JJEE
Volume 4, Number 2, 2018
Pages 114-128
Jordan Journal of Electrical Engineering
ISSN (Print): 2409-9600, ISSN (Online): 2409-9619

Path Loss Characterization of Long Term Evolution Network for Lagos, Nigeria

Agbotiname L. Imoize[a], Abiodun I. Dosunmu[b]

Department of Electrical and Electronics Engineering, University of Lagos, Akoka-Lagos, Nigeria
[a]e-mail: aimoize@unilag.edu.ng
[b]e-mail: abiodun_dosunmu@yahoo.com

Received: March 28, 2018 *Accepted: May 24, 2018*

Abstract— Results of propagation measurements campaign at 1900MHz in selected hotspot areas in Lagos, Nigeria, were compared against predictions made by some existing path loss models. Findings showed that the free space model, Ericsson 9999 model, ECC-33 model, and the SUI model over predict the path loss along the investigated routes in the hotspot areas, with root mean squared errors (RMSEs), relatively higher than the acceptable range of up to 6.0dB. The COST 231-Hata model showed the most promising performance with RMSEs of 4.63dB, 7.36dB and 4.45dB at the University of Lagos (UNILAG), Ikorodu and Oniru, respectively. In order to improve the prediction accuracy of the COST 231 Hata model, there is a need to optimize the model. Results showed that the optimized model predicted the path loss obtained from the fixed base stations at UNILAG, Ikorodu and Oniru with improved RMSEs of 4.61dB, 5.70dB and 4.43dB, respectively. These RMSEs are found to be within the acceptable range of up to 6.0dB; and are acceptable for quality signal prediction in the investigated environments.

Keywords— 4G LTE network, COST 231-Hata model, hotspot areas, minimum mean square error, optimization, path loss characterization, propagation measurements, root mean squared error.

I. INTRODUCTION

Mobile and wireless communication systems have tremendously developed over the years leading to research works on developing techniques to increase capacity and improve quality of service for subscribers. The trend in the development of wireless communication requires the use of higher data rates and speed as well as a good quality of service [1]. With the evolution of cellular network, there is a tremendous need for internet access by mobile users. Today, mobile users access the internet at various places and environments like homes, offices, even public locations such as hotspot areas like airports, shopping malls, hotels, restaurants, libraries, and other places where mobile users can spend a lot of time outside private networks. Wireless access points known as Wi-Fi Hotspots are available in public locations, providing local coverage to these mobile users [2]. However, these cellular networks require tools for wireless network planning for ease of deployment in any geographical location. These tools often referred to as propagation models are very useful for proper network planning and deployment.

The evolution of wireless network requires the knowledge of propagation models, which are specifically developed in order to help predict path loss in different hotspot areas and provide design guidelines for mobile network operators. The strength of a network signal reduces as it propagates through space due to parameters such as distance, reflection, diffraction and scattering [3]. In [4], a comparative analysis of a typical LTE network was reported at 1000MHz, 1500MHz and 2000MHz, using the well-known Okumura-Hata and COST 231-Hata models. It was reported that the COST 231-Hata model provided a lower path loss at 200m than the Okumura-Hata model in urban environment.

Corresponding author's e-mail: aimoize@unilag.edu.ng

Similarly, Shabbir et al. [5] reported a related work, using measurements taken at 1900MHz and 2100MHz. Here, the authors compared the measured data with the Stanford University Interim (SUI) model, Ericsson 9999 model, and the COST 231-Hata model. Results revealed that the SUI model shows the lowest path loss predictions at the operating frequencies of 1900MHz and 2100MHz, at 30m and 80m. This is perhaps to be expected due to the impact of the BS heights and frequency selection, as the higher the BS height, the better the path loss. Dalela [6] reported a related study for LTE Advanced network at 2400MHz, 2600MHz and 3500MHz. In addition, Dalela [1] reported a comparative study of radio channel propagation and modeling for a 4G network at 1900MHz, 2100MHz and 2300MHz. The results of both studies reveal that the COST 231-Hata model provided the least path loss. This is perhaps due to its adaptability and availability of correction factors to ease the applicability of the model in different environments. In the same vein, Rani et al. [7] presented a comparison of a standard propagation model (SPM) and the SUI model for LTE network at 1900MHz and 2100MHz. Results show that the SPM model is a preferred candidate to the COST 231 Hata model in terms of performance and least path loss.

In the existing literature, most authors are proposing models through a comparison of existing radio wave propagation models for 4G LTE network with field tests in the environments of interest. However, there arises a problem when inappropriate propagation models not suitable for an environment are applied especially to environments other than the ones for which they were designed. This often results in poor quality of service; and there is a need to perform appropriate measurements-based analyses on these models to derive the most suitable model for the investigated environment.

The existing free space models, Okumura model [8], COST 231 Hata model [9], SUI model [9], and the Ericsson 9999 model [10], have been reported for flat and mountainous terrains, rural, suburban, and urban areas. However, to the best of our knowledge, there has not been a fair treatment of specific models for applications in hotspot areas especially for the Nigerian scenario. In this paper, we propose a suitable model for predicting path loss for 4G LTE deployment in hotspot areas, based on field measurement campaigns at 1900MHz, a suitable frequency band in 4G LTE networks. We identified the best-fit propagation model among the contending models; and presented an optimized model based on the existing COST 231 Hata model for path loss prediction in the tested LTE network in Lagos, Nigeria.

The remainder of this paper is organized as follows. Section II presents theoretical background; and Section III covers propagation measurements. Section IV presents the results of the measurement campaign and discussions. Finally, Section V draws conclusion to the paper; and states useful recommendations for future studies.

II. THEORETICAL BACKGROUND

A) Propagation Models

These models are mathematical tools used by engineers and scientists to design wireless communication systems. Path loss prediction plays a vital role in the design of cellular systems where transmission power, frequency and antenna heights are key parameters. There are different path loss models to be considered based on some parameters such as frequency, antenna heights, and propagation distance, which will aid in the selection of an appropriate propagation model for a particular environment. These models can be broadly categorized into three types: empirical, deterministic and stochastic.

1) Empirical Models: These models are based on observation and measurement of data. They are not very accurate. These models are mainly used to predict the path loss of the measured data in the area of interest. Empirical models can be categorized into two parts, namely time dispersive and non-time dispersive. Typical examples of empirical model are Stanford University Interim (SUI) model, COST 231-Hata Model, COST 231-Walfish-Ikegami Model, Okumura Model and ITU-R. Examples of non-time dispersive empirical models include, Hata-extension of Okumura model [8].

2) Deterministic Models: These models are a site-specific (SISP) propagation model, which requires an enormous number of geometry information about the site. These models utilize the laws guiding electromagnetic wave propagation to determine the received signal power at a particular location. These models often require a complete 3D map of the propagation environment. Ray-tracing models are the best example of the deterministic model. Unlike empirical models, ray-tracing technique does not provide simple formulae for the calculation of path loss [11].

3) Stochastic Models: These models utilize statistical tools to describe the investigated environment as a series of random variables [9]. They require the least information about the environment; and use less significant processing power to generate predictions. However, these models predict mean path loss as a function of various parameters such as distance, antenna heights and other dynamic factors.

B) Propagation Models Used for Comparison

The propagation models used for comparison with the measured data are briefly described as follows:

1) Free Space Path Loss Model: This model assumes an ideal situation. Here, it is assumed that there is no obstruction in the pathway between the transmitter and receiver. There is a loss in signal strength because of the line of sight path (LOS) through free space (usually air). During propagation, the reduction in signal which travels through space from the transmitter to the receiver causes path loss. The free space propagation loss is given in [12] as (1). This shows the relationship between the path loss, frequency and distance of the transmission medium.

$$\mathrm{PL(dB)} = 32.45 + 20\log_{10}(\mathrm{d}) + 20\log_{10}(\mathrm{f}) \tag{1}$$

where f =frequency in MHz and d = distance in Km.

2) COST 231 Hata model: This is a radio propagation model that is widely used for path loss prediction in wireless communication systems. It is based on Hata-Okumura model to provide more range of frequencies. It is designed for a frequency range of 1500-2000MHz mobile antenna height ranges from 1m and 10m, while base station antenna height ranges from 30m and 200m. The distance required between the transmitter and receiver ranges between 1km and 20km. It is applicable to urban, suburban and rural environments with correction factors. This model is quite simple and easy to use for path loss prediction; the path loss for this model is given [9], [13];

$$\mathrm{P_L(dB)} = 46.3 + 33.9\log(\mathrm{f}) - 13.82\log(\mathrm{h_b}) - \mathrm{a(h_r)} + [44.9 - 6.55\log(\mathrm{h_b})]\log\mathrm{d} + \mathrm{c} \tag{2}$$

where f is frequency in MHz; d is distance between transmitter and receiver in km; h_b is base station antenna height above ground level in meters. The parameter c is 0dB for suburban or open environment; and 3dB for urban environments. $a(h_r)$ is defined for urban environments as:

$$\mathrm{a(h_r)} = 3.20\ [\log(11.75\mathrm{h_r})]^2 - 4.97\ \mathrm{f} \geq 400\mathrm{MHz} \tag{3}$$

where h_r is mobile antenna height in meters.

3) Ericsson 9999 Model: In order to predict propagation path loss to ensure high degree of reliability, network-planning engineers used a model developed by Ericsson Company. This model is based on the modification of the Okumura-Hata model to allow changes in parameters according to propagation environments. The frequency used is up to 1900MHz; and the path loss prediction for this model is given in [10], [14]:

$$\mathrm{P_L} = \mathrm{a_0} + \mathrm{a_1}\log_{10}(\mathrm{d}) + \mathrm{a_2}\log_{10}(\mathrm{h_b}) + \mathrm{a_3}\log_{10}(\mathrm{h_b}).\log_{10}(\mathrm{d}) - 3.2(\log_{10}(11.75\mathrm{h_r})^2) + \mathrm{g(f)} \tag{4}$$

where $g(f) = 44.49\ log_{10}(f) - 4.78\big(log_{10}(f)\big)^2$; f is frequency in MHz; $h_b$is base antenna height in meters; and $h_r$is receiver antenna height in meters.

The parameters $a_{0,}a_1, a_2, and\ a_3$ in (4) are constants, which can be changed depending on the environment. The parameter values for Ericsson 9999 model are as shown in Table 1.

TABLE 1

PARAMETER VALUES FOR ERICSSON 9999 MODEL

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	-12.0	0.1
Suburban	43.20	43.20	12.0	0.1
Rural	45.95	45.95	12.0	0.1

4) ECC-33 Path Loss Model: ECC-33 Model is the mostly used empirical propagation model. It is based on the popular Okumura model for the UHF (Ultra High Frequency) band due to its accuracy for higher frequencies. A different approach taken by the Electronic Communication Committee (ECC) contributed to extrapolation of the original measurements obtained from Okumura model and modification of its assumptions. Abhayawardhana *et al.* [9] gives the path loss for the ECC-33 model as:

$$P_L = A_{fs} + A_{hm} - G_b - G_r \tag{5}$$

where $A_{fs}, A_{hm}, G_b\ \ and\ G_r$ are the free space attenuation in dB, the basic median path loss in dB, base station height gain factor and receiver antenna height gain factor, respectively. These parameters are defined as:

$$\mathrm{A_{fs}} = 92.4 + 20\log_{10}(\mathrm{d}) + 20\log_{10}(\mathrm{f}) \tag{6}$$

$$\mathrm{A_{hm}} = 20.41 + 9.83\log_{10}(\mathrm{d}) + 7.984\log_{10}(\mathrm{f})\ 9.56[\log_{10}(\mathrm{f})]^2 \tag{7}$$

$$\mathrm{G_b} = \log_{10}(\mathrm{h_b}/200)\{13.958 + 5.8[\log(\mathrm{d})]^2\} \tag{8}$$

$$\mathrm{G_r} = [42.57 + 13.7\log_{10}(\mathrm{f})]\ [\log_{10}(\mathrm{h_r}) - 0.585] \tag{9}$$

where $f$is frequency in GHz; d is distance between transmitter and receiver in km; $h_b$is base station antenna height in meters; and h_r is receiver antenna height in meters.

5) Stanford University Interim (SUI) Model: The Stanford University Interim (SUI) model is developed for applications in Institute of Electrical and Electronics Engineers, IEEE 802.16. The frequency band required is from 2.5 GHz to 2.7 GHz. In this model, there are three types of terrains called terrains A, B and C. Terrain A is associated with the highest path loss in a very dense populated region. Terrain B is associated with moderate path loss or very dense vegetation, a suburban environment. Terrain C has the least path loss, which represents a flat area. According to [14], the path loss for this model is as shown in (10).

$$P_L = A + 10\gamma \log\left(\frac{d}{d_0}\right) + X_f + X_h + S \quad d > d_0 \tag{10}$$

where d is the distance between the transmitter and receiver in meters; d_0=100m; X_f is the frequency correction factor; X_h is the base station height correction factor; A is the free space path loss; γ is path loss exponent; and S is the shadowing factor. The path loss exponent from (10) is given as:

$$\gamma = a - bh_b + \frac{c}{h_b} \tag{11}$$

where h_b is the base station height; a, b and c are terrain factors listed as shown in Table 2. The free space path loss from (10) is given as:

$$A = 20\log\left(\frac{4\pi d_0}{\lambda}\right) \tag{12}$$

where $d_0$is distance between transmitter and receiver; and λ is the wavelength in meters. The correction factor for frequency and base station height for various terrains is given as:

$$X_f = 6\log\left(\frac{f}{2000}\right) \tag{13}$$

$$X_h = -10.8\log_{10}\left(\frac{h_r}{2000}\right) \text{ for terrain type A and B} \tag{14}$$

$$X_h = -20\log_{10}\left(\frac{h_r}{2000}\right) \text{ for terrain type C} \tag{15}$$

where f is the frequency in MHz; and h_r is the height of receiver antenna.

TABLE 2
DIFFERENT TERRAIN PARAMETERS FOR SUI MODEL

Parameters	Terrain A	Terrain B	Terrain C
A	4.6	4	3.6
B (1/m)	0.0075	0.0065	0.005
C (m)	12.6	20	20

III. PROPAGATION MEASUREMENTS

A) Investigated Environments

The investigated environments are the University of Lagos, Ikorodu and Oniru, all located in Lagos, Nigeria. Lagos falls within the South-West geo-political zone of Nigeria and currently estimated to be the second fastest growing city in Africa and the seventh in the world with a population over 21 million people, occupying 999.6km^2 of land out of which 171.68km^2 is water. Most of the population lives on the mainland; and most industries are located there too. The city of Lagos is the main city of the southwestern part of Nigeria. Some rivers, like Badagry Creek, flow parallel to the coast for some distance before exiting through the sand bars to the sea. The two major urban islands are Lagos Island and Victoria Island. These Islands are separated from the mainland by the main channel draining the lagoon into the Atlantic Ocean, which forms Lagos Harbor. The Islands are separated from each other by creeks of varying sizes; and are connected to Lagos Island by Bridges. Lagos boasts of Africa’s longest bridge called Third Mainland Bridge.

B) Selected Environments

The selected environment includes the University of Lagos campus and two shopping malls located in Lagos. The University of Lagos popularly known as UNILAG is a federal government University in Lagos State, Southwestern Nigeria. It is situated on latitude 6^{o} 31’ 0’’ North of the Equator and longitude $3^{o}23^{'}10^{''}$ East of the Greenwich meridian, located at Akoka, Yaba, Lagos. It is a Centre for Academic Research. Fig. 1 shows the entrance road of the campus. Maryland shopping Mall also known as the Big Black Box is situated at Ikorodu Road, Anthony Village located in Lagos, Nigeria. It is one of the most important traffic routes in Lagos. The hall sits on a total land size of 7,700sqm; and the building contains a variety of stores and a cinema. Fig. 2 and Fig. 3 show the front and side view of the mall, respectively. The Palms Shopping Mall is located at Lekki, Lagos, Nigeria on latitude $6^{o}26^{'}9^{''}$ North of the Equator and longitude 3^{o} 27’ $4^{''}$ East of the Greenwich Meridian. The mall sits on a 45,000 square-meter plot of land. The shopping mall is the second largest shopping mall by gross leasable area and first of its kind in Nigeria. Major anchor tenants at the mall include Game, ShopRite and The Hub Media Store. Restaurants and hostels such as the Prest Lunch and Dinner Cruise, Villa Toscana Hotels, and Lekki Peninsula surround the mall. The mall is surrounded by public locations with hotspot. Fig. 4 shows the front view of “The Palms”.

Fig. 1. University of Lagos (UNILAG) campus road

Fig. 2. Front view of Maryland shopping mall

Fig. 3. Side view of Maryland shopping mall

Fig. 4. Front view of the Palms shop

C) Experimental Setup

The measurement equipment comprises of Huawei Modem E392 and a GPS unit to accurately track the location of the mobile equipment. These are connected via a USB hub port to a personal computer with Genex probe (Drive Test software) installed. The modem receives data from the base station via internet; and sends it to the personal computer, which stores the data as recorded log files. The recorded log files were extracted and analyzed using MapInfo Professional tool (version 12.0), and MATLAB software. Fig. 5 shows the diagram of the experimental set-up for the drive test. Field measurements were recorded within a propagation distance of 400m with reference distance of 20m at an interval of 20m, and recording time of approximately 5 seconds. The mobile height was set at a near constant height of 1.5m with base stations heights in the range 34-50m. Table 3 shows the model parameters [15].

Fig. 5. Pictorial view of the experimental set-up

TABLE 3
PARAMETERS FOR PROPAGATION MODELS

Parameters	Values
Operating Frequency	1900MHz for all environments
Distance between Tx-Rx	400m
Base Station Transmitted Power	43dBm
Transmitter antenna height in each environment.	30m in Urban
Receiver antenna height	1.5m
Average Height of building	25m
Average separation between buildings.	30m
Street Orientation angle	90^o in urban area
Correction factor for Shadowing	10.6 dB in urban area

IV. RESULTS AND DISCUSSION

Results of Mean Reference Signal Received Power RSRP in (dBm) from three different locations are as shown in Fig. 6. The signal strength for each of the location measured at a distance $d\ (km)$ is converted into path loss $PL_m(dB)$; and is given [10], [15], [16] as:

$$\mathrm{PL_m(dB) = EIRP_t\ (dBm) - P_r(dBm)} \tag{16}$$

where $EIRP_t$ is effective isotropic radiated power in dBm; and P_r is mean reference signal received power (RSRP). The effective isotropic radiated power $EIRP_t$ is given as:

$$\mathrm{EIRP_t = P_T + G_T - L_T} \tag{17}$$

where P_T is transmitter power in dBm; G_T is transmitter antenna gain in dBi; L_T is total transmission losses in dB.

The values of the transmitter power, transmitter antenna gain and the total transmission loss are given as [10]: $P_T = 43\ dBm$, $G_T = 18\ dBi$, and $L_T = 22\ dB$.

Substituting these values into (17) gives;

$$\mathrm{EIRP_t = 43 + 18 - 22 = 39dBm}$$

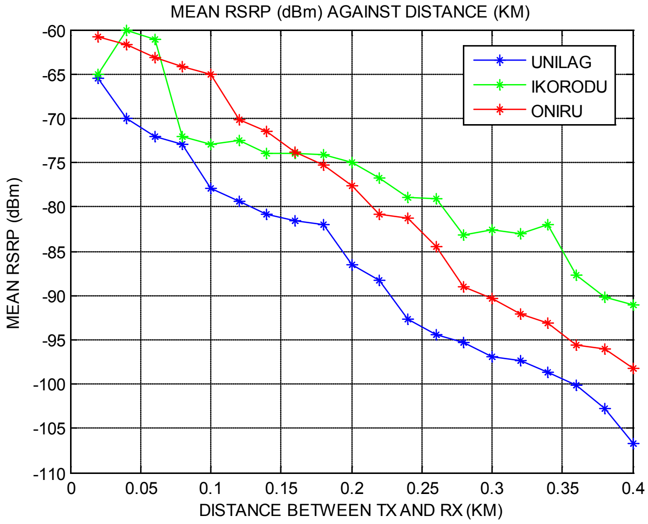

Fig. 6. Mean reference signal received power (RSRP) in Unilag, Ikorodu, and Oniru

The path loss values measured in dB are obtained by substituting the calculated value of $EIRP_t\ (dBm)$ and the measured values of $P_r(dBm)$ into (16). Path losses of the measured data at 1900MHz for 1.5m mobile antenna heights at three locations are compared as shown in Fig. 7. Transmitter and receiver distance increases in steps of 20m from 20m to 400m and receiver antenna height 1.5m. Path loss prediction with the measured path loss is shown in Fig. 8, Fig. 9, and Fig. 10, for UNILAG, Ikorodu and Oniru, respectively.

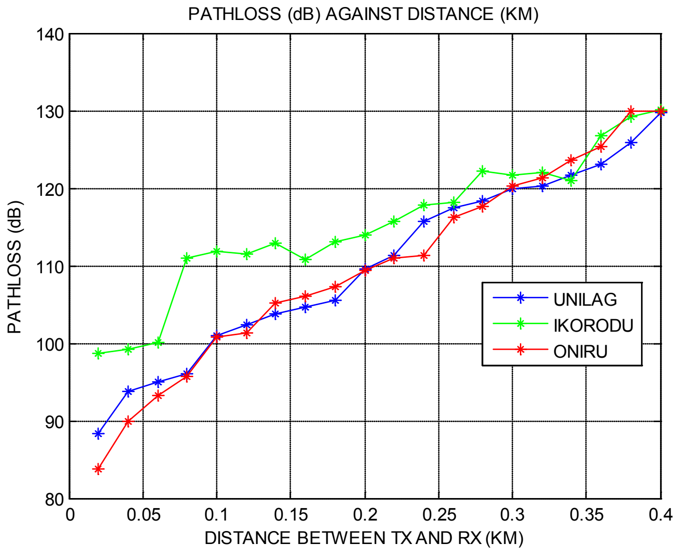

Fig. 7. Measured path loss in Unilag, Ikorodu and Oniru

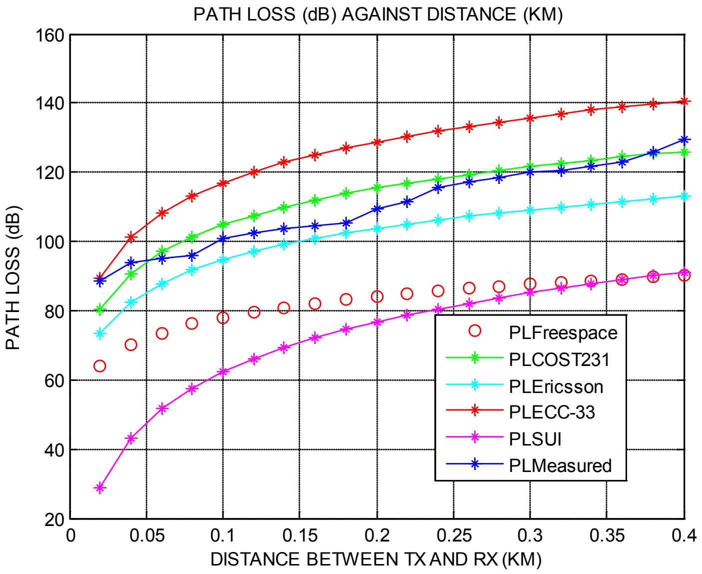

Fig. 8. Comparison of the measured and predicted path loss in Unilag

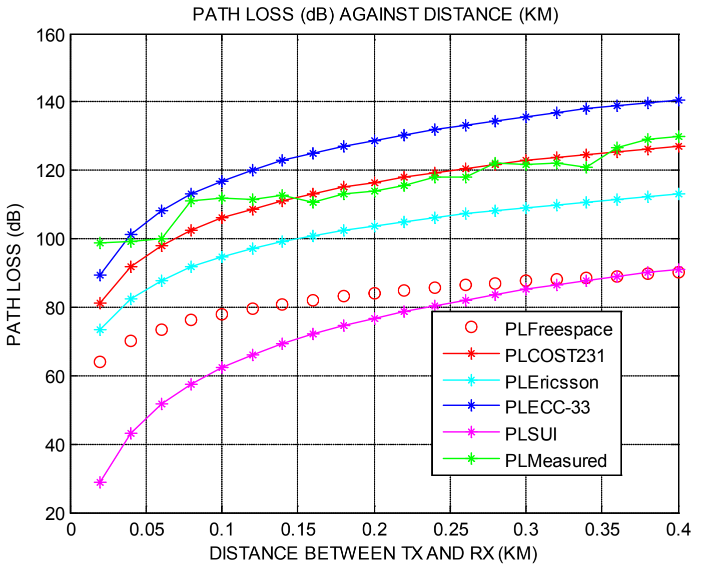

Fig. 9. Comparison of the measured and predicted path loss in Ikorodu

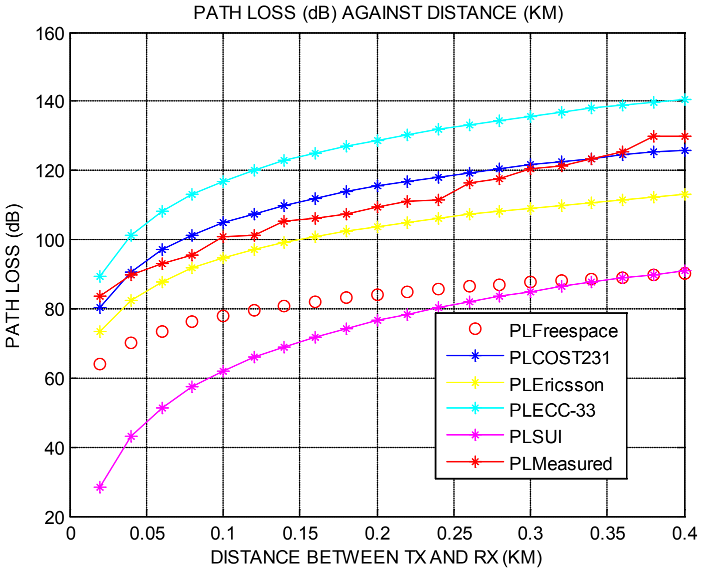

Fig. 10. Comparison of the measured and predicted path loss in Oniru

A) Statistical Analysis

Root mean square error (RMSE) is used as a standard statistical metric to measure model performance. It shows how close the predicted path loss values are to the measured path loss values as given in equation (18) [15], [17]. The basic statistics and the standard deviation errors of the measured and predicted path loss are as shown in Tables 4 and 5, respectively.

Equation (18) is applied to the numerical values of the predicted and measured path loss based on each propagation model to obtain RMSEs for UNILAG, Ikorodu and Oniru as shown in Table 6.

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{k} \frac{[\mathrm{PL_m(d)} - \mathrm{PL_r(d)}]^2}{k}} \tag{18}$$

where $PL_m(d)$ is the measured path loss (dB); $PL_r(d)$ is the predicted path loss (dB); and k=20 (number of the measured data points).

TABLE 4
BASIC STATISTICS OF THE MEASURED AND PREDICTED PATH LOSS

Locations	Data Statistics	Measured Path Loss, dB	Free Space Model, dB	COST 231-Hata Model, dB	Ericsson 9999 Model, dB	Stanford University Interim Model, dB	ECC-33 Model, dB
UNILAG	Mean	110.16	82.43	112.57	101.14	72.63	125.68
	Median	110.43	84.46	116.15	104.22	77.49	129.67
	Mode	88.41	64.05	80.19	73.24	28.55	89.47
	Standard Deviation	11.89	7.06	12.43	10.71	16.92	13.90
	Range	41.29	26.02	45.83	39.48	62.38	51.24
IKORODU	Mean	115.40	82.43	112.57	101.14	72.63	125.68
	Median	114.88	84.46	116.15	104.22	77.49	129.67
	Mode	98.77	64.05	80.19	73.24	28.55	89.47
	Standard Deviation	9.07	7.06	12.43	10.71	16.92	13.90
	Range	31.30	26.02	45.83	39.48	62.38	51.24
ONIRU	Mean	109.95	82.43	112.57	101.14	72.63	125.68
	Median	110.15	84.46	116.15	104.22	77.49	129.67
	Mode	83.79	64.05	80.19	73.24	28.55	89.47
	Standard Deviation	13.23	7.06	12.43	10.71	16.92	13.90
	Range	46.21	26.02	45.83	39.48	62.38	51.24

TABLE 5
STANDARD DEVIATION ERRORS OF THE MEASURED AND PREDICTED PATH LOSS

Locations	Data Statistics	Measured Path Loss, dB	Free Space Model, dB	COST 231-Hata Model, dB	Ericsson 9999 Model, dB	Stanford University Interim Model, dB	ECC-33 Model, dB
UNILAG	$\sigma(dB)$	11.89	7.06	12.43	10.71	16.92	13.90
	$\sigma_{error}(dB)$	-	4.83	0.54	1.18	5.03	2.01
	$\delta_{error}(\%)$	-	40.62	4.54	15.22	42.30	16.90
IKORODU	$\sigma(dB)$	9.07	7.06	12.43	10.71	16.92	13.90
	$\sigma_{error}(dB)$	-	2.01	3.36	1.64	7.85	4.83
	$\delta_{error}(\%)$	-	22.16	37.04	18.08	86.55	53.25
ONIRU	$\sigma(dB)$	13.23	7.06	12.43	10.71	16.92	13.90
	$\sigma_{error}(dB)$	-	6.17	0.8	2.52	3.69	0.67
	$\delta_{error}(\%)$	-	46.63	6.04	19.04	27.89	5.06

TABLE 6
ROOT MEAN SQUARED ERROR (RMSE)

Root mean squared errors (RMSEs) in dB			
Path loss model	UNILAG	Ikorodu	Oniru
Free space	28.26	31.24	28.30
COST 231 Hata	4.63	7.36	4.45
Ericsson 9999	9.77	15.47	9.71
SUI	38.06	48.24	37.68
ECC-33	16.20	10.41	16.17

B) Best Model Selection

Results presented in Table 6 indicate that the Stanford University Interim (SUI) model has predicted the path loss with the highest RMSEs values of 38.06dB for Unilag, 48.24dB for Ikorodu and 37.68dB for Oniru, followed by the free space model, ECC-33 model and the Ericsson 9999 model. Among these models, the Ericsson 9999 model showed a satisfactory performance with RMSE of 9.71dB at Oniru. However, this model over predicts the path loss in UNILAG and Ikorodu with RMSEs of 9.77dB and 15.47dB, respectively.

In addition, the ECC-33 and the SUI models generally predict the path loss in the investigated areas with RMSEs higher than the acceptable range of up to 6dB [18]-[20].

These were not selected as the most appropriate models for the environment of interest. Overall, the COST 231 Hata model showed the best performance in Unilag, Ikorodu and Oniru with RMSEs of 4.63 dB, 7.36dB, and 4.45dB, respectively. This model was selected as the best model for path loss prediction due to the lower values of RMSEs on the average. However, these RMSEs values are reasonably high; and there is a need for optimization of the COST 231 Hata model. The optimization was carried out using the Minimum Mean-Square Error (MMSE) presented in [20]. The formula for the optimized COST 231-Hata model based on MMSE criterion is derived as:

$$L(n) = 140.025 + 35.26\log_{10}(d) \tag{19}$$

The logarithm curves showing the comparison of empirical and optimized COST 231 Hata model for the measured data at Unilag are as shown in Fig. 11; and the comparison of empirical and optimized COST 231 Hata model for measurements at Ikorodu and Oniru are as shown in Fig. 12, and Fig. 13, respectively.

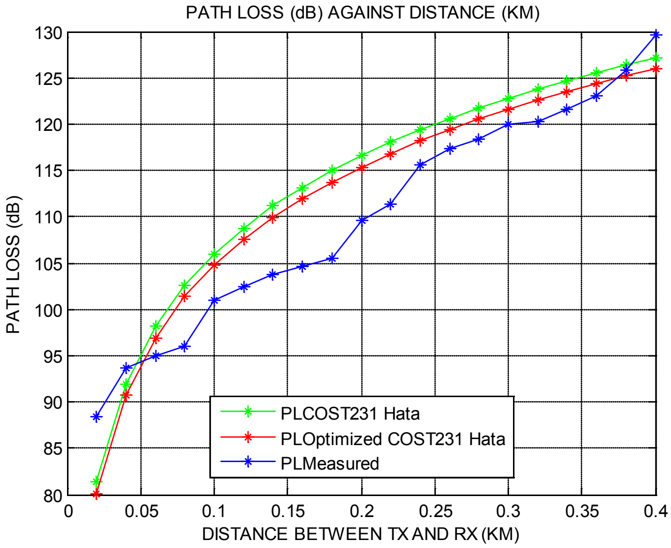

Fig. 11. Comparison of empirical model and optimized COST 231 Hata path loss model in UNILAG

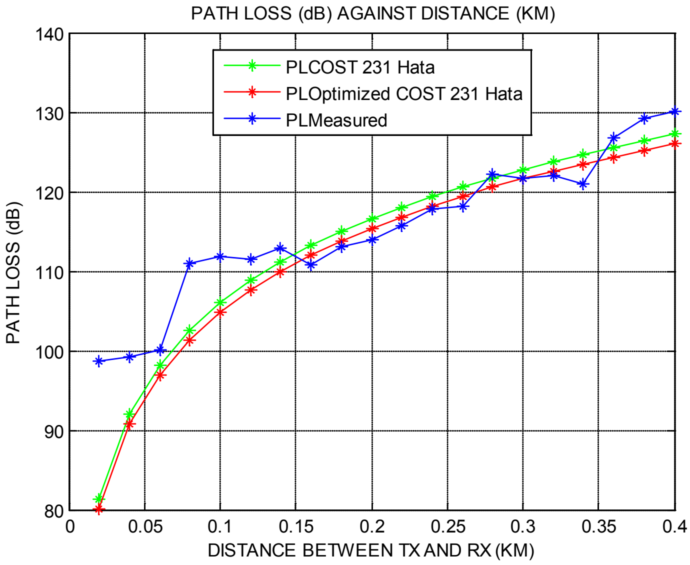

Fig. 12. Comparison of empirical model and optimized COST 231 Hata path loss model in Ikorodu

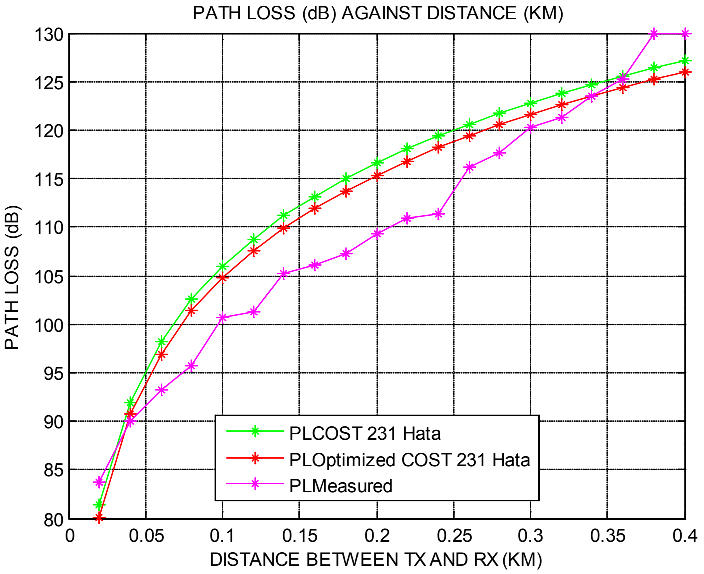

Fig. 13. Comparison of empirical model and optimized COST 231 Hata path loss model in Oniru

C) *Validation of the Optimized Model*

In order to test for the validity of the optimized model for the tested areas, the RMSE is used to determine the error between the measured and the predicted path loss based on the optimized COST 231 Hata model for the three locations. Applying (18) to the numerical values is derived from the formula. The predicted path loss is denoted as $PL_r(dB)$ which is computed for the three locations by applying the Minimum mean- square error (MMSE) in (30). The RMSEs of the optimized model are compared with the RMSEs of the existing COST 231 Hata Model shown in Table 7. The acceptable RMSE is up to 6dB [18], [20]. Our results compare favorably with related works reported in [21]-[23].

TABLE 7
ROOT MEAN SQUARED ERRORS OF PREDICTED AND OPTIMIZED COST 231 HATA MODEL

Location	COST 231 Hata model RMSE (dB)	Optimized COST 231 Hata model RMSE (dB)
Unilag	4.63	4.61
Ikorodu	7.36	5.70
Oniru	4.45	4.43

V. CONCLUSION

In this paper, we present an optimized COST 231 Hata model for path loss prediction in Hotspot areas, using 4G LTE data obtained through measurements. The measured path loss was compared against the predicted path loss derived from well-known propagation models. Results show that the COST 231-Hata model showed the best average performance for the measured data at Unilag, Ikorodu and Oniru in Lagos Nigeria, with RMSEs of 4.63dB, 7.36dB, and 4.45dB, respectively. This model was selected and optimized using the Minimum Mean-Squared Error method (MMSE). The optimized model predicts the measured path loss in the hotspot areas with acceptable RMSEs of 4.61dB, 5.70dB, and 4.43dB, respectively. Given appropriate correction factors, the optimized model could be very useful in predicting the path loss of a typical LTE network in similar environments. Our future work will focus on optimizing the parameters of the SUI model to accommodate similar environments, and finding useful parameters for the ECC-33 model for improved signal prediction in the investigated environments.

ACKNOWLEDGEMENT

The authors thank the Telecommunications Laboratory of the University of Lagos, and Huawei Technologies Limited for the RF measurement equipment.

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