter and receiver.

3. COST 231-HATA MODEL

COST-231 working committee of the European Cooperative for Scientific and Technical Research (EURO-COST) developed an extended version of the Hata model for scientific frequencies of interest [2]. The model is used in the frequency range of 1500-2000 MHz to predict the median path loss [17]. Cost 231-Hata model is a highly used model for signal attenuation prediction in the mobile wireless system [18]. For median path loss in urban areas, the expression is given as [19], [20]:

$$PL(dB) = 46.3 + 33.9\log_{10}(f) - 13.8(hb) - a(hr) + [44.9 - 6.55l\log_{10}hb]\log_{10}(d) + c \tag{12}$$

Where;

f = frequency (in MHz) from 150 MHz to 1500 MHz.

d = distance (in km) between transmitter and receiver.

c = 0 for suburban and rural environments, but 3 for an urban area while h_b and h_r is the correction factor for base station height and receiver height respectively.

The function a(hr) for urban and suburban areas are given in (13) and (14) respectively.

$$a(h_r) = 3.2(\log_{10} 11.75(h_r))^2 - 4.97 \tag{13}$$

$$a(h_r) = 1.1\log_{10}(f) - 0.75(h_r) - (1.58\log_{10}(f) - 0.8) \tag{14}$$

4. STANFORD UNIVERSITY INTERIM (SUI) MODEL

Stanford University developed Stanford University Interim (SUI) model for IEEE 802.16 which is used for frequencies above 1900 MHz [19]. The model is fitting for signal attenuation prediction in the entire three macro-cellular environments. The model is divided into three categories of terrains known as A, B, and C. Terrain A represents an area with a very densely populated region that has the highest path loss. B is a suburban environment that represents an area with moderate path loss while Terrain C has the least path loss which describes a rural or flat area.

The basic path loss formula for SUI model is described as [21]:

$$P_{Loss} = A + 10\gamma\log_{10}\left(\frac{d}{d_0}\right) X_f + X_h + S \text{ for } d > d_0 \tag{15}$$

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \tag{16}$$

$$\gamma = a - bh_t + \frac{c}{h_t} \tag{17}$$

$$X_f = 6\log_{10}\left(\frac{f}{2000}\right) \tag{18}$$

$$X_h = -10.8\log_{10}\left(\frac{h_r}{2000}\right); \text{ for terrains A and B} \tag{19}$$

$$X_h = -20\log_{10}\left(\frac{h_r}{2}\right); \text{ for terrains C} \tag{20}$$

Where; d = Link distance, d_0 =Initial distance, λ = Wavelength, f = Frequency, h_t = Transmitter height, h_r = Receiver height, γ = Path loss exponent, S is the log-normally distributed factor for shadow fading because of trees and other clutter on propagation path.

The constants a, b, and c depend on the types of terrain for SUI model, as given in Table I.

Table I: The Parameter Values of Different Terrains for SUI Model [22]

Model Parameter	Terrain A	Terrain B	Terrain C
A	4.6	4.0	3.6
bm^{-1}	0.0075	0.0065	0.005
c(M)	12.6	17.1	20

5. ECC-33 MODEL

The Electronic Communication Committee 33 model was developed by Electronic Communication Committee to predict path loss at a higher frequency greater than 3GHz [23]. This model is predicted by Electronic Communication Committee based on analysis in the 3.4 and 3.8 GHz band [21]. The path loss is calculated as [23]:

$$L_{ECC\_33} = A_{fs} + A_{bm} - G_t - G_r \tag{21}$$

Where; Afs = the free space attenuation (dB), Abm is the basic median path loss (dB), Gt is the transmitter antenna height gain factor, Gr is the receiver antenna height gain factor for medium cities.

The expressions for Afs, Abm, Gt, and Gr are defined in (22), (23), (24), and (25) respectively.

$$A_f s = 92.4 + 20\log_{10}(d) + 20\log_{10}(f_c) \tag{22}$$

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f_c) + 9.56(\log_{10}(fc))^2 \tag{23}$$

$$G_t = log_{10}\left(\frac{h_t}{200}\right)\left(13.958 + 5.8log_{10}(hr))^2\right) \tag{24}$$

$$G_r = \left(42.57 + 13.7log_{10}(f_c)\right)\left(log_{10}(h_r) - 0.585\right) \tag{25}$$

Where*f* = operating frequency (in GHz), *d* = link distance in (in km), h_t = transmitter height (in m), h_r = receiver height (in m).

III. THEORETICAL ANALYSIS

The importance of the path loss prediction model for the planning and execution of modern wireless communication networks cannot be overemphasized. Signal attenuation prediction using theoretical analysis is used to determine the optimum base location without the need for carrying out field measurement in the environment of interest. Unlike empirical models in which measurements are required for model predictions, theoretical models are established on the indispensable principles of radio wave propagation. The signal strength of the network transmitted in an environment cannot be exactly the signal strength received. The disparity that exists between the strength of the transmitted signal and the received signal is known as path loss which increases with distance. But the signal strength of the network reduces with distance [24]. The path loss increases proportionally to the square of the distance and frequency of the radio signal while the signal strength reduces proportionally to the square of the distance in an ideal free space path loss. Mathematically the free space propagation path loss is expressed as [25]:

$$FSP_{loss} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \tag{26}$$

Where the wavelength is measured in meters and the frequency of operation in hertz which are represented with λ and f respectively, and d is the path distance measured from the source, while c symbolizes the velocity of light in a space. But due to environmental factors, this formula does not hold in non-free space cases.

IV. RESEARCH METHOD

For a specific environment, carrying out field measurement in the area is very pertinent for reliable path loss model prediction. Hence, to come up with a dependable path loss model capable of forecasting signal attenuation in Nsukka urban, field measurements were conducted in the locality bi-monthly from January to December for the year, 2020. Repeated field measurements were adopted to cover all the seasons in the environment to get the actual signal behavior of the GSM network in the area to develop a reliable and formidable path loss model.

The field measurements were performed to measure the received signal strength and path loss of GSM networks operating at 1800Mhz using a set of equipment which includes spectrum analyzer, communication software, Hp laptop, global position system (GPS), uninterruptible power supply (UPS), Google earth, and a car. Aaronia communication software is installed in the HP laptop that is connected to the spectrum analyzer used for data logging. The GPS is employed to determine the distance covered in meters from the base station to the receiver at an interval of 100m up to 1000m. For appropriate identification of the BTS that is providing a particular network, net monitor software is used which provides the Location Area Code (LAC), the cell identification number (CID), the exact location of the base transceiver station, and also the reception level in dBm of different networks in the environment. Google earth helped to give information about the terrain of Nsukka urban. The UPS is used as an alternate source of power while the car is used for drive test movement in the town.

A total of four hundred (400) samples were collected from ten different routes during the field measurements at different distances. The average of all the same distances was statistically analyzed and used to develop the perfect path loss model that is capable of predicting the signal attenuation for every 1-meter change in distance in the environment.

V. PROPOSED MODEL

To forecast path loss for the GSM network at any given distance in Nsukka urban, the data collected from field measurements at a space of 100m from the base station were analyzed. For every received signal strength measured in the field the corresponding path loss is gotten using the expression in (27) [12], [26].

$$P_{loss}(d_i) = 10log\left(\frac{P_T}{P_R}\right) \ (dB) \tag{27}$$

Where $p_{loss}(d_i)$ stands for the measured path loss at a given distance while p_T and p_R signify the transmitting and received power accordingly. The measured path loss is calculated from the mean of the received signal strength gotten from field measurement as demonstrated below.

At, distance d_1 = 100m , mean power received, $P_R = -49dB_m$

Therefore, $P_R = 10^{-4.9} = 1.259x^{-05} d_B$

The transmitted power p_t is 20W, thus p_t =13.01dB

Hence, the measured path loss value in dB for the GSM network at a distance of 100m becomes:

$P_{loss}(d_1) = 10\log\left(\frac{P_T}{P_R}\right) = 10\log\left(\frac{13.01}{1.259x^{-05}}\right) = 60.14 d_B$ At the distance of 200m, the power received is -55 d_{Bm} therefore the measured path loss is:

At d_2 = 200m

Mean power received $P_R = -55 d_{Bm}$, therefore $P_R = 10^{-5.5} = 3.16x^{-6} d_B$

The measured path loss at 200m distance is: $P_{loss}(d_2) = 10\log\left(\frac{13.01}{3.16x^{-6}}\right) = 66.14 d_B$

Subsequent values were gotten using the same method of evaluation in determining the measured path loss at a different distance up to 1000m.

Statistical analysis is one of the most reliable techniques for path loss modeling [27], is employed here to model the GSM path loss in the area. Statistical regression analysis techniques help to model the relationship between two or more variables related in a nondeterministic manner. Linear regression is a predictive modeling technique that illustrates the correlation between the dependent and the independent variable on the assumption that the relationship between the variables is linear. A simple statistical linear regression model used in modeling the path loss in the considered area is given as [28]:

$$y = b_o + b_1 x + e \tag{28}$$

While *y* is the dependent variable, b_o is the intercept on the y axis, b_1 is the slope of the straight line, *x* represents the independent variable while *e* symbolizes the random error associated with y.

The least-square error estimator of the slope, b_1 of the regression line, is given as:

$$\hat{b}_1 = \frac{n\sum(x_i y_i) - (\sum x_i)(\sum y_i)}{n\sum(x_i)^2 - (\sum x_i)^2} \tag{29}$$

While the least square error estimator of the intercept b_o is given as:

$$\hat{b}_0 = \frac{\sum y_i - b_1 \sum x_i}{n} \tag{30}$$

From the analysis results, the expected change in the mean path loss in the area under study relative to 1- meter increase in transmitter-receivers separation is approximately 0.034dB, with b_0 = 58.273

Hence, the forecast or fitted path loss model for Nsukka urban is represented as:

$$P_{loss}[dB] = 58.273 + 0.034x \tag{31}$$

The separation between the transmitter and the receiver in the studied area is represented by *x*.

VI. PREDICTION ACCURACY EVALUATING METRICS

To evaluate the performance of different empirical path loss models, the metrics used are mean absolute error (MAE) and root mean square error (RMSE). The mean absolute error and root mean square error are calculated as:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|p_m - p_t\right| \tag{32}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(p_m - p_t\right)^2} \tag{33}$$

Where$N$ is the number of samples, p_m is the actual path loss while p_t is the predicted path loss.

VII. MODEL VALIDATION, RESULTS, AND DISCUSSION

The performance of this model is evaluated using results obtained from standard empirical path loss models which include Hata, COST 231–Hata, ECC-33, and SUImodels. The performance parameters, as well as the path loss values for the standard empirical models, were gotten from the simulation of the R programming language 3.6.3 version.The predicted model has also been tried in other similar environments and the outcome is very impressive.

VIII. DISCUSSION

As shown in Table II, the predicted model provides the best fit to the actual path loss with mean absolute error (MAE) 7.19dB and root mean square error (RMSE) 8.72 dB. SUI model overestimates the measured path loss and has the highest predictions followed by the ECC-33 model while the predicted models were found to be the most suitable for all the four propagation models compared followed by COST-231 Hata model.This shows that the model is statistically adequate.

Table II: Statistical Presentation of the Performance Parameters

Evaluation indicators	Hata	COST 231-Hata	SUI	ECC-33	Predicted model
MAE (dB)	28.93	24.59	52.12	36.77	7.19
RMSE (dB)	30.50	25.92	54.94	38.76	8.72

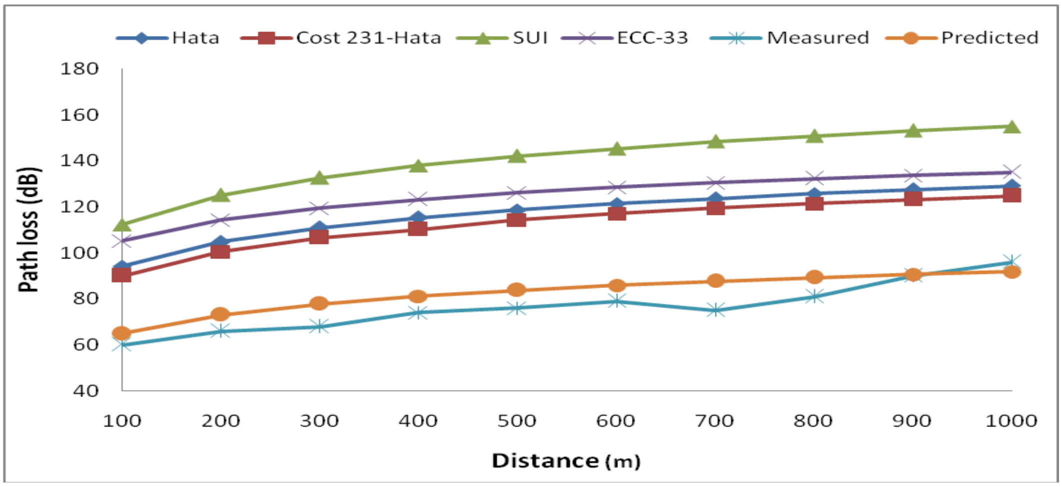

Fig. 2. A Plot Comparing Measured Path loss, Predicted Model, Hata, Cost 231-Hata, SUI, and ECC-33 standard propagation models

As shown in Fig. 2, the predicted model is found to be the most fitted among other four popular standard empirical signal attenuation models considered for the Nsukka Urban. The SUI and ECC-33 models exhibited a high deviation from the measured path loss while Cost 231-Hata model is the most appropriate among the four standard empirical models appraised for the area.

From Fig. 3 and 4, the graphs of the residual against the fitted values and the standard quantiles-quantile (Q-Q) plot respectively show that the residuals are randomly spread around the horizontal line following a normal distribution. These show that the model is fit for making predictions. The scale-location plot in Fig. 5, which represents the plot of the square root of the standardized error versus the fitted values, indicates that residuals are spread equally along with the ranges of predictors with equally spread points. In the plot of residuals versus leverage in Fig. 6, there is no influential observation case in the plot. The entire cases are within the cook's distance line which shows that the prediction is a perfect one.

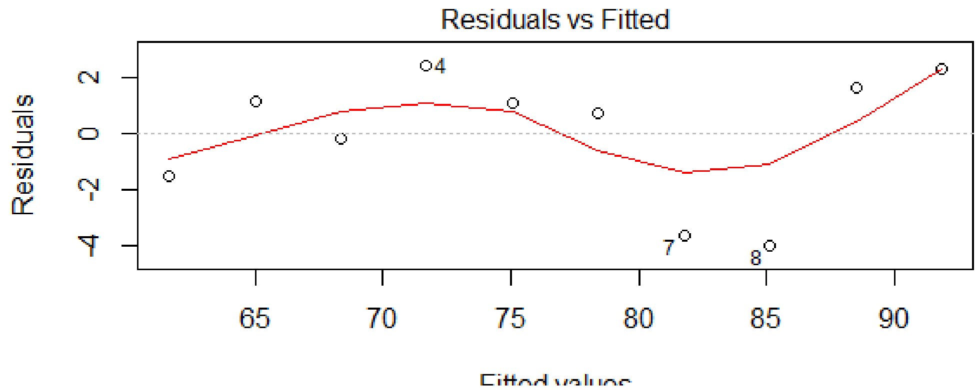

Fig. 3. A Plot of Residual Errors Versus Fitted Values

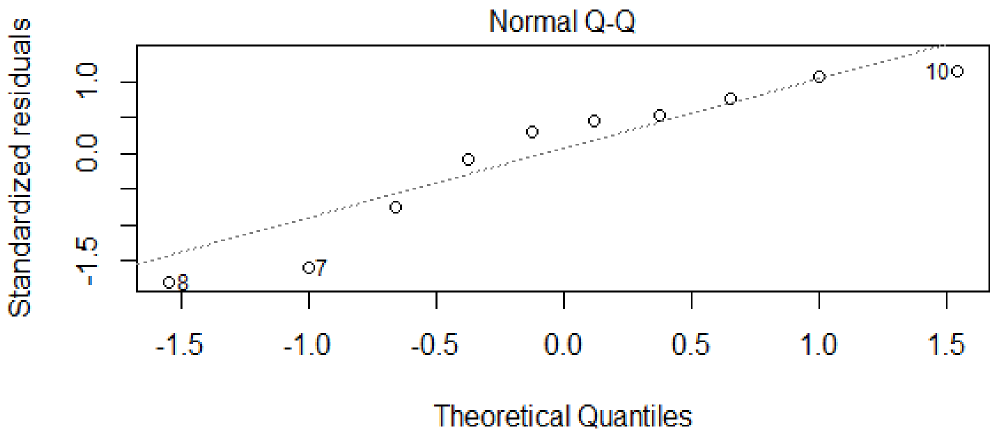

Fig. 4. A Plot of normal q-q (quantiles-quantile)

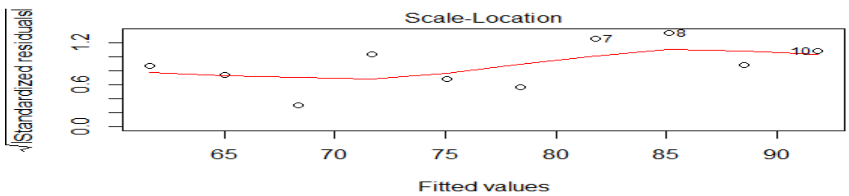

Fig. 5. A Plot of Scale-Location

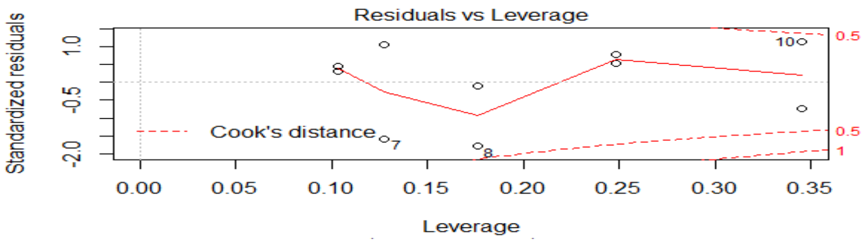

Fig. 6. A Plot of standardized residuals against leverage

IX. CONCLUSION

In this paper, a statistical approach in forecasting path loss for Nsukka urban is presented using live data collected at GSM received signal strength functioning at 1800MHz. The result of the analysis showed that the R-squared and adjusted R-squared values are 95% and 94% respectively with a p-value of $1.66e^{-6}$. The received signal strength of the propagating electromagnetic wave decreases with distance while the path loss increases which agrees with the theoretical analysis, even though there were some fluctuations in the measured path loss. These fluctuations can be attributed to uneven obstruction of waves and the nature of structures in the environment. Generally, this regression model can be useful in predicting path loss in the environment at present and in the future. It will also be useful in the optimization of the GSM network in the area.

ACKNOWLEDGMENT

Our thanks go to the Management of Centre for Basic Space Science (CBSS), University of Nigeria, Nsukka branch for providing us with the equipment used in carrying out the field measurements, not minding the duration of the data collection

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