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STATISTICAL TUNING OF COST 231 HATA MODEL IN DEPLOYED 1800MHZ GSM NETWORKS FOR A RURAL ENVIRONMENT

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ABSTRACT
Radio propagation planning requires the use of propagation models in planning cell size as well as frequency assignment. This paper presents a comparative study of path loss predicted using COST 231 Hata model and ECC-33 model on received signal strength data collected from three deployed GSM networks at 1800MHz in Nigerian Institute for Oil Palm Research environment (NIFOR), Edo State, Nigeria. Based on the Mean Prediction Error (MPE) and Root Mean Square Error (RMSE) values obtained from the comparison, the COST 231 Hata model was tuned using the least square approach. The result obtained after tuning shows that for Network A; MPE and RMSE values reduces to 1.17 dB and 5.5dB. For Network B, MPE and RMSE values reduces to 2.26 dB and 7.16dB. While, for Network C; MPE and RMSE values reduces to 6.21 dB and 10.78dB. The results obtained show that the tuned COST 231 Hata model can be used for radio planning in the study environment as well as other environment with similar terrain profile.

Keywords: *Propagation model, Path loss, COST 231 Hata model, ECC-33 model, Least square tuning approach, MPE and RMSE*

1. INTRODUCTION

Improving coverage and capacity is the goal of every network service provider in the Mobile Communication Industry. While capacity can be improved by cell splitting and cell sectoring [1], coverage is usually determined by the suitability of the propagation model deployed during the network planning stage. A propagation model is a set of mathematical expressions, diagrams, and algorithms used to represent the radio characteristics of a given environment [2]. Radio propagation models are used to describe the relationship between the signal radiated and signal received as a function of distance and other variables [3]. Propagation models find application in network planning, especially during feasibility studies as well as during the network deployment stage. They are also used for determining the coverage area of the network, performance optimization of the network, determining base station placement and also for interference analysis [4]. The strength of a wireless communication signal decreases as the distance between the transmitter and the receiver increases [4]. Generally, propagation models can be categorized into two categories: deterministic and empirical propagation models [5]. Deterministic radio propagation models are path loss models that uses the laws governing the propagation of electromagnetic wave for determination of the power of a received signal at a given location [5]; while empirical propagation models are mathematical formulations based on observation and measurement obtained from the propagation environment. These type of propagation models are derived empirically from statistical analysis of large number of field measurement [6]. There is also the Stochastic propagation models that models the environment as a series of random variables to determine the path loss in a propagation environment. Several existing empirical models have been proposed for predicting radio coverage in literatures [7] - [9]. However, the uniqueness of

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these models give rise to high prediction errors when deployed in a different environment other than the environment it was initially built for. Thus, this work is aimed at statistically tuning of the COST 231 Hata model to predict path loss for GSM 1800MHz network at NIFOR environment in Edo state, Nigeria using the method of least squares.

2. PROPAGATION MODEL

The success of the mobile communication industry can be traced to the development of propagation models [10]. In this research work, the ECC-33 model and COST 231 Hata model were used to compare the path loss values obtained from measurement. The model with the lowest root mean square error (RMSE) value will be tuned to optimize its prediction accuracy based on the measurement data.

2.1 ECC-33 Model

The ECC empirical formulation is a path loss prediction model developed by the Electronic Communication Committee (ECC) based on the original measurement data from Okumura model in Tokyo, Japan [10]. The ECC group extrapolated the original data by Okumura and modified its assumptions. This model is valid for the frequency band of 700MHz to 3500MHz [10].

This model presented the Path loss ($P_{l_{(i)}}$) equation based on four factors in [11] as given in equation (1):

$$P_{l(i)} = A_{fs} + A_m - G_{tx} - G_{rx} \quad (1)$$

Where each of these factors are individually defined as:

$A_{fs}\ (dB)$ is the free space path loss, $A_m(dB)$ is the basic median path loss, $G_{tx}(dB)$ is the transmitter antenna height gain factor and $G_{rx}(dB)$ is the mobile receiver antenna height gain factor.

$$A_{fs}\ (dB) = 92.4 + 20\log_{10}(d_{(i)}) + 20\log_{10}(f) \quad (2)$$

$$A_m(dB) = 20.41 + 9.83\log_{10}(d_{(i)}) + 7.894\log_{10}(f) + 9.56[\log_{10}(f)]^2 \quad (3)$$

Where $d_{(i)}$ is the transmitter-receiver separation in km at the ith measurement point and f is the frequency in GHz.

$$G_{tx}(dB) = \log_{10}\left(\frac{h_{tx}}{200}\right)\left\{13.958 + 5.8\left[\log_{10}(d_{(i)})\right]^2\right\} \quad (4)$$

where h_{tx} is the height of the base station antenna in metres.

The mobile receiver antenna height gain factor ($G_{rx}(dB)$) for medium cities is given as in (Sharma and Singh 2010):

$$G_{rx}(dB) = [42.57 + 13.7\log_{10}(f)](\log_{10}(h_{rx}) - 0.585) \quad (5)$$

Where h_{rx} is the height of the mobile unit antenna in metres.

And the mobile antenna height gain factor for large cities is given as :

$$G_{rx}(dB) = 0.759h_{rx} - 1.862 \quad (6)$$

2.2 Cost-231 Hata Model

The Cost-231 Hata model is a radio propagation model that is used to predict pathloss in wireless communication channels. The Cost-231 Hata propagation model is designed for $1500MHz$ to $2000MHz$ frequency range (Sharma, et.al., 2010). The basic path loss equation in dB as given in [12] for a rural environment is;

$$P_{l_{(i)}}(dB) = 46.33 + 33.9\log_{10}(f_{[MHz]}) - 13.82\log_{10}\left(h_{tx_{[m]}}\right) - a(h_{rx}) + \left(44.99 - 6.55\log_{10}\left(h_{tx_{[m]}}\right)\right)\log_{10} d_{(i)} \quad (7)$$

Where $P_{l_{(i)}}$ is the pathloss predicted at the ith measurement point in decibel(dB), ht_x is the base station antenna height, hr_x is the mobile station antenna height above ground level in meters, $d_{(i)}$ is the propagation distance in kilometers at the ith measurement point, a(hr_x) is the mobile station antenna height correction factor and it is given in equations(8) as;

$$a(hr_x) = (1.1\log_{10}(f) - 0.7)hr_x - (1.56\ \log_{10}(f) - 0.8) \quad (8)$$

The validity range of this model is from a frequency band (f) of 1500MHz to 2000MHz, base station antenna height (ht_x) of 30 – 200m, mobile unit antenna height of hr_x of 1-10m and transmitter-receiver separation distance of 1-20km [12].

3. METHODOLOGY

In this study, measurements were carried out for three 1800MHz networks deployed in Nigerian Institute for Oil Palm Research (NIFOR) environment in Edo state, Nigeria. These networks are referred to as Network A, Network B and Network C. Received signal strength data were collected using an Acer smart phone which run a network info lite software as in Figure 1. NIFOR is a rural environment with semi thick vegetation mostly of palm trees, with scattered settlements as in the Google map Earth view of Figure 2. Received Signal Strength data (RSSL) was collected on active mode for a period of 120s at an interval of 100m due to the size of the cells at a mobile antenna height of 1.5m for a period of 6 months. RSSL data was collected for three radial directions which corresponds to the three sectorial antennas mounted at $120°$ to achieve $360°$ coverage. In addition to RSSL data collected, base station parameters collected were the base station antenna height $(h_{tx})(m)$ and the standard transmit power $'P_t'$ (dB).

Figure 1: A screen shot of the Network cell Info

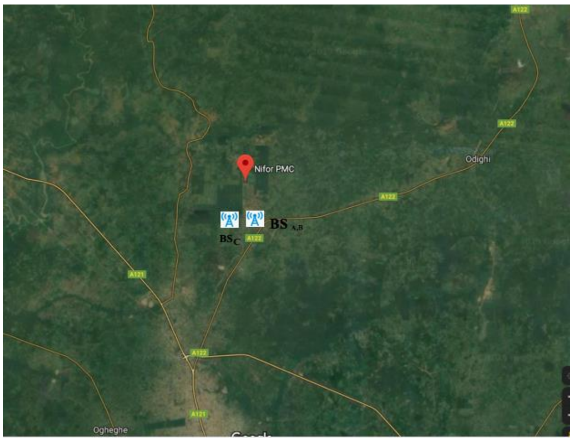

Figure 2: Google map Earth view of lite software interface NIFOR

4. RESULTS BEFORE TUNING

In propagation studies, there are several existing empirical propagation models that can be used to predict path loss in a rural environment. For this study the ECC-33 model and the COST 231 Hata model were used to compare the path loss (dB) estimated from the measured received signal strength data.

For easy comparison, a graphical plot showing the measured and predicted path loss values for the ECC-33 model and COST 231 Hata model plotted with respect to distance for the Network A, B and C with MATLAB_ R2017b software are given in Figure 3 through to Figure 5.

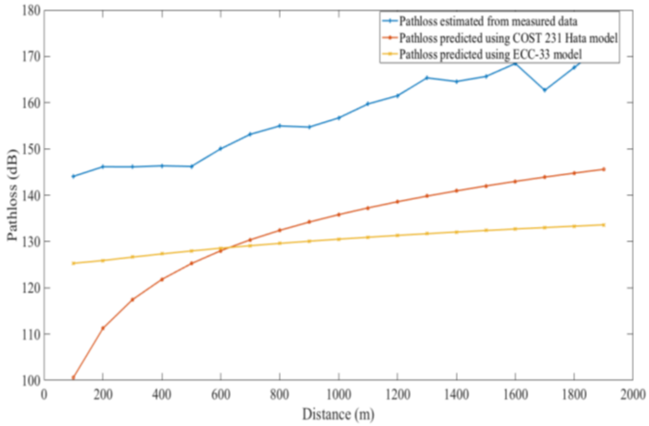

Figure 3: Plot of estimated path loss from measured data and path loss obtained from existing empirical models for Network A at 1800MHz in NIFOR, Edo state.

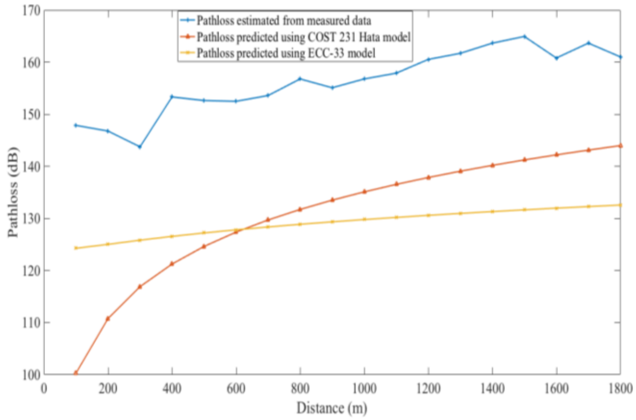

Figure 4: Plot of estimated path loss from measured data and path loss obtained from existing empirical models for Network B at 1800MHz in NIFOR, Edo state.

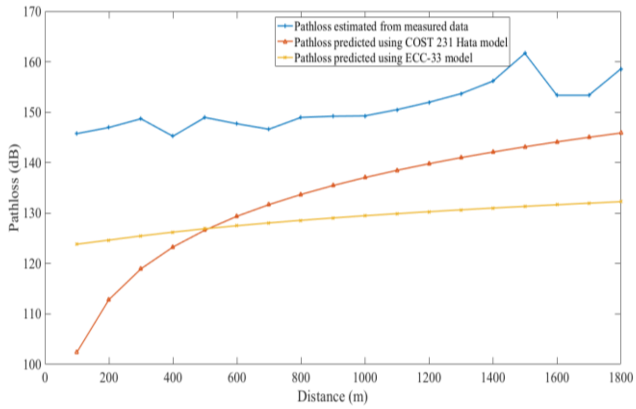

Figure 5: Plot of estimated path loss from measured data and path loss predicted from existing empirical models for Network C at 1800MHz in NIFOR, Edo state.

5. MODEL VALIDATION BEFORE TUNING

The performance evaluation of a model is a vital aspect of path loss prediction and essential to its evaluation are the values of the goodness of fit indices obtained from the analysis of the given model. In this section, the COST 231 Hata model and the ECC-33 models are validated to ascertain its suitability for the Networks investigated. The Mean Prediction Error (MPE) and Root Mean Square of Errors (RMSE) in equation (9) and equation (10) are used to evaluate the goodness of fit of these models, and the computational results are presented in Table 1.

$$MPE = \frac{1}{n}\sum_{i=1}^{n}\left(P_{lm_{(i)}} - P_{lp_{(i)}}\right) \quad (9)$$

$$RMSE = \sqrt{\left(\sum_{i=1}^{n}\frac{\left(P_{lp_{(i)}} - P_{lm_{(i)}}\right)^2}{n}\right)} \quad (10)$$

where n=number of measurement points, $P_{lm_{(i)}}$ is the path loss estimated from measured data at the ith measurement point and $P_{lp_{(i)}}$ is the path loss predicted at the ith measurement point using the COST 231 Hata Model and the ECC-33 model.

Based on the the error values in Table 1, the COST 231 Hata model has the minimum MPE and RMSE values of Networks A, B and C. Thus, the COST 231 Hata model will be tuned to improve its prediction accuracy.

6. TUNING OF COST-231 HATA MODEL

The high RMSE values obtained from the COST 231 Hata model is as a result of the different characteristics of the environment in which this model was built for. The least square tuning approached as in [13] will be utilized in this study.

If the error term $\left(P_{lp_{(i)}} - P_{lm_{(i)}}\right)^2$ in equation (10) can be minimized, then the accuracy of predictions from this model will improve. For the purpose of tuning, let equation (7) be written as in equation (11) and equation (12) as;

$$P_{l_{(i)}}(dB) = 46.33 + 33.9\log_{10}\left(f_{[MHz]}\right) - 13.82\log_{10}\left(h_{tx_{[m]}}\right) - a(h_{rx}) + 44.99\log_{10} d_{(i)} - 6.55\log_{10}\left(h_{tx_{[m]}}\right)\log_{10} d_{(i)} \quad (11)$$

$$P_{l_{(i)}}(dB) = A_1 + A_3\log_{10}\left(f_{[MHz]}\right) - A_4\log_{10}\left(h_{tx_{[m]}}\right) - a(h_{rx}) + A_2\log_{10} d_{(i)} - A_5\log_{10}\left(h_{tx_{[m]}}\right)\log_{10} d_{(i)} \quad (12)$$

where A_1 to A_5 are the model tuning parameters. For each measurement point, f, h_{tx}, h_{rx} are fixed values; but $d_{(i)}$ is a variable, so the model tuning mainly depend on A_1 and A_2.

Thus, the equation that needed to be tuned is;

$$\Delta_A = A_1 + A_2\log_{10} d_{(i)} \quad (13)$$

Assuming the error term $P_{lp_{(i)}} - P_{lm_{(i)}} = E_{o_{(i)}}$, then the total error can be calculated as;

$$E(A_1, A_2) = \sum_{i=1}^{n}\left(\Delta_A - E_{o_{(i)}}\right)^2 \quad (14)$$

Let

$$\Delta_A = C_1 + C_2\log_{10} d_{(i)} \quad (15)$$

Where C_1 is the attenuation constant and C_2 the attenuation parameter about the distance $d_{(i)}$.

By substituting the value of equation (15) in equation (14),

$$E(C_1, C_2) = \sum_{i=1}^{n}\left(C_1 + C_2\log_{10} d_{(i)} - E_{o_{(i)}}\right)^2 \quad (16)$$

According to linear least square theory [11], in order to make sure that the value of error function $E(C_1, C_2)$ is minimum,

$$\begin{cases} \dfrac{d\,E(C_1, C_2)}{dC_1} = 0 \\ \dfrac{d\,E(C_1, C_2)}{dC_2} = 0 \end{cases} \quad (17)$$

By substituting equation (16) in equation (17), and evaluating it;

Table 1. Mean Prediction Error (MPE) and Root Mean Square Error (RMSE) values for Networks A, B and C at 1800MHz

NETWORK	Mean Prediction Error (MPE)		Root Mean Square Error (RMSE)	
	ECC-33 Model	Cost 231 Hata Model	ECC-33 Model	Cost 231 Hata Model
A	27.07	24.90	27.80	25.51
B	27.14	25.43	27.40	26.36
C	22.11	18.11	22.29	20.22

$$\begin{cases} \sum_{i=1}^{n} 2\left(C_1 + C_2 \log_{10} d_{(i)} - E_{o_{(i)}}\right) \times 1 \\ \sum_{i=1}^{n} 2\left(C_1 + C_2 \log_{10} d_{(i)} - E_{o_{(i)}}\right) \times \log_{10} d_{(i)} \end{cases} = 0 \quad (18)$$

This implies that,

$$\sum_{i=1}^{n}\left(C_1 + C_2 \log_{10} d_{(i)} - E_{o_{(i)}}\right) = 0 \quad (19)$$

and

$$\sum_{i=1}^{n}\left(\left(C_1 + C_2 \log_{10} d_{(i)} - E_{o_{(i)}}\right) \times \log_{10} d_{(i)}\right) = 0 \quad (20)$$

By re-positioning the elements, equations (19) and (20) are expressed as;

$$nC_1 + C_2\left(\sum_{i=1}^{n} \log d_{(i)}\right) = \sum_{i=1}^{n} E_{o_{(i)}} \quad (21)$$

$$C_1 \sum_{i=1}^{n} \log d_{(i)} + C_2 \sum_{i=1}^{n}\left(\log d_{(i)}\right)^2 = \sum_{i=1}^{n}\left(E_{o_{(i)}} \times \log d_{(i)}\right) \quad (22)$$

From equation (21),

$$C_1 = \frac{\sum_{i=1}^{n} E_{o_{(i)}} - C_2\left(\sum_{i=1}^{n} \log d_{(i)}\right)}{n} \quad (23)$$

By substituting the value of C_1 in equation (22),

$$\left(\sum_{i=1}^{n} E_{o_{(i)}} - C_2\left(\sum_{i=1}^{n} \log d_{(i)}\right)\right) \times \sum_{i=1}^{n} \log d_{(i)} + nC_2 \sum_{i=1}^{n}\left(\log d_{(i)}\right)^2 = n\sum_{i=1}^{n}\left(E_{o_{(i)}} \times \log d_{(i)}\right) \quad (24)$$

$$C_2 = \frac{n\sum_{i=1}^{n}\left(E_{o_{(i)}} \times \log d_{(i)}\right) - \sum_{i=1}^{n} E_{o_{(i)}} \times \sum_{i=1}^{n} \log d_{(i)}}{\left(n\sum_{i=1}^{n}\left(\log d_{(i)}\right)\right)^2 - \left(\sum_{i=1}^{n} \log d_{(i)}\right)^2} \quad (25)$$

From equation (19),

$$C_2 = \frac{\left(\sum_{i=1}^{n} E_{o_{(i)}}\right) - nC_1}{\sum_{i=1}^{n} \log d_{(i)}}$$

By substituting the value of C_2in equation (22),

$$C_1 \sum_{i=1}^{n}\left(\log d_{(i)}\right) + \left(\frac{\left(\sum_{i=1}^{n} E_{o_{(i)}}\right) - nC_1}{\sum_{i=1}^{n} \log d_{(i)}}\right) \times \sum_{i=1}^{n}\left(\log d_{(i)}\right)^2 = \sum_{i=1}^{n}\left(E_{o_{(i)}} \times \log d_{(i)}\right) \quad (26)$$

$$C_1\left(\sum_{i=1}^{n}\left(\log d_{(i)}\right)\right)^2 + \left(\sum_{i=1}^{n} E_{o_{(i)}}\right) \times \sum_{i=1}^{n}\left(\log d_{(i)}\right)^2 - (nC_1)\sum_{i=1}^{n}\left(\log d_{(i)}\right)^2 = \sum_{i=1}^{n}\left(E_{o_{(i)}} \times \log d_{(i)}\right) \times \left(\sum_{i=1}^{n}\left(\log d_{(i)}\right)\right) \quad (27)$$

So

$$C_1 = \frac{A - B}{C} \quad (28)$$

Where:

$$A = \left(\sum_{i=1}^{n} E_{o_{(i)}}\right) \times \sum_{i=1}^{n}\left(\log d_{(i)}\right)^2$$

$$B = \sum_{i=1}^{n}\left(E_{o_{(i)}} \times \log d_{(i)}\right) \times \left(\sum_{i=1}^{n}\left(\log d_{(i)}\right)\right)$$

and

$$C = n\sum_{i=1}^{n}\left(\log d_{(i)}\right)^2 - \left(\sum_{i=1}^{n}\left(\log d_{(i)}\right)\right)^2$$

The numerical values of the attenuation parameter C_2 and and attenuation constant C_1 in equations (24) and (25) are obtained using the measured data and are presented in Table 2.

Table 2: Table of attenuation constant C_1 and Attenuation parameter C_2 for Networks A, B and C at 1800MHz

Network	Attenuation Constant C_1	Attenuation Parameter 2
A	23.69	-0.3835
B	23.12	-0.4531
C	15.05	-0.5993

7. RESULTS AFTER TUNING

The tuned statistical parameters C_1 and C_2 presented in Table 2 are substituted in the original equation of COST 231 Hata model (equation (23)) as given in equation (29).

$$P_L(dB) = (A_1 + C_1) + A_3 \log_{10}\left(f_{[MHz]}\right) - A_4 \log_{10}\left(h_{tx_{[m]}}\right) - a(h_{rx}) + (A_2 + C_2)\log_{10} d - A_5 \log_{10}\left(h_{tx_{[m]}}\right)\log_{10} d \quad (29)$$

By substituting the measurement data in equation (26) with the values of C_1 and C_2 in Table 2 for the three 1800MHz Networks investigated, the path loss values obtained from the tuned COST 231 Hata model are compared with path loss values estimated from measured received signal strength using Matlab-R2017B software and presented graphically as in Figure 6 through to Figure 8.

8. VALIDATION OF TUNED RESULTS

The validation of a model is a vital aspect of the model tuning and essential to its evaluation are the values of the goodness of fit indices obtained from the analysis of the given model. In this section, the tuned model is validated to ascertain its suitability for the Networks investigated. The Mean Prediction Error (MPE) and Root Mean Square of Errors (RMSE) in equation (9) and equation (10) are used to evaluate the goodness of fit of the developed model, and the computational results are presented in Table 3.

Table 3: Mean Prediction Error (MPE) and Root Mean Square Error (RMSE) values for Networks A, B and C at 1800MHz with the Tuned COST 231 Hata model

NETWORK	MPE (dB)	RMSE (dB)
A	1.17	5.58
B	2.26	7.16
C	6.21	10.78

By comparing the values obtained in Table 1 with that in Table 3 for the COST 231 Hata model, equation (30) and equation (31) are used to calculate the percentage decrease in MPE and RMSE values.

$$\text{Percentage decrease (MPE)} = \frac{Initial\ value_{(MPE)} - Final\ value_{(MPE)}}{Initial\ value_{(MPE)}} \times 100 \quad (30)$$

$$\text{Percentage decrease (RMSE)} = \frac{Initial\ value_{(RMSE)} - Final\ value_{(RMSE)}}{Initial\ value_{(RMSE)}} \times 100 \quad (31)$$

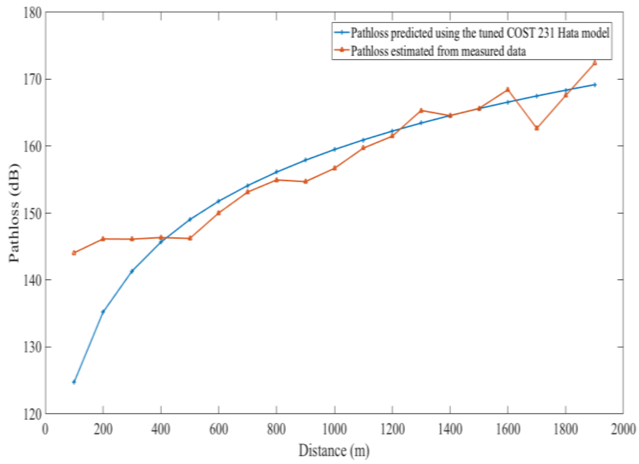

Figure 6: Plot of estimated path loss from measured data and path loss predicted using the tuned COST 231 Hata model for Network A at 1800MHz in NIFOR, Edo state.

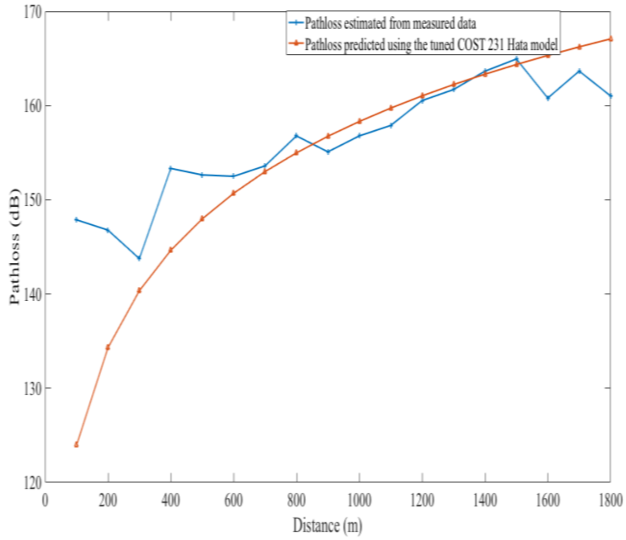

Figure 7: Plot of estimated path loss from measured data and path loss predicted using the tuned COST 231 Hata model for Network B at 1800MHz in NIFOR, Edo state.

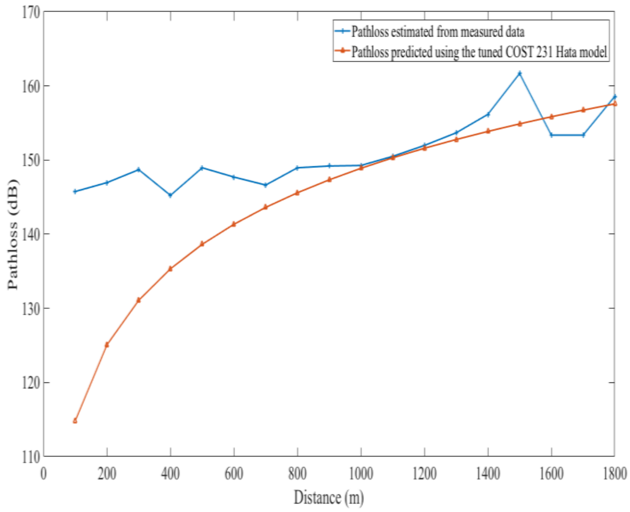

Figure 8: Plot of estimated path loss from measured data and path loss predicted using the tuned COST 231 Hata model for Network C at 1800MHz in NIFOR, Edo state.

Results of this computation show a percentage decrease of MPE values of 95.30%, 91.11% and 65.71% for Networks A, B and C respectively. While a percentage decrease of RMSE values of 78.13%, 72.84% and 46.69% was also obtained for Network A, B and C respectively.

9. CONCLUSION

This paper presents a study into the characteristics of radio signals for a rural environment (NIFOR) in Benin City, Edo state, Nigeria. An experimental campaign was conducted in the study environment using three deployed GSM networks transmitting at

1800MHz. Received signal strength data was collected using an Acer smart phone for three radial directions for a period of 120 seconds in (dBm) for a period of 6 months. Path loss was estimated from the measured data using standard transmit power values and compared with path loss predicted using COST 231 Hata model and ECC-33 model. The COST 231 Hata model equation was tuned using the least square tuning approach. The tuned values of the attenuation constant C_1 and attenuation parameter C_2 obtained can be effectively applied to the COST 231 Hata model equation for predicting path loss. This is because of the low MPE and RMSE values obtained. Results of the tuned COST 231 Hata model gave a percentage decrease of MPE values of 95.30%, 91.11% and 65.71% for Networks A, B and C respectively. While a percentage decrease of RMSE values of 78.13%, 72.84% and 46.69% was also obtained for Network A, B and C. The tuned COST 231 Hata model shows better performance when compared to the original COST 231 Hata model and it can be used to predict path loss in environments with similar terrain profile.

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