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Research article

Comparison of 1800MHz Frequency Bands Path Loss Measurements with Conventional Models in Osun State, Nigeria

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Abstract

The role of propagation models in the planning of wireless network, evaluation of cell parameters and frequency assignment cannot be overemphasized. One of the major difficulties with the application of path loss predicting models for any environment is that no two environments are the same in building patterns, terrain, atmospheric conditions, etc. It is therefore impracticable to formulate a single path loss model for all environments. In this study, an assessment of microwave frequency band measurement results based on received signal strength (RSS) values from four base stations in four urban environments in Osun State, Nigeria, are presented. The measured path loss values of each base station were extracted from the RSS values and compared with the results estimated from five conventional path loss models. Model comparison results based on three metric measures and fitting accuracy showed that a log-normal shadowing model exhibited a better agreement with the measured path loss with RMSE of less than 8 dB, the lowest RE, and R^2 closer to one, in all the environments monitored. The best probable probability distribution for modelling the path loss at the investigated urban environments was also determined. The result of the various distribution functions tested using three goodness of fits showed that the normal distribution function offered the best match with the path loss values based on RMSE, RE, and R^2 values calculated and fitting accuracy for both environments. Practical path loss parameters were also estimated for each of the base stations considered. The overall results should be useful for planning future mobile network channels.

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1. Introduction

Path loss models are essential in the propagation of GSM wireless network and are important in planning wireless communication systems. They are also fundamental in assignment of frequencies, cell parameter evaluation and estimation of interferences. Radio propagation path loss models are meant to provide empirical formulation for radio signal propagation scenario significant to the micro-cellular radio networks as a function of distance, frequency and other visible parameters [1].

Propagation models are classified into three basic categories; empirical, theoretical and physical models [2]. It is difficult to model accurately actual propagation environments due to their complexities. Most simulation studies in practice, use the empirical propagation models formulated based on measurement investigations conducted over a given range of distance for a specific range of frequency and in a particular environment, geographical area or topology. Several propagation path loss models for wireless communication systems had been published in the literature [3-5]. However, choosing a propagation model that is most suitable for a particular environment is not an easy task because of terrain description and variation of land-use acts in different countries.

Several GSM network propagation investigations conducted in Nigeria and several other countries showed that many GSM propagation path loss models performed less effectively in comparison with measured values [6]; this was because they were used in environments that were different from the ones for which they had been designed. Many conventional propagation empirical path loss models in existence can be used to predict path loss over a given distance in a specific terrain. However, they have different approaches in terms of complexity of the terrain and accuracy. Among several propagation models, Cost-231 Hata model, Ericson, Erceg, Standard university interim (SUI) and Log normal shadowing models selected for use in this research work, are the most common propagation path loss models used for predicting signal path losses between transmitter and mobile receiver over irregular and different terrain types by applying desired correction factors.

Cost-231 Hata model: The European commission for Science and Technology project developed a propagation model for outdoor application in urban, suburban and rural environments by extending the original Hata-Okumura model to support higher frequencies up to 2000 MHz. The model also contains corrections for rural, suburban and urban environments. The Cost-231 Hata model basic propagation path loss equation can be expressed as follows [7].

$$P_{loss}(dB) = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - (ah_m) + [44.9 + 6.55\log_{10}(h_b)]\log_{10}(d) + C_m \quad (1)$$

Where d (km) is the distance between transmitter and receiver, f (MHz), is the frequency of transmission, h_b(m) is the base station antenna height. Cm is a correction factor for different terrain type, it is 0 dB for suburban and rural environments and 3 dB for urban environments.

ah_m for urban area is defined as:

$$ah_m = 3.20[\log_{10}(11.75h_r)]^2 - 4.79, for\ f > 300\ MHz \quad (2)$$

For suburban and rural environments, ah_m is:

$$ah_m = [1.11\log_{10}(f_c) - 0.7)h_r - (1.56\log_{10}(f_c) - 0.8] \quad (3)$$

h_r is the mobile receiver height.

Ericson model: Ericsson model is a software provided for network planning engineers by Ericsson Company to predict path loss of wireless network. The path loss expression according to the model mentioned by Mogensen *et al*. [8]

$$P_{loss}(dB) = a_0 + a_1 \log_{10}(d) + a_2 \log_{10}(h_b) + a_3 \log_{10}(d) - 3.3[\log_{10}(11.78 h_r)^2) + g_2(f) \quad (4)$$

Where;

$$g_2(f) = 44.5(\log_{10}(f) - 4.79(\log_{10}(f))^2 \quad (5)$$

f (MHz) is the frequency of transmission, h_b(m) is the antenna height and h_r (m) is the mobile receiver height. The values of the field parameters a_0, a_1, a_2, and a_3 for different environments are given in Table 1.

Table 1. Field parameters for Ericsson model

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	12.00	0.10
Suburban	43.20	68.93	12.00	0.10
Rural	45.95	100.60	12.00	0.10

Erceg Model: This model, formulated by Vinko Erceg, presents a statistical path loss derived from 1900 MHz experimental results across selected suburban environments in the United States of America in existing 95 macro-cells. The model distinguishes between different terrain categories; it can be applied for base station antenna heights from 10 m to 80 m, base to mobile distances from 100 m to 8000 m, and describes three types of terrain categories with correction factors for each terrain type. The expression for the Erceg path loss model is as follows [9].

$$P_{Loss}(dB) = [A + 10\left(a - bh_b + \frac{c}{h_r}\right)\log_{10}(\frac{d}{d_0})] + [10x\sigma_\gamma \log_{10}(\frac{d}{d_0}) + y\mu_\sigma + yz\sigma_\sigma],d0\leq d \quad (6)$$

Where the terms in the first bracket is the median path loss at a distance (d) between the transmitter and mobile receiver over all the cells, and the term in the second bracket is the random variation about the median. x, y and z are zero mean independent Gaussian variables of unit standard deviation. x and z vary from one cell to the other while y is location dependent within each cell. A is the free space path loss, expressed as;

$$A = 20\log_{10}(4\pi d_0/\lambda) \quad (7)$$

Where λ is the wavelength corresponding to the frequency of transmission for this study, while d_0 is the reference distance. Table 2 shows the numerical values of the model parameters for different terrains.

Table 2. Model parameters for Erceg model

Model Parameter	**Terrain Category**		
	Terrain A	**Terrain B**	**Terrain C**
A	4.6000	4.0000	3.6000
b (m^{-1})	0.0075	0.0015	0.0050
c (m)	12.600	17.100	20.000
σ_γ	0.5700	0.7500	0.5900
μ_σ	10.600	9.6000	8.2000
σ_σ	2.300	3.0000	1.6000

Standard University Interim (SUI) model: This is an empirical model recommended by 802.16 standardizing committee. It is an extended Hata model with correction for frequencies above 2000MHz. The SUI model describes three terrain types; terrain A (urban), terrain B (suburban) and terrain C (rural). The basic equation for the SUI path loss model with the correction factors is as follows [10].

$$P_{Loss}(dB) = A + 10\gamma \log_{10}(\frac{d}{d_0}) + X_f + X_h + S,\ \ d0 \leq d \tag{8}$$

Where d (m) is the transmitter-receiver distance, d_0 (m) is the reference distance, X_f is the correction factor for frequencies above 2000 MHz, X_h is the mobile receiver height correction factor, S is the shadow fading factor, γ is the path loss exponent, and A (dB) is the free space path loss expressed in (7).

The path loss exponent γ is expressed as:

$$\gamma = a - bh_b + (\frac{c}{h_b}) \tag{9}$$

Where h_b (m) is the transmitter height between 10 m to 80 m. The values of the constants a, b and c are terrain dependent and are given in Table 3 [10].

Table 3. Model parameters for SUI model

Model Parameter	**Terrain Category**		
	Terrain A	**Terrain B**	**Terrain C**
A	4.6000	4.000	3.600
b (m^{-1})	0.0075	0.0015	0.005
c (m)	12.600	17.100	20.000

The expression for the frequency correction factor X_f is:

$$X_f = 6.0 \log_{10}(\frac{f}{2000}) \tag{10}$$

For mobile-receiver height, the correction factors for terrain A and terrain B are:

$$X_h = -10.8 \log_{10}(\frac{h_r}{2000}) \tag{11}$$

and for terrain C

$$X_h = -20 \log_{10}(\frac{h_r}{2000}) \tag{12}$$

Where f is the transmission frequency in MHz and h_r is the mobile-receiver height in meters.

Log-Normal Shadowing model: Measurement based and theoretical propagation path loss models have shown RSS decreases logarithmically with distance in outdoor or indoor wireless network channels [11].

The average large-scale propagation path loss for an arbitrary transmitter-receiver distance (d) is a function of the path loss at a reference distance (d0), making use of the path loss exponent, n. The basic expression for this model is;

$$P_{Loss}(dB) = P_{Loss}(d_0) + 10n\log_{10}(\frac{d}{d_0}) \tag{13}$$

Where n is the path loss exponent which denotes the rate of increase of path loss with receiver distance from the transmitter.

The value of n depends on the particular propagation environment. It is 2 in free space and will have a larger value when there are obstructions in signal paths [11]. Measurement results have indicated that at any distance (d), the path loss (dB) at a specific location is random and distributed log-normally about the mean distance as [12]:

$$P_{Loss}(dB) = P_{Loss}(d_0) + 10n\log_{10}(\frac{d}{d_0}) + X_\sigma \tag{14}$$

Where X_σ is a zero mean Gaussian distributed random variable with standard deviation σ in decibels (dB). The random shadow fading which occurs over a large number of measurement locations with the same transmitter-receiver distance but have different clutter levels on the propagation path is described by a log-normal distribution. The values of σ and n, in practice, are computed from measured values by linear regression in such a way that the difference between the predicted and measured path losses is minimized in a mean square error sense over a range of transmitter-receiver distances [12].

Table 4 shows the model parameters based on the measured values from the four base stations considered in the urban area of Osun state.

Table 4. Log-normal shadowing model parameters

Model Parameter	**Environment**			
	Ita-Balogun	**Beuris**	**Moore**	**Ondo Road**
N	4.30	4.10	3.80	3.60
σ(dB)	4.00	3.00	5.00	8.00
$P_{Loss}(d_0)$	90.00	90.00	90.00	90.00
(d_0) m	100.00	100.00	100.00	100.00

Abiodun *et al*. [13] had earlier observed similar trend of path loss exponents in the study they carried out on 1800 MHz frequency bands in urban environments of Ekiti state.

The present study, which is concerned with experimentally investigating and determining the closer propagation pathloss model and distribution functions that better suit measured path loss values in the urban environment of Osun state, in the south-western region of Nigeria. In this research work, we investigate the level of performance of five empirical propagation models and five probability distribution functions for two locations each in the urban area of Ilesa and Ile-Ife in Osun state.

2. Materials and Methods

With GSM frequency of L-band (1.8 GHz) radio frequency signals, measurements were conducted during the wet and dry seasons of 2017. The measurement campaign took place in three slightly different environments in Osun State, South-western part of Nigeria. The field measurement survey was carried out at Ita-Balogun quarters and Beuris quarters in Ilesa as well as at Moore and Ondo roads in Ile-Ife, at 1.8 GHz. The sites represented typical urban environments of the state which typified had blocks of densely constructed buildings with height between 3 and 15 meters, market places, hills, parks, mountains and trees of average height. Typically, more than 75% of the environments were filled with houses constructed with concrete, blocks and tiles. The Google map and environmental view of the environments are shown in Figures 1 and 2.

A drive test was performed to measure the RSS levels of GSM base station transmitters using a Sony Ericsson TEMS phone equipped with TEMS software. The device was connected via a USB cable to a laptop equipped with TEMS software. A GPS receiver was also connected to measure the location, elevation, coordinates as well as the distance between the transmitter and the mobile receiver [2]. In each of the sites, measurements were carried out at distances ranging from 50 to 1,200 meters and path loss values averaged at 50-meter interval along each sector of each base transmitter station considered. Measured RSS values were also recorded in a log file for each of the sites. The transmitting power of the transmitter at 1800 MHz was +43 dBm while the sensitivity of the mobile receiver was -110 dBm and height of 1.2 meters. Detailed features of the base stations and the characteristics of each of the sites are shown in Table 5.

2.1 Path loss calculation

The path loss in dB is calculated from the measured RSS values using [1, 14]:

$$\mathrm{P}_{Loss}\,(\mathrm{dB}) = \mathrm{P_t} + \mathrm{G_t} + \mathrm{G_r} - \mathrm{L_C} - \mathrm{RSS} \tag{15}$$

Where P_{Loss} is the path loss, $\mathrm{P_t}$ is the transmitting antenna power, $\mathrm{G_t}$ is transmitting antenna gain, $\mathrm{G_r}$ (2 dB) is the receiving antenna gain, and $\mathrm{L_C}$ (10 dB) is the cable loss.

Figure 1. A typical urban environment path in Ilesa

Figure 2. A typical map showing one of the investigated urban environments (Moore)

Table 5. Details of the base stations and characteristics of each of the sites in the urban environment

Name of base station	Cell identity code	Coordinate		Elevation (m)	Antenna height (m)	Antenna type	Frequency (MHz)	Antenna gain (dB)
		°N	°E					
Ita-Balogun	OS2836	7.63	4.74	396.00	36.00	Sectorial	1800.00	17.00
Beuris	OS3023	7.62	4.79	412.00	36.00	Sectorial	1800.00	17.00
Moore	OS3080	7.46	4.54	278.00	36.00	Sectorial	1800.00	17.00
Ondo Road	OS3798	7.49	4.57	310.00	36.00	Sectorial	1800.00	17.00

2.2 Evaluating the performance of propagation and distribution models

Three different statistical goodness of fits were selected as tools for checking how accurately the theoretical propagation and distribution function fitted with the measured path loss. The statistical tools were: Root Mean Square Error (RMSE), a RMSE value between 6 to 8 dB indicates a better fit for urban environments [15], Relative Error (RE) and Coefficient of Determination (R^2). The closer the value of R^2 to 1, the better the fit to the measured variables. The equations for the fitness tools are given as;

$$RMSE = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(P_m(j) - P_r(j))^2} \tag{16}$$

$$RE = \sum_{j=1}^{n}\left[\frac{P_m(j) - P_r(j))}{P_m(j)}\right] \times 100 \tag{17}$$

$$R^2 = \left[\frac{n(\sum_{j=1}^{n} P_m(j)P_r(j)) - ((\sum_j^n P_m(j))(\sum_j^n P_r(j))}{\sqrt{[n\sum_{j=1}^{n}(P_m(j))^2 - (\sum_{j=1}^{n} P_m(j))^2][(n\sum_{j=1}^{n}(P_r(j))^2 - (\sum_{j=1}^{n} P_r(j))^2]}}\right]^2 \tag{18}$$

Where $P_m(j)$ is the jth measured path loss, $P_r(j))$ is the jth estimated path loss.

3. Results and Discussion

Path loss values have been estimated using the five models discussed earlier. These models were chosen because they were suitable for frequencies ranging from 900 MHz to 1900 MHz, and were data dependent. In addition, path loss can be estimated by these models as a function of various field parameters and application of correction factors.

Figures 3 to 6 present the comparison of the measured and predicted path losses for the four urban locations considered. The observed path loss values for the four base stations investigated were estimated for distances ranging from 50 to 1200 m. At some distances close to the base station, path loss values of about 90 to 110 dB were observed, except for Beauris base station in Ilesa where high path loss values of up to about 120 dB was observed at distances closer to the base station. This could possibly have been a result of high-rise trees around sector A of the base station. Generally, the lowest measured path loss value observed was 90 dB, and the highest was about 150 dB. The measured RSS values were observed to be increasing with transmitter-receiver separation in all the monitored base stations. Figures 3 to 6 also revealed that the SUI model in all the four environments overestimated the measured path loss by about 18 to 22 dB while the Ericsson model over predicted the measured values by approximately 2 to 8 dB from 50 m to around 650 m away from the transmitter and passed through the upper edge of the measured values onward showing some level of agreement. The Erceg model curve passed through the centre of the measured path loss from about 100 m to around 500 m showing a good agreement with the measured data but deviated onward up to around 1000 m and passed through the upper edge of the measured values thereafter, as depicted in Figures 5 and 6. However, at the Ita-Balogun and Beauris base stations, the Erceg model over predicted the measured values by 2 to 5 dB at all distances considered, as presented in Figures 3 and 4. The Cost-231 Hata model overestimated the measured values by about 3 dB at distances close to the transmitter up to around 480 m but showed slightly better agreement from 480 m onward than the SUI, Erceg and Ericsson models at all the four base stations. Generally, the log-normal model produced the better agreement with the measured data when compared with the other empirical models.

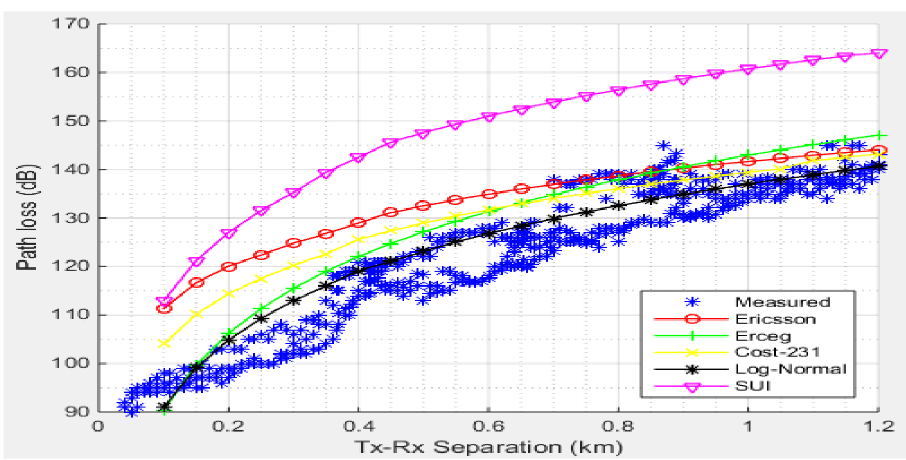

Figure 3. Comparison of various models with measured values for Ita-balogun base station

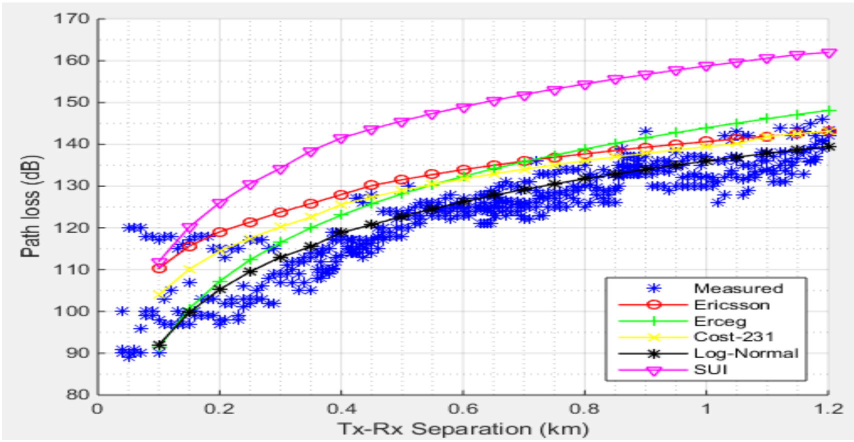

Figure 4. Comparison of various models with measured values for Beuris base station

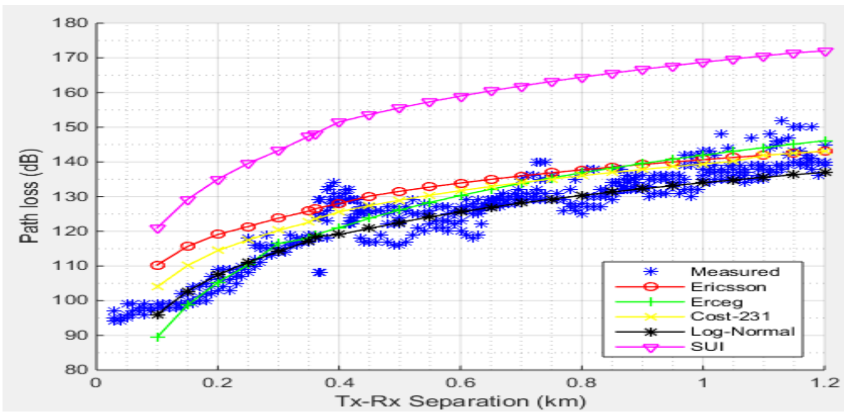

Figure 5. Comparison of various models with measured values for Moore base station

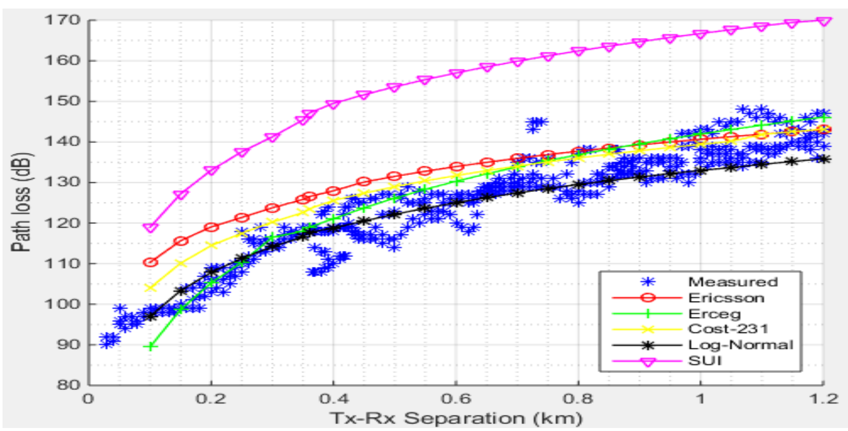

Figure 6. Comparison of various models with measured values for Ondo road, Ile-Ife base station

Table 6 presents the statistical evaluation of the selected models based on root mean square error, relative error and coefficient of determination evaluations. The errors are estimated for transmitter-receiver separation ranging from 50 to 1200 m for the four different base stations. The results reveal that the error statistics for the log-normal model are least when compared to the other prediction models considered in this study. The average root mean square error was 7.11 for log-normal model, while for other models, the RMSE values were 8.47, 9.35, 12.62 and 17.65 for Cost-231 Hata, Erceg, Ericsson and SUI model, respectively. The log-normal model also exhibited the least relative error between 17 and 20% followed by Cost-231 Hata model between 24 and 26% when compared to the other models. The SUI model exhibited the highest relative error between 43 and 47%, indicating a wide range of deviation from the measured path loss values as observed in a similar urban environment of Ekiti state [13].

Based on the results, it was observed that the log-normal and Cost-231 Hata models showed symmetry at some distances from the base station as depicted in Figures 7 to 10, for example, in Ita-balogu environment, the error between both models and the measured values were symmetrical from around 0.7 km to 1.2 km. A similar trend could be seen in the other environments although at different distances from the base station, with log-normal shadowing model giving the best results in all monitored environments.

Figure 11 also presents a typical statistical distribution that can model accurately the measured path loss values at Ilesa. The results show that the normal distribution more closely matches the measured path loss values than other distribution functions, followed by the Weibull distribution. Although, not shown here, a similar trend could also be observed in the distribution of path loss values at the other locations in the Ile-Ife environment.

Table 7 summarizes the performance evaluation of the distribution functions based on the selected different metric measures. It can be seen that the normal distribution shows the best statistical fit in modelling the path loss values for the Ilesa environment with RMSE of 4.15 dB, relative error of 8.50% and R^2 of 0.972. The normal distribution was relatively followed by the Weibull distribution with RMSE of 6.8 dB, relative error of 9.70% and R^2 of 0.969 when compared with the other distribution functions. This was in accordance with the work of Abiodun and Ojo [16] and Ukhurebor and Aigbe [17].

The overall result of this study indicates that both log-normal and Cost-231 models could be the most suitable models for path loss estimation in the studied region, as precisely reported by Ojo *et al*. [1], while both the normal and the Weibull distribution functions were the best distribution functions for modelling the urban pathloss values in the studied locations. However, it must be noted that other factors such as climate variables and refractivity indices as reported by previous studies [18-25], could also affect the base-mobile propagation systems.

4. Conclusions

In this paper, the experimental study of radio channel behaviour and prediction of propagation model based on the path loss measurement in the 1800 MHz frequency bands was presented. The investigation was carried out in four urban environments of Osun State, South-western Nigeria. Prediction of measured path loss values was carried out using five propagation prediction models, namely the log-normal shadowing model, the Cost-231 Hata model, the Erceg model, the SUI model and the Ericsson model. The comparison of measured path losses with the different prediction models and their statistical error analysis showed that the log-normal shadowing model gave a better prediction for distances up to about 1100 m from the base station, and exhibited the lowest RMSE and relative error values followed by the Cost-231 Hata model, which exhibited a better fit

Table 6. Performance evaluation of the prediction models for modelling measured path loss

Model	Ita Balogun			Beuris			Moore			Ondo Road		
	RMSE (dB)	**RE (%)**	**R^2**	**RMSE (dB)**	**RE (%)**	**R^2**	**RMSE (dB)**	**RE (%)**	**R^2**	**RMSE (dB)**	**RE (%)**	**R^2**
Shadowing	6.50	17.02	0.78	6.45	17.50	0.68	8.20	20.13	0.80	7.30	20.10	0.77
Cost-231	8.70	25.00	0.72	8.60	25.25	0.66	8.61	24.04	0.69	8.00	24.50	0.70
Erceg	9.85	25.23	0.66	10.01	26.00	0.56	9.00	23.09	0.68	8.55	22.80	0.63
Eric.	13.00	28.70	0.60	13.04	30.40	0.50	12.05	27.33	0.59	12.40	27.09	0.60
SUI	17.00	45.00	0.50	17.60	43.50	0.45	18.02	47.08	0.47	18.10	46.80	0.47

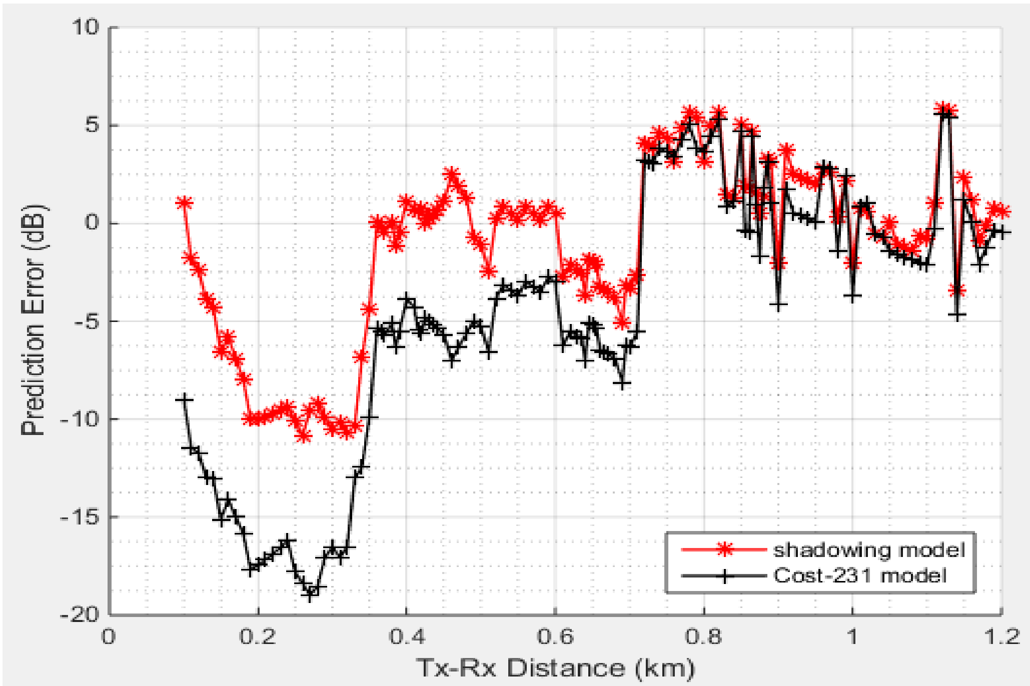

Figure 7. Prediction error of Ita-balogun environment

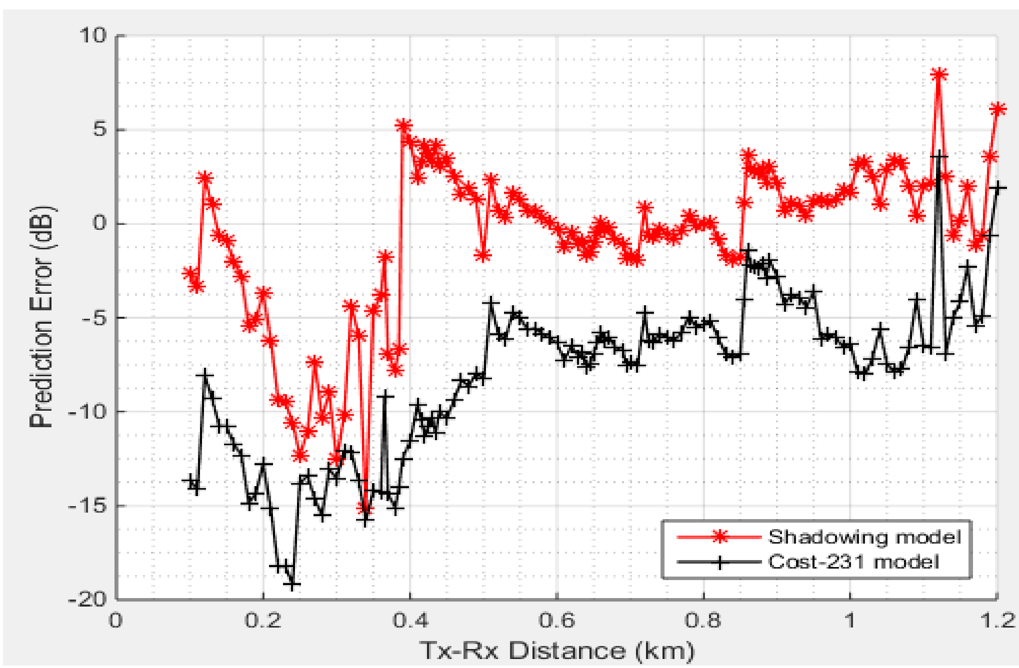

Figure 8. Prediction error of Beuris environment

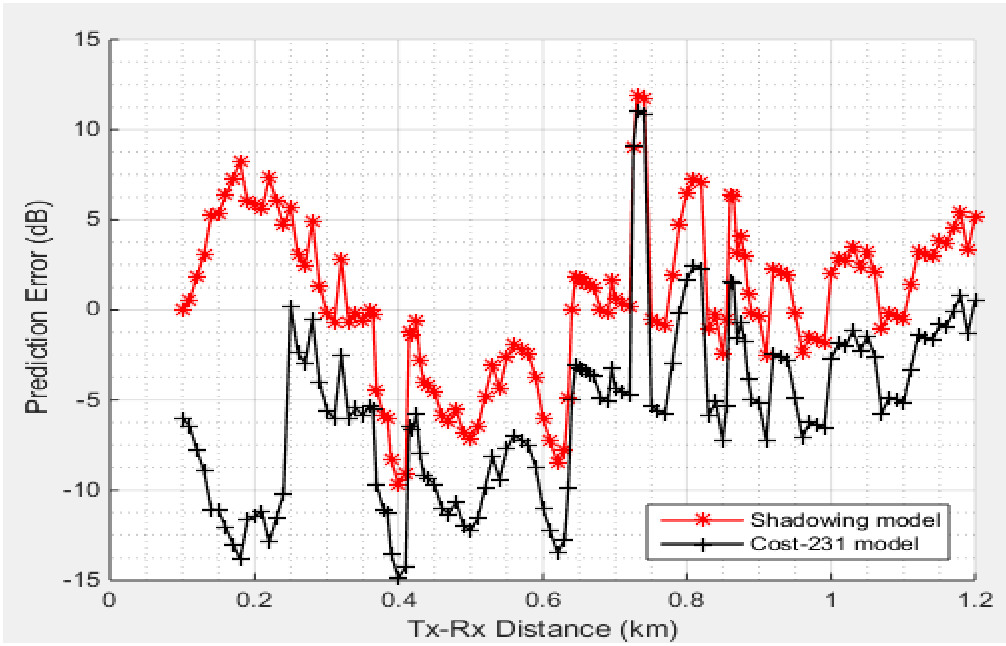

Figure 9. Prediction error of Ondo road environment

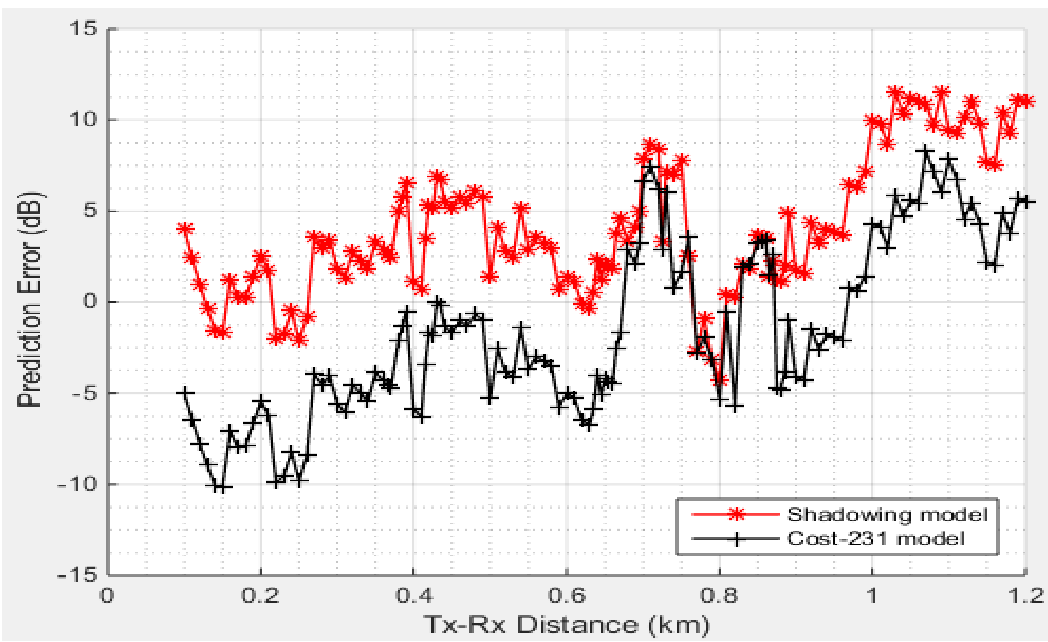

Figure 10. Prediction error of Moore environment

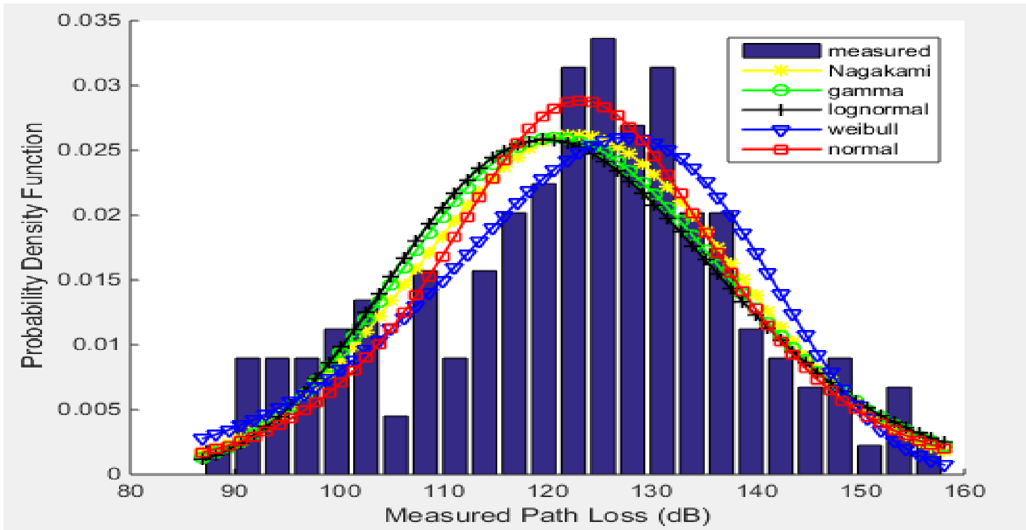

Figure11. Fitting of Probability distributions to the measured path loss values in Ilesa environment

Table 7. Performance evaluation of statistical distribution for modelling measured path loss

Statistical distribution	Ilesa			Ile-Ife		
	RMSE (dB)	RE (%)	R^2	RMSE (dB)	RE (%)	R^2
Weibul	6.80	9.70	0.67	6.73	10.00	0.64
Gamma	9.50	10.60	0.66	7.55	9.50	0.60
Nakami	10.20	12.61	0.55	9.00	11.00	0.57
Normal	4.15	8.70	0.68	3.90	8.55	0.66
Log-normal	6.90	11.00	0.66	6.45	11.20	0.60

with the measured path loss values at higher distances from 600 m, and lower RMSE and relative error values when compared with the Erceg, Ericsson and Standard University Interim models. Fitting of the various distribution functions with the measured path loss values showed that the normal distribution function was the best probability distribution function for modelling path loss at the Ilesa and Ile-Ife urban areas in Osun state, with the least root mean square error, relative error and coefficient of determination closer to one, when compared with the Weibull, gamma, Nakagami and log-normal probability distribution functions. Practical field parameters such as path loss exponents and shadow fading values were also calculated from measured path loss values for the estimation of log-normal model in each studied environment.

However, adjustment of the Cost-231-Hata model is essential for a better fit with the measured path loss values in order to minimize the prediction error. The results of this investigation will be useful in the prediction of future reliable links for base-mobile propagation systems in the studied urban areas. It is therefore suggested that some other recent innovative models that incorporate smart applications should be included in future research.

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