KAMPALA INTERNATIONAL UNIVERSITY
KIU
Journal of Science, Engineering and Technology

KJSET Research Article

A Modified COST-231-Hata Path Loss Model for Typical Semi-Urban Environments in Nigeria

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Paper history:
February 20th, and accepted 28th March 2024

Keywords
COST-231-Hata,
Path loss,
RSSI,
Standard Deviation,
Root Mean Square

Abstract

Outdoor path loss propagation modeling is critical in the planning and design of the coverage area by the Global System for Mobile Communication (GSM). For the best prediction of GSM signal at any location within its coverage region, an accurate forecast based on critical characteristics and a mathematical model is necessary. Multiple studies on path loss propagation model prediction for GSM networks conducted at various semi-urban environments in Nigeria proclaimed that propagation path loss models may provide different results when utilized in environments other than those in which they were initially designed, that car drive-test methodology was used during the data collection, and that COST-231-Hata model provides closet prediction to the practical measure values. This paper created an appropriate path loss model based on the COST-23-Hata model and outdoor measurement at 1800 MHz frequency range for the semi-urban area of Kwara State, Nigeria. The created model was used and validated with the measured data and COST-231-Hata model at other different semi-urban environments in Nigeria. The results analysis shows that the created model performed satisfactorily given the closet path loss prediction to the practical measure path loss values at all the study locations. It also gives the lowest Square Root Means Error (SRME) and Standard Deviation (SD) in all the base stations that were tested in semi-urban environments. The newly created model would therefore be more appropriate for GSM 1800 network design and installation in semi-urban environments in Kwara State, Nigeria, as well as any other semi-urban locations in Nigeria.

Nomenclature and units

P_L	Pathloss
f_c	Frequency of transmission
C_1	Inception offset intake parameter
C_2	Inception system absorption parameter
S	Establish slope of the model flexion parameter

1.0 Introduction

One of the fundamental components of the design of a GSM network is the forecasting of signal propagation, therefore models for this prediction must be as accurate as possible while taking the propagation territory's constraints into account (Akanni et al., 2023). In GSM services, path loss is a significant issue that frequently results in poor reception and signal failures in numerous areas. This accounts for the growing attenuation of wireless network signal intensity as a mobile user moves from one location to another. Path loss is affected by a variety of phenomena, including reflection, diffraction scattering, and so on (Akanni et al., 2021).

The behavior of GSM signals in various locations and under diverse geographic and environmental conditions has been the subject of numerous scientific efforts. The study's conclusions resulted in the creation of a number of transmission path loss expressions for assessing the quality of GSM service delivered. The models that are created are environment-specific.

There are basically two kinds of propagation models in wireless communication: deterministic and empirical (statistical). The ability to forecast radio path loss and coverage using a deterministic model hinge on the application of scientific rules governing wave transmission. When implementing this approach, every factor in the specific environment must be studied. That is, it is required to thoroughly evaluate each credible signal contribution in order to determine the error-free value within a specific region. The deterministic procedure entailed lengthy calculations and a large amount of topographically obtained data (Sidhu et al., 2012). If carefully formulated, the results are often accurate or highly close to the environment's actual path loss.

Empirical methodologies for estimating signal path loss employ estimated mean values obtained from the investigation of the attenuation of signal links (Sidhu et al., 2012). These average values are then utilized in the estimating model to provide forecasts based on frequency and transmission path gaps. The Free Space, Plane Earth, Egli, COST-231-Hata, and COST-231-Walfisch-Ikegami (COST-231-WIM) models are the empirical models that are widely adopted and utilized in current research and application (Obot et al., 2012).

1.1 Free Space Path Loss Model (FSPLM)

FSPLM is the basic reference for all other forms of propagation models**.** It refers to the decrease in the strength of the signal that occurs as an electromagnetic wave travel through open space in the paths within a line-of-sight.

In an ideal case, electromagnetic radiation in empty space travels in a straight path without any obstructions that may cause attenuation (Obot et al., 2012; Oguejiofor et al., 2013). FSPLM is given in Eq. (1) (ITU-R P.525-2, 2000) as:

$$P_{L(FSL)} = 32.4 + 20\,log(f) + 20\,log(d) \qquad (1)$$

P_L(FSL) signifies the propagation loss in decibels, f the propagation frequency in megahertz, and d the distance in kilometers that lies between the base transceiver station (BTS)antenna and the mobile station (MS) antenna.

1.2 Plane Earth Path Loss Model (PEPLM)

FSPLM signal prediction assumes that there are no obstacles in the way that could possibly attenuate the signal. In the real world, such an ideal situation does not exist; thus, an alternative wave propagation model termed PEPLM was developed to account for wave reflection (Nadir et al., 2010)**.** In this situation, a radio wave strikes a surface and is reflected in the same way as light waves are reflected, with the magnitude of reflection fluctuating depending on how much of the wave is absorbed by the reflecting plane, which is also affected by the surface properties (ITU-R.1008-1 R, 2000). The PEPLM Propagation equation is given in Eq. (2) (Leonard and Nnamani, 2015) as:

$$P_{(PEPL)} = 40\log d - 20\log h_b - 20\log h_m \qquad (2)$$

$P_{(PEPL)}$ signifies the propagation loss in decibels, d defines the span in meters that separates the BTS and MS antennas, and h_b and h_m describe the altitudes of the BTS and MS antennas, accordingly.

1.3 Egli Path Loss Model (EPLM)

EPLM, which debuted in 1957**,** is a semi-empirical empirical model built around a smooth rolling terrain. This presupposition negates the need for topographical data regarding elevation between broadcasting and receiving stations. In EPLM, the open-space transmission loss is modified to make room for the altitude of transmitter and receiver antennas above the earth's surface (Akanni and Oliseloke, 2020). EPLM approach is utilized for estimating transmission loss for outdoor line-of-sight and point-to-point communications, taking distance and frequency variations into consideration. It is a good technique in mobile communication whenever one antenna is fixed and the other is mobile; however, it is not appropriate when vegetation interrupts the connection (John and Yekeen, 2013). Egli Path Loss Model is presented in Eq. (3) (Roslee and Kwan, 2010) as:

$$P_{EPLM} = 6.3 + 20logf + 40logd - 20logh_b - 10logh_m \qquad (3)$$

P_{EPLM} signifies the power in decibels at a distance r, d implies the distance in meters separating the BTS and MS antennas, and h_b and h_m define the altitudes in meters of the BTS and MS antennas, accordingly. hb designates the "Height of BTS Antenna" (m), hm the "Height of MS Antenna" (m), d the "Distance separating BTS Antenna and MS Antenna" (km), and f the "Transmission Frequency" (MHz).

1.4 COST-231-Hata Path Loss Model

The COST-231-Hata model obtained its name from the European Co-operative for Sciences and Technical Research (EUROCOST), an organization that expands the Hata-Okumura model (Prajesh and Singh, 2012). According to Deme et al. (2013), it is the most widely used empirical model. Correction factor, C_m, was incorporated, and the operating frequency was raised to 2000MHz (Dajab and Ogundapo, 2008). Cost-231-Hata propagation approach for semi-urban area is presented in equation (4) (Raturi et al., 2014) as:

$$P_L = 46.3 + 33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m + (44.9 - 6.55\log_{10} h_b)\log_{10} d \qquad (4)$$

$$ah_m = (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8), for\ semi\ urban\ area \qquad (5)$$

Where h_m stands for the MS antenna height (1–10 m), h_b for the BS antenna height (30–200 m), d for the distance between the BTS and MS (km), f_c for the frequency transmission (1–500–2000 MHz), and ah_m for the adjustment factor for the height of the MS antenna.

1.5 COST-231-Walfisch Ikegami (COST-231-WIM) Path Loss Model

COST-231-WIM is an amalgamation of two models invented by J. Walfisch and F. Ikegami (Seker et al., 2010; Shabbir, et al., 2011). It is employed to calculate path loss within the frequencies ranging from 0.8 to 2 GHz in a given terrain. The model is made up of three elements: multi-screen, roof-to-street diffraction and dispersion loss, and open space loss**.** Cost-231-WIM addressed two separate situations, as indicated in Eqs. (5) and (6) **(**Shabbir et al., 2011) as follows:

Case #1: Line of Sight (LOS):

$$L_{50} = 42.6 + 26\log d + 20\log f \qquad (5)$$

Case #2: Non-Line-of-Sight (NLOS):

$$L_{50} = L_f + L_{rts} + L_{msd} \qquad (6)$$

L_{50} is the average path loss decibel;

L_f denotes open space loss decibel;

L_{rts} s signifies deflection and dispersion loss in decibels from roof to street, and L_{nsd} denotes multiple-screen loss in decibels.

$$L_f = 32.4 + 20\log(f) + 20\log(d) \qquad (7)$$

d specified the TX to RX distance, and it spans between 0.02 and 5 km, with f signifies the transmission frequency.

$$L_{rts} = 16.9 + 10\log(b) + 20\log(\Delta d) - 10\log(w) + L_{ori} \qquad (8)$$

The road width is identified by the letter "w" in meters; stands for the height of the MS antenna beneath roof tops in meters; b signifies the building separation (in the range of 20 and 50 meters); and Lori acts as the route orientation characteristic.

$$L_{ori} = \begin{cases} -10 + 0.354\emptyset & 0° \le \emptyset \le 35° \\ 2.5 + 0.05(\emptyset - 35) & 35° \le \emptyset \le 55° \\ 4.0 + 0.114(\emptyset - 55) & 55° \le \emptyset \le 90° \end{cases} \qquad (9)$$

The symbol $\emptyset$ signifies the road inclination in relation to the radio channel.

$$L_{msd} = L_{bsh} + k_a + K_d \log d + K_f \log f - 9\log b \qquad (10)$$

K_a signifies multiple-screen in deflection loss decibels, K_d implies separation factor in decibels, and K_f defines frequency factor.

$$L_{bsh} = \begin{cases} 0, & h_{base} \le h_{roof} \\ -18(1 + \Delta b_{base}), & h_{base} > h_{roof} \end{cases} \qquad (11)$$

h_{Base} refers to the BTS height of 4 to 50 m and h_{Mobile} to the MS height of 1 to 3 m. Δh_b signifies the elevation of the BTS antenna in meters above the roofs. and h_{Roof} signifies structures' heights in meters.

$$k_a = \begin{cases} 54, & h_{base} > h_{roof} \\ 54 - 0.8\Delta h_{base}, & d \ge 0.5\ km, H_{base} \le h_{roof} \\ 54 - 0.8\Delta h_{base} km/0.5, & d < 0.5\ km, H_{base} \le h_{roof} \end{cases} \qquad (12)$$

$$k_d = \begin{cases} 0, & h_{base} > h_{roof} \\ 18 - 15\Delta H_{base} km/H_{roof}, & h_{base} \le h_{roof} \end{cases} \qquad (13)$$

$$k_f = -4 \begin{cases} 0.9(f/951 - 1), & small\ city \\ 1.5(f/951 - 1), & large\ city \end{cases} \qquad (14)$$

1.6 Related Works

Sunny et al. (2017) investigated the pattern of cellular signal transmission attenuation within Uyo environments in Nigeria. Using simple least square regression, a model prediction equation was created based on the estimated route loss assessed against distance inside the Uyo urban region. A signal path loss comparison test in three major routes within Uyo, Akwa-Ibom state, Nigeria, revealed that the developed model outperformed the COST-Hata and Okumura-Hata models.

Path loss model improvement for mobile communication was proposed by Garah et al. (2016). After multiple studies on signal propagation path loss prediction utilizing some of the available path loss models on GSM 908-957 in Batna, Algeria, it was found that the COST-231 path loss mode provides a value that is closer to the measured value than other empirical models. As a result, COST-231 was modified for optimization using a genetic algorithm. The modified COST-231 model outperformed the other route loss models in the Batna, Algeria, RMSE, MER, and PRE tests comparing actual and forecasted data.

Imhomoh et al. (2011) used a comparison method to optimize the COST-231 Hata model for GSM (1800) signal transmission path loss prediction within Lagos, Nigeria. Reasonable number of measured signal path loss data were acquired along various paths, starting at 100 meters from the BS and extending outward at intervals of 100 meters up to 2 kilometers. The least squares method was employed to calculate the path loss exponent, and optimization was accomplished by evaluating the differences in MSE between the observed and forecasted route loss for each location. The created model predicted observed path loss with an allowable MSR of 5.25 dB within urban Lagos.

In Malaysian suburbs, Mardeni and Kwan (2010) studied radio frequency attenuation path loss behavior. The research focused on the development and improvement of a path loss model built around the current Hata path loss approach as well as measurements made outdoors at frequencies between 400 MHz and 1800 MHz. The least square approach was used to achieve the optimization process. The improved modal was verified for various base stations in, and it was discovered that practically Each of the base stations matches perfectly with the optimized design. It was concluded that the optimized Hata technique is the most suitable because it gives the least error compared to the other models stated.

Bhuvaneshwari et al. (2018) suggested a stochastic mixed genetic approach for optimizing mobile radio path loss models by combining the stochastic Weighted Least Squares approach with the genetic algorithm. The developed approach was utilized to improve the characteristics associated with the Cost 231 Hata transmission approach. The field strength measurements at 0.900 GHz in the suburb domain validated it. The effectiveness of the hybrid technique was tested using path loss comparison and error metrics, and the tuning accuracy was demonstrated by the lowest values of MER, RMSE, and percentage relative error.

Popoola and Olasunkanmi (2014) assessed the effectiveness of four statistical attenuation models in order to establish the best model for wireless service implementation in Makurdi settings. A surveillance gadget equipped with software was utilized for carrying out signal strength measurements while driving along present routes for a distance of around 2 km. It was pointed out that the COST 231-Hata Model is one of the best for 1800 wireless service planning and deployment in Makurdi settings.

Adesoko et al. (2012) conducted comparative analyses on selected existing radio propagation models in Kano, Nigeria. A multiple-band mobile device, a global positioning system, and a sensor device, all linked to a computer inside a car, were used to measure (receive) signal strength while driving around a predetermined course. According to their findings, it is more acceptable to employ COST 231 in the Kano setting.

In 2016, Anamonye et al. compared the signal path loss estimated from the Free-Space and Okumura-Hata models to real measurements taken in Warri, Delta State, Nigeria. From 0.1 kilometers to a total distance of 1.5 kilometers, the received signal intensity was measured using a Lenovo A859 and a program named Net Monitor for tracking received signal strength. The outcomes demonstrate that the Okumura-Hata model did a good job of estimating signal path-losses in Warri.

Imoize et al. (2019) proposed a model for forecasting radio frequency propagation within vegetation settings for two cellular frequency ranges. A surveillance gadget equipped with software installed on a computer was utilized for carrying out measurements. A drive test was conducted in and around a vegetation environment. The observed path loss was contrasted with the forecasts generated by some empirical models, and it was found that the COST-235 model gave a better prediction model in terms of Root Mean Square Errors (RMSEs) and mean attenuation.

Ogundapo et al. (2011) conducted a comparative analysis of path loss models for wireless network planning within Kano, Nigeria's semiurban environment. Four path loss models were exploited to investigate the coverage area forecast with the aid of signal intensity measurements obtained from a cellular network. The signal strengths were measured via drive tests using a signal strength measuring device around nine GSM base stations operating at 0.900 GHz. According to their results, the COST-231 Hata and Lee typically underestimate route loss, and the COST-231 Walfisch-Ikegami typically overestimates route loss for the environment when compared to the average measured data.

In order to determine which path loss model would be most appropriate for the study contexts, Salau et al., (2017) conducted field measurements at various places in Lagos, Nigeria, including rural, suburban, and urban areas. They then compared the observed data with that of some of the existing path loss models. The measuring system is made up of live radio base stations that transmit at frequencies of 0.900 GHz, 1.800 GHz, and 2.100 GHz Data on the intensity of the downlink signal was acquired by means of a drive test, and the equipment used included a cellphone, research software, and Google Earth for site information. The results reveal that the COST-231-Hata radio wave propagation model is quite good at predicting radio frequency transmission path loss in semi-urban areas of Nigeria's western region.

An evaluation of some of the empirical path loss expressions using observed values for large city, medium city, and rural settings in Rivers State was enumerated by Akinwole and Biebuma (2013). The efficacy of currently available, widely used models for cellular transmission was examined. The outcomes show that the COST-231 Hata model has the minimal value for MSE and SD, resulting in better forecasts, and is suggested for forecasting path loss in River State, Nigeria.

In a quest to establish adaptive and adequate propagation attenuation expressions within Port-Harcourt and Enugu metropolises, two statistical propagation expressions were investigated by Ogbulezie et al. (2013). Two locations were chosen for every city that was under consideration, and a drive test was conducted along the key roads. The observed and predicted values generated by two statistical models were contrasted. It was discovered that there was diversity in the mean attenuation, the MSR, and the SD at 1.800 GHz for the two metropolis settings.

Evaluation of relevant literature reveals that propagation path loss models may provide different results when utilized in environments other than those in which they were initially designed. It also, reveals that no generic model is adequate for all the environments, and that the classic convectional drive-test methodology was used during the collection of the data that was used for all the newly created or modified path loss models in Nigerian. Due to the African road networks and building construction patterns, this method (drive-test methodology) may prevent accessibility to some important area where data measurements supposed to be taken. Also, because continuous measurements are obtained at the same location, systematic errors are reduced by properly windowing and averaging data, which is another advantage over the driving test approach.

In this respect, it is evident that a superior modeling technique is required. This study examines the challenges and seeks to offer solutions that are reasonably accurate and pertinent in the Nigerian environment.

The subsequent sections of the manuscript are structured as follows: Section 2 expounds on the description of the study area, materials employed, and experimental procedure. The data analysis is comprehensively narrated in Section 3. The ensuing section, Section 4, features the presentation of the results and discussion. Lastly, the conclusive remarks are posited in Section 5.

2.0 Description of the Study Environment, Materials Employed and Experimental procedure

2.1 Description of the Study Environment

The three semi-urban areas used for the study are Jebba, Omuaran, and Aroje-Ogbomoso. Jebba, a semi-urban town in north-central Nigeria, is located between latitude 9.122 N and 9.831 N and longitude 4.812 E and 4.832 E (Google, 2024) and has an area of approximately 2.985 km² (City-facts, 2024). With an estimated population of 31,181 (City-facts, 2024), it is portrayed by a complicated landscape due to the existing of diverse hills and valleys across the city. Jebba was selected as the experimental study location for the purpose of developing the modified COST-231-Hata model because the town possesses qualities that reflect typical Nigerian semi-urban environmental. Omu-Aran in north-central Nigeria and Aroje-Ogbomoso in south-west Nigeria are used to validate the developed model.

2.2 Materials Employed

The experimental setup included a GPS (Garmin-nuvi 40GPS) and Nokia phones as a Mobile Station (MS). A *surveillance* gadget equipped with software was employed to link Nokia phones to a laptop's serial port. The selected base station information, time, and signal strength values in Received Signal Strength Indication (RSSI) format that were read from the ports were all saved in a text file. The research locations' coordinates and elevation were obtained with the aid of a GPS.

2.3 Experimental Procedures

Measurements were conducted at study locations across the research sites using a similar grid of outdoor spaces. This approach offers an advantage over the classic convectional drive-test methodology, which may miss certain inaccessible locations because of African building construction patterns. Another benefit of this approach over the driving test technique is that systematic errors are minimized by appropriate windowing and averaging of data, as continuous measurements are acquired at the same spot.

A Google map of Jebba town was obtained for easy navigation. Figure 1 depicts the aerial photograph of Jebba town with the regular grid lines (yellow solid lines), clusters of buildings, and the unmotorable road networks. Within the research zone, GSM signal strengths were measured at each predetermined spot (dotted red spots in Figure 1) on the regular grid drawn on a Google map. The measurements started approximately 0.1 kilometer from the base transceiver station (BTS) of the chosen GSM operator and continued at intervals of approximately 0.1 km up to a distance of approximately 1.5 km. All measurements were obtained in mobile active mode to ascertain that the phone is in continual contact with the BTS. In order to achieve this, calls were sent to a predefined number at each study location, and the received signal strength in RSSI format was saved in a text file. The measured path loss, $P_{i,}$ and the predicted path loss, $P_{r,}$ at the study locations were calculated using the measured signal strength value, the transmitter, the MS parameters, and the COST-231-Hata model. The values of $P_{i,}$ and P_r were then used to develop the model. The developed model and the COST-231-Hata model were then deployed in another two semi-urban towns in Nigeria (Omun-Aran and Aroje-Ogbomoso). A comparison was made between the measured practical path loss values, the estimated values derived from the proposed path loss model, and the COST-231-Hata path loss models.

3.0 Data Analysis

The MS antenna's height was 1.5 meters, and the base transceiver station (BTS) has the following measurements: 1.5 meters, 25 meters, 4.08^0, and 9.10^0, for the MS height, BTS height, latitude, longitude, and frequency of operation (MHz), in that order. Experimental results of the observed (measured) signal strengths and distances relative to the BTS in the selected study area (region) were recorded. The statistical "Ad-in" tool in Microsoft Excel is used to compute the practical measured signal path loss, P_i, and the path loss generated from the COST-231-Hata model, P_r.

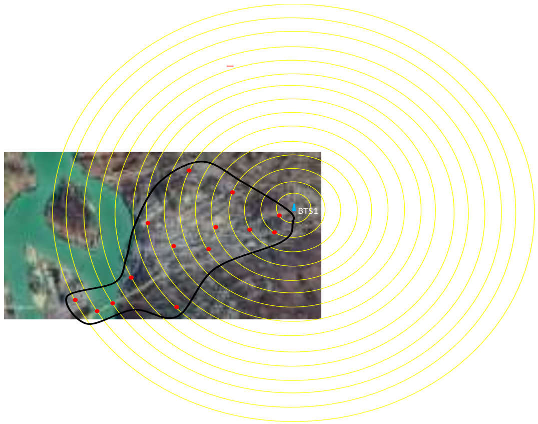

Figure 1: The Aerial Photograph of Jebba Town (Google, 2024)

3.1 Path loss Optimization Process

After a thorough review of several studies on path loss transmission approach prediction for GSM mobile networks carried out in several semi-urban settings in Nigeria, it was established that the COST-231-Hata path loss model predicts path loss more accurately than other empirical path loss models when compared to the practical path loss measurement data obtained. From this perspective, the COST-231-Hata path loss model is modified for the investigation's environment. The characteristics of the COST-231-Hata path loss model were changed using the least square approach to fit the measured data. The measured signal path loss value, P_i, and the predicted value, P_r (by the COST-231-Hata path loss model), are calculated for each location point at any distance d_i from the base station.

Since most of the variables in the selected model (the COST-231-Hata model) remain unchanged, (4) can be expressed as follows for semi-urban environments: (Akanni et al., 2023):

$$P_L = 46.3 + 33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m + (44.9 - 6.55\log_{10} h_b)\log_{10} d + +\delta \quad (15)$$

To investigate the presumption that other variables stay constant, Eq. (15) was reconstituted and redefined to incorporate the following parameter (Akanni et al. 2023):

$$C_1 = 46.3 + \delta (\text{Inceptive offset intake parameter}) \quad (16)$$

$$C_2 = 33.9\log_{10} f_c - 13.82\log_{10} h_b - ah_m \quad (\text{Inceptive System absorption parameter}) \quad (17)$$

$$C = C_1 + C_2 \quad (18)$$

$$S = S_1(44.9 - 6.55\log_{10} h_b) \quad (\text{Establish slope of the model flexion parameter}) \quad (19)$$

Least square approach is used to calculate the value of C_1 and S_1

For a specified route, f_c, h_b and h_m are fixed and (15) is remodeled as follow:

$$P_L = (C_1 + C_2) + S\log_{10} d = C + S\log_{10} d \quad (20)$$

The function of the summation of deviation squares is minima when theoretical mode flexion is optimal with respect to the actual data, i.e.

$$F(C,S) = \sum_{i=1}^{n} [P_i - P_r(d_i, C, S)]^2 \quad (21)$$

Where P_i is the measured signal path loss (the observed outcome) at any distance d_i, P_r (d_i, C, S) is the model prediction outcome at any distance d_i. C and S are model parameters, while n is the total number of data sets.

For optimization,

$$\frac{\partial F}{\partial C} = 0 \quad (22)$$

$$\frac{\partial F}{\partial S} = 0 \quad (23)$$

But $P_r = C + S\log_{10} d_i$

For simplicity, let $\log_{10} d_i$be written as y_i

Therefore,

$$P_r = C + Sy_i \quad (24)$$

Solving (23) and (24)

$$C = \frac{\sum y_i^2 * \sum p_i - \sum y_i * p_i}{n * \sum y_i^2 - (\sum y_i)^2} \quad (25)$$

$$S = \frac{n * \sum y_i * p_i - \sum y_i * \sum p_i}{n * \sum y_i^2 - (\sum y_i)^2} \quad (26)$$

The values of C and S in equations (25) and (26) are determined with the aid of Microsoft EXCEL for f_c = 1826.4 MHz, h_b = 25 m and h_m = 1.5 m to be 131.37 and 34.53 respectively.

$$\Rightarrow C = C_1 + C_2 = 46.3 + \delta + C_2 = 131.37$$

$$\Rightarrow \delta = C - 46.3 - C_2 = 131.37 - 46.3 - 91.27 \approx -6.2\ dB$$

Therefore,

$$C_1 = 46.3 + \delta = 46.3 + (-6.2) = 40.1\ dB$$

$$S_1 = \frac{S}{(44.9 - 6.55\log_{10} h_b)} = 0.994 \approx 1$$

Finaly, the modified path loss model, $P_{L(Mod)}$ becomes:

$$P_{L(Mod)} = C_1 + C_2 + S_1(44.9 - 6.55\log_{10} h_b)\log_{10} d$$

$$P_{L(Mod)} = 46.3 - 6.20 + (33.9\log_{10} f_c - 13.82\log_{10} h_b - a_h) + (1 \times (44.9 - 6.55\log_{10} h_b)\log_{10} d)$$

$$P_{L(Mod)} = 40.1 + (33.9\log_{10} f_c - 13.82\log_{10} h_b - a_h) + (44.9 - 6.55\log_{10} h_b)\log_{10} d \quad (27)$$

3.2 Performance Analysis of the Optimized Path Loss Model

The MS antenna's height was 1.5 meters, and the various BTS attributes used to calculate path loss at different research locations are listed in Table 1. The experimental results of the observed signal strengths and distances relative to BTS2 and BTS3 performed within the selected study area (region) at Omu-Aran and Aroje-Ogbomoso were recorded. The statistical "Ad-in" tool in Microsoft EXCEL, is used to compute the practical measured signal path loss, P_i, the path loss generated from the COST-231-Hata model P_r, and the path loss generated from the modified model $P_{L(Mod)}$ at any distance d_i using the measured signal strengths and distances for various study locations at Omu-Aran and Aroje-Ogbomoso.

The statistical "Ad-in" tool in Microsoft EXCEL, is also used to determine the Root Means Error (RME) and Standard Deviation (SD) values of signal path loss for the modified model and the COST-231 model associated with the three BTSs at selected study locations within Jebba, Omu-Aran, and Aroje-Ogbomoso towns.

Table 1: Base Transceiver Station Information

BTS No.	Study Location	HT (m)	Elev. (m)	Long. (m)	Lat. (m)	Freq. (MHz)
BTS 1	Jebba	25	144.8	4.08	9.10	1826.4
BTS 2	Omu-Aran	28	534.3	5.08	8.13	1820.4
BTS 3	Aroje-Ogbomoso	30	355.4	4.25	8.17	1820.6

4.0 Results and Discussions

In order to validate the developed model, signal path loss was conducted in two different semi-urban towns in Nigeria (Omun-Aran and Aroje-Ogbomoso), using the same method applied at Jabba town, and a comparison was made between the developed path loss model and the COST-231-Hata path loss models. Further validation of the modified path loss model for improved performance accuracy was carried out by comparing the Square Root Means Error (RME) and Standard Deviation (SD) values (generated using Microsoft EXCEL) of signal path loss between the modified path loss model and the COST-231 model linked to the various BTSs at specific study locations within the three chosen semi-urban environments.

Figures 2 through 4 shows the variation of the path loss with the distance associated with the BTS1, BTS2, and BTS3 at various study locations obtained using the regular grid outdoor foot method within the study areas in Jebba, Omu-Aran, and Aroje-Ogbomoso). It is observed from Figures 2 through 4 that the path loss increases with distances for all the study locations. It is also observed that the COST-231-Hata model overpredicts the path loss for most cases when compared to the practical measure path loss values at all the study locations, while the developed model gives the closest path loss prediction to the practical measure path loss values at all the study locations, and this can be traced to the impact of the distinctive African road networks and building patterns on the cellular signal strength.

Table 2 shows the statistical evaluation of the Root Means Error (RME) and Standard Deviation (SD) values (generated with the aid of Microsoft EXCEL) of signal path loss for the modified path loss model and the COST-231 model associated with the three BTSs at selected study locations within Jebba, Omu-Aran, and Aroje-Ogbomoso) towns. It is observed that the modified path loss model has the lowest Square Root Means Error and Standard Deviation (SD) for any of the tested Base Transceiver Stations (BTSs) in all three semi-urban areas under investigation.

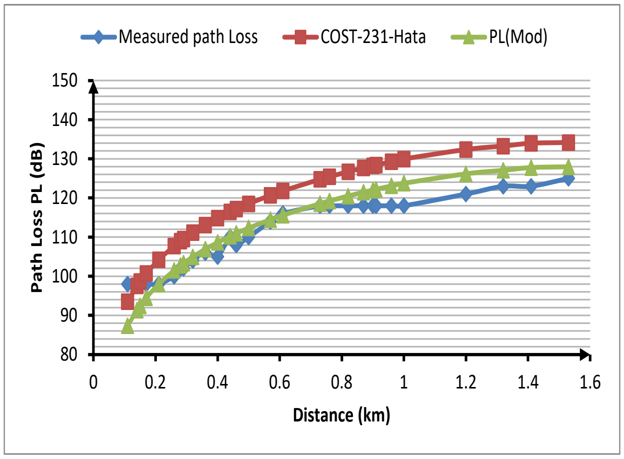

Figure 2: The variation of path Loss (dBm) with distance (km) for BTS 1 at Jebba, Nigeria

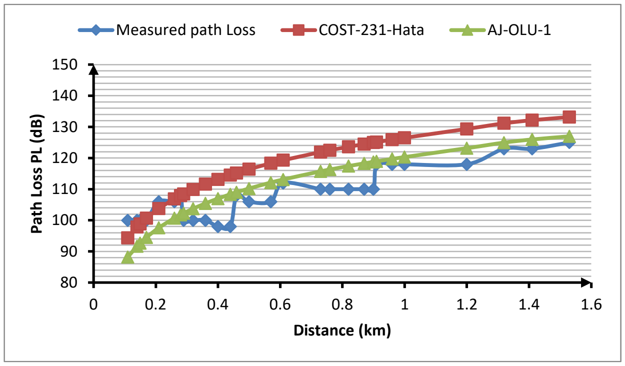

Figure 3: The variation of path Loss (dBm) with distance (km) for BTS 2 at Omu-Aran, Nigeria

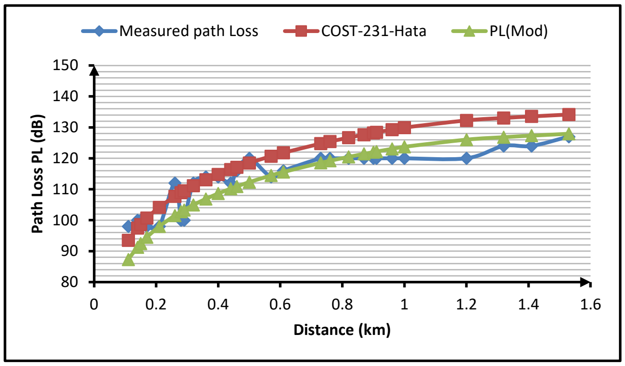

Figure 4: The variation of path Loss (dBm) with distance (km) for BTS 1 at Aroje-Ogbomoso, Nigeria

Table 2: Statistical Evaluation of RME and SD between Modified model and COST-231 Hata model for various BTS at selected Study Location (Towns)

Study Location	**BTS No.**	**RMSE**		**SD**	
		Modified Model	**COST-231 Hata**	**Modified Model**	**COST-231 Hata**
Jebba	1	2.73	23.74	3.81	24.47

Omu-Aran	4	3.30	21.84	3.41	22.55
Aroje-Ogbomoso	8	2.73	22.15	2.88	23.35

5.0 Conclusion

A modified COST-231-Hata path loss model was developed. The developed model was used and validated with the measured and COST-231-Hata model in various locations in the three selected semi-urban environments in Nigeria. The results analysis revealed that the developed model performed satisfactory given the closet path loss prediction to the practical measure path loss values at all the study locations. It also has the lowest Square Root Means Error and Standard Deviation (SD) at any of the tested Base Stations (BTSs) in the three selected semi-urban environments in Nigeria. As a result, it is concluded that the newly developed model would work better for 1800 MHz cellular service design as well as installation in three selected semi-urban environments in Nigeria, as well as any other semi-urban locations in Nigeria and other nations with a comparable environment.

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