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Urban Area Path loss Propagation Prediction and Optimisation Using Hata Model at 800MHz

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Abstract: *This paper describes how Okumura Hata's model is chosen and optimized for urban outdoor coverage in the Code Division Multiple Access (CDMA) system operating in 800MHz UHF frequency band, South-south Nigeria. This optimized path loss model is based on the empirical measurements collected in the CDMA network focusing on the city centre of Benin, Edo state. It is developed by comparing the calculated path loss from collected measurements with the well-known path loss models within applicable frequency range of CDMA system, such as Hata, SUI, Lee, and Egli's Model. The Hata model was chosen as a reference for this optimized path loss model development based on the closest path loss exponent and smallest mean error as compared to the measured path loss. This optimized Hata model is implemented in the path loss calculation during the validation process. Thus, this optimized model is successfully improved and would be more reliable to be applied in the Nigeria CDMA system for urban path loss calculation in the 800MHz frequency band.*
Key Words: *propagation loss prediction, optimisation, Hata model, urban area*

I. Introduction

In wireless communications, the information that is transmitted from one end to another propagates in the form of electromagnetic (EM) wave. All transmitted information incurs path loss as electromagnetic waves propagate from source to destination (due to e.g., reflection, diffraction, and scattering). It has been expressed in [1] that electromagnetic effects (such as power attenuation, deep fading and so on) is the major cause of dropped calls in cellular networks. Hence accurate estimation of propagation path loss is a key factor for the good design of mobile systems. Propagation path loss models are mathematical tools used by engineers and scientists to plan and optimize wireless network systems. The main goal in the planning phase of the wireless network is to predict the loss of signal strength or coverage in a particular location. Manoj opined in [2], that the quality of coverage of any wireless network design depends on the accuracy of the propagation model. In order words, the coverage reliability of a wireless network design depends on the accuracy of the propagation model. In the optimization phase, the objective is to make sure the network operates as close as possible to the original design by making sure handoff points are close to prediction; coverage is within design guidelines such as in-door, in-car, and on-street RSS; and co-channel interference is low at neighboring sites. Also, in the optimization phase measured data collected from the live network may be used to tune the propagation models utilized in the design phase.

Specifically, it has been reported in many academic literature (e.g. [3]) that the propagation models applied for macrocell mobile systems have built-in-error (generally of the order of 7-10dB standard deviation- a factor of ten in signal power) accounted for during the network design through a margin added to the overall signal strength calculations to take account of the natural signal fading phenomenon. Any reduction that can be achieved in this error will increase the quality of service, reduce undesirable power losses, increase coverage area, and determine best arrangements of base stations. Put in order words, any reduction of the error will have a direct and significant impact on the size and performance of the network and hence in both the economics and customer satisfaction of the service. In order to overcome this problem, the parameters of certain empirical models must be adjusted with reference to the targeted environment in order to achieve minimal error between predicted and measured signal strength.

Code division multiple access is a channel access method that allows simultaneous transmission of information from several sources over a single communication channel, with different distinguishing code patterns [4]. CDMA employs both the spread-spectrum technology and a special coding scheme to allow multiple users to be multiplexed over the same physical channel. In the CDMA system, the duplex channel is made of two 1.25MHz-wide bands of spectrum. The carrier frequency of the studied CDMA system network operator in Benin, South-South Nigeria is called operator B in this paper because of legal reasons and it transmits at 800MHz band.

The path loss model for the CDMA system is different in that several propagation factors such as the soft handoff gain, Pilot Number (PN) pollution, Pilot energy over total energy received (Ec/Io), etc are taken into consideration. The soft handoff factor can provide multi-path diversity on the forward link at sites' edges. It helps to improve channels' anti-fading capability and reduces Mobile Station's transmit power. As such, it decreases the interference caused by the system mobile station.

On the other hand, it supplies some significant gains on the reverse coverage. However, the path loss calculated for the CDMA network can be derived from the forward link and the transmission path from a base transceiver station to the mobile station. All measurements are collected within a radius of 2km away from the base station, with seamless coverage and no blind spots. Thus, the minimum allowable path loss is not considered as the tested base station. Nearing the adjacent base stations, noted that handover occurred as signal is weak.

In this study we describe how Hata model is chosen and optimized for urban outdoor coverage in the Code Division Multiple Access (CDMA) system in Benin City, South-south Nigeria.

II. Methodology

Several existing path loss models such as Hata's Model [5], Stanford University Interrim (SUI) model [6], Lee's Model [7] and Egli's Model [8] are chosen for comparison with measurement data. The best existing path loss model with the closest propagation exponent [8], to the measured path loss data will be chosen as a reference for the development of the optimized path loss model. The optimized path loss model will be tested during the validation process by comparing the calculated path loss to the measured path loss in Benin City CDMA Network.

Propagation Models

Four existing path loss models are chosen as reference in the development of the optimized path loss model. These existing path loss models are Hata's Model, Lee's model, SUI model and Egli Model. These path loss models were developed empirically in the system with similar antenna heights and frequency ranges which are applicable to the CDMA network in Benin City.

HATA Path loss Model

The Hata model is based on Okumura's measurements in Tokyo, which were fitted into a mathematical model by Hata. The original Okumura-Hata formula is given in Equation (1) [9]:

$$L = 69.55+26.16log10\,(f)-13.82log10\,(h_{BS})-a\,(h_{MS}) + [44.9-6.55log10\,(h_{BS})\,log10\,(d) \qquad (1)$$

where a is defined as:

$$a(h_{MS}) = [1.1\,log10(f) - 0.7]\;\; h_{MS} - [1.56\,log10(f) - 0.8] \qquad (2)$$

$$a(h_{MS}) = 3.2\,[log10(11.75h_{MS})]^2 - 4.97 \qquad (3)$$

Equation (2) is used for small and medium cities and Equation (3) for large cities.

Other definitions used in Equation (1) are:

L= Path loss (dB)

F= Frequency (150 – 1500) MHz

h_{BS} = Base station effective antenna height (20 – 200) m)

h_{MS}= Mobile station antenna height (1 – 10) m)

d =Distance between base and mobile station (1 – 20) km)

The original Okumura-Hata has some limitations. The most restrictive is that Okumura's measurements were made at 1920 MHz, and Hata's formulas cover only frequencies range from 150 to 1500 MHz. Also antennas have been over average rooftop level.

The original formula has been modified by COST-231 -project, which resulted in extending Okumura-Hata formula to cover frequencies from 1500 to 2000 GHz. This makes it possible to use the formula in simulations for 3G-networks for a reasonable accuracy. Constants A and B are redefined, and distance dependence parameter C is recommended to be defined by measurements, but value 44.9 is still often used. The COST-231-Hata –formula is given in Equation 2.69. Constants A and B are chosen from the Table 1. Also an additional environment dependent parameter, area type correction factor, Cm, is given. It is above 0 dB in urban areas, but in rural areas it can be even below -15 dB [10]:

$$L = A+B\,log_{10}(f)-3.82log_{10}(h_{BS})-a\,(h_{MS})+[C-6:55\,log_{10}(h_{BS})]\,log10(d)+C_m \qquad (4)$$

New definitions in the formula are:

A Constant, see Table 1

B Constant, see Table 1

C User defined value for distance dependence (slope factor)

Cm Area correction factor.

TABLE 1: CONSTANTS A AND B FOR HATA

	150-1000MHz	1500-2000MHz
A	69.55	46.3
B	26.16	39.9

Stanford University Interim (SUI) Model

The SUI model was developed under the Institute of Electrical and Electronics Engineers (IEEE) 802.16 working group for prediction of path loss in urban, suburban and rural environments [5].The applicability of this model in the 800 MHz and 1900MHz band has not been validated. However, due to the availability of correction factors for the operating frequency, this model is selected. The SUI models are divided into three types of terrains, namely, A, B, and C. Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities. Type C is associated with minimum path loss and applies to flat terrain with light trees densities. Type B is associated characterized with either mostly flat terrains with moderate to heavy three density or hilly terrains with light tree densities. The basic path loss equation with correction factors is presented in [5]:

$$L(dB) = A + 10n \log_{10}\left(\frac{d}{do}\right) + X_f + X_b + S \quad for \ d > do \tag{5}$$

where d is the distance between the Access Point (AP) and mobile station in meters, $do = 100m$ and S is a log normally distributed factor that is used to account for the shadow fading owning to tree and other cluster and has a valued between 8.2 dB and 10.6dB [11]. The other parameters are defined as

$$A = 20\log_{10}\left(\frac{4\pi d_o}{A}\right) \tag{6}$$

$$n = a - bh_b + C/h_b \tag{7}$$

where the parameter h_b is the base station height above the ground in metres and should be between 10m and 80m. The constants used a, b, and c is given in Table 2. The parameter n in (1) is equal to the path loss exponent. For a given terrain type the path loss exponent is determined by h_b

Table 2: The parameters of SUI model in different environment

Model parameter	**Terrain A**	**Terrain B**	**Terrain C**
a	4.6	4.0	3.6
b (m^{-1})	0.0075	0.0065	0.005
c (m)	12.6	17.1	20

The correction factors for the operating frequency and the mobile station antenna height for the model are [12]:

$$X_f = 6.0 \log_{10}\left(f/2000\right) \tag{8}$$

and

$$X_h = -10.8\log_{10}\left(\frac{hr}{2000}\right) \quad for \ Terrain \ A \ and \ B \tag{9}$$

$$= -20.0\log_{10}\left(\frac{hr}{2000}\right) \text{ for Terrain type C} \tag{10}$$

where, f is the frequency in MHz and hr is the mobile antenna height above the ground in metres. The SUI model is used to predict the path loss in all three environments, namely rural, suburban and urban.

The LEE Model

W. C. Y. Lee proposed this model in 1982 [6]. In a very short time it became widely popular among researchers and system engineers (especially among those employed by U.S. companies) mainly because the parameters of the model can be easily adjusted to the local environment by additional field calibration measurements (drive tests). By doing so, greater accuracy of the model can be achieved. The LEE path loss model is given by [12]:

$$Lp = Lo + \beta og_{10}\left(\frac{r}{1.6km}\right) + 10n\log_{10}\left(\frac{f}{900MHz}\right) - \alpha_o \qquad (11)$$

$$\alpha_o = \alpha_1\alpha_2\alpha_3\alpha_4\alpha_5$$

Where $\alpha_1 = \left(\frac{newBS\ antenna\ hight(m)}{30.48m}\right)^2$

Table 3: Parameters for Lee's path loss model

Environment	L_o	β
Free space	80	2.0
Open Area	89	4.35
North American Suburban	101.7	3.85
North American Urban	110	3.68
North American Urban	104	4.31
Japanese Urban	124	3.05

$$\alpha_2 = \left(\frac{newMS antenna\ hight(m)}{3m}\right)^{\xi}$$

$$\alpha_3 = \left(\frac{new transmitter\ power}{10W}\right)^2$$

$$\alpha_4 = \frac{new\ BS\ antenna\ gain\ with\ respect\ to\ \lambda_c / 2dipole}{4}$$

$$\alpha_5 = different\ antenna\ gain\ correction\ factor\ at\ the\ MS$$

$the\ values\ of\ n\ in\ (20)\ and\ \xi\ in\ (23)\ are\ also\ based\ on\ empirical\ data\ recommended\ to\ take\ the\ following\ values:$

$$n = 2.0\ for\ f_c < 450MHz\ and\ in\ suburban/open\ area$$
$$3.0\ for\ f_c > 450MHz\ and\ in\ urban\ area$$

$$\xi = 2.0\ for\ MS\ antenna\ hight > 10m$$
$$3.0\ for MS\ antenna\ hight < 3m$$

The Clutter Factor Model

The Egli Model is a terrain model for radio frequency propagation. This model consists of the plane earth loss plus an extra loss component called the clutter factor. An example of clutter factor model is the method due to Egli, which is based upon a large number of measurements

The formulas for the Egli's propagation loss prediction model are as below [12]:

For $hms \leq 10$,

PL (dB) = 20 $\log_{10} fc$+40 $\log_{10} R$+20 $\log_{10} hbs$+76:3-10 $\log_{10} hms$ (12)

For $hms \geq 10$,

PL (dB) = 20 $\log_{10} fc$+40 $\log_{10} R$+20 $\log_{10} hbs$+85:9-10 $\log_{10} hms$ (13)

III. Measurement Configuration

A schematic diagram of the Field measurement set-up is shown in Figure 1. The testing tool used in the measurement was NOKIA 1265 CDMA test phone handset in the Net Monitor mode, in conjunction with a digital Global positioning System (MAP76CSX GPS) receiver antenna to determine distance (d) from the Base Station (BS). The software comprises a scale, which is calibrated in (dBm) [13]

In all the study locations, BS transmitting antenna were dual band with inbuilt features, which enables them to radiate at 800MHz for operator A with antenna height of 40m above the sea level in all study access sites. The antennas were sectored 120^0. An approximate height of 1.5m was used as mobile receiver height.

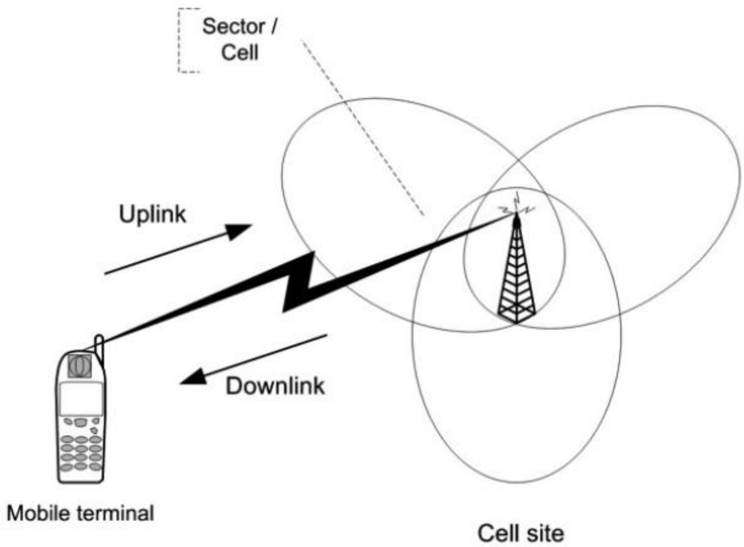

Figure1: A set-up Field-test measurement

Measurement Environment

Past study reveals that determining the propagation of a city requires taking measurement at various high and low environment or taking exhaustive measurement round the city to cover all the possible terrain conditions [14]-[15]. In this study, the focus is on the first approach. A total of four base station sites were investigated and the choice of the number of sites in each environment was based on the availability of the network provider.
Benin City was chosen to represent a typical urban region which consists of blocks densely built-up buildings of different heights and streets widths with small bushes and few trees. It lies within latitude 6.31760N and longitude 5.61450E [16]. It is situated 200 miles by road, east of Lagos with a population of about 1,147,188.

Measurement Procedure

With the aid of testing tool (i.e. NOKIA mobile handset) running on the software mode, calls were initiated at each test point until it is established and the signal strength information sent over the air interface between the base and the mobile station were read. For every site, received signal strength was measured at a reference distance of 100m from the base station and at subsequent interval of 100m up to 2000m. All measurements were taken in the mobile active mode and in three sectors of each base station. This was to ensure that the mobile phone was in constant touch with the base station. Also, measurements were taken on a uniform grid of outdoor static positions. This methodology is slightly different from the usual convectional drive-test procedure which may not cover certain inaccessible areas. At the same time, it presents some advantages because continuous measurement at the same point is captured, and this reduces systematic errors by properly windowing and averaging data.
Given in table 1 are the definition of the basic parameters/ specification of the CDMA networks of the two operators in the chosen area of study.

IV. Results and Discussion

The path loss estimated by the SUI, COST-231 Hata, and Egli models are calculated, and plotted against distance on the same graph as that of the measured path loss (figure 2-5).

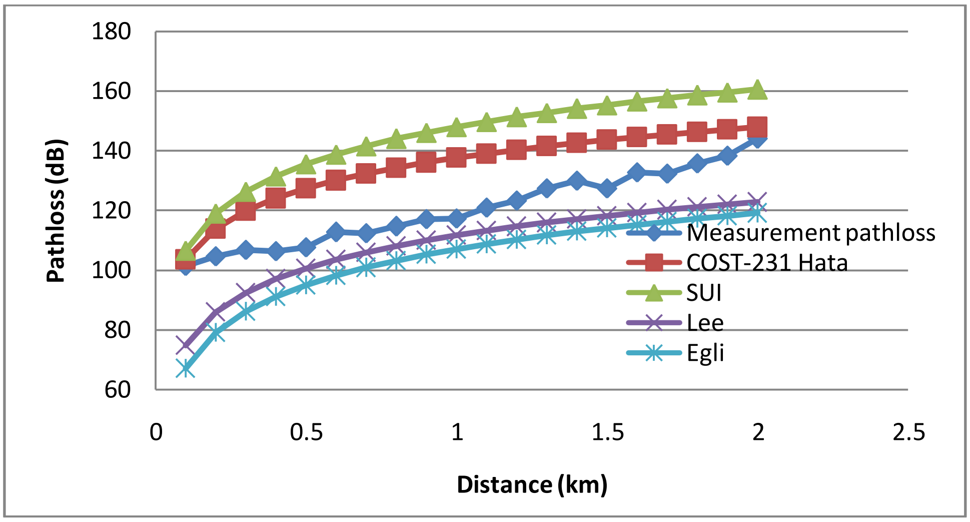

Figure 2: Comparative path loss model in BS 1

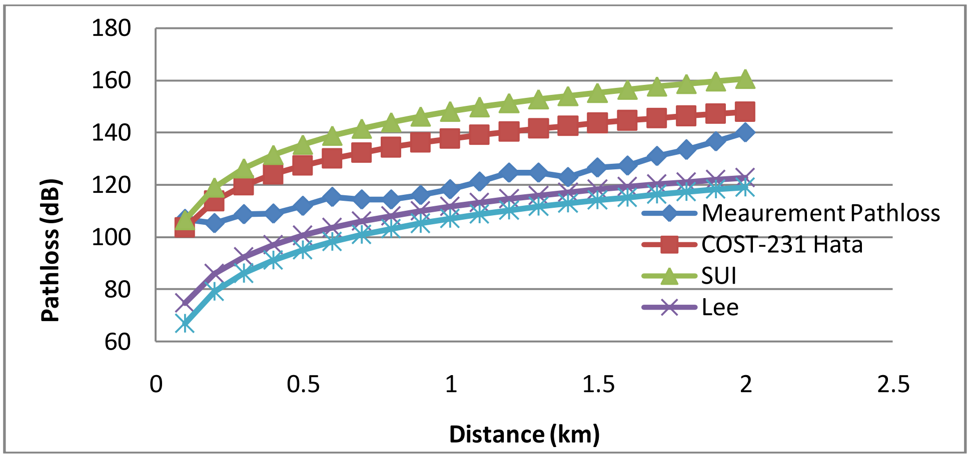

Figure 3: Comparative path loss model in BS 2

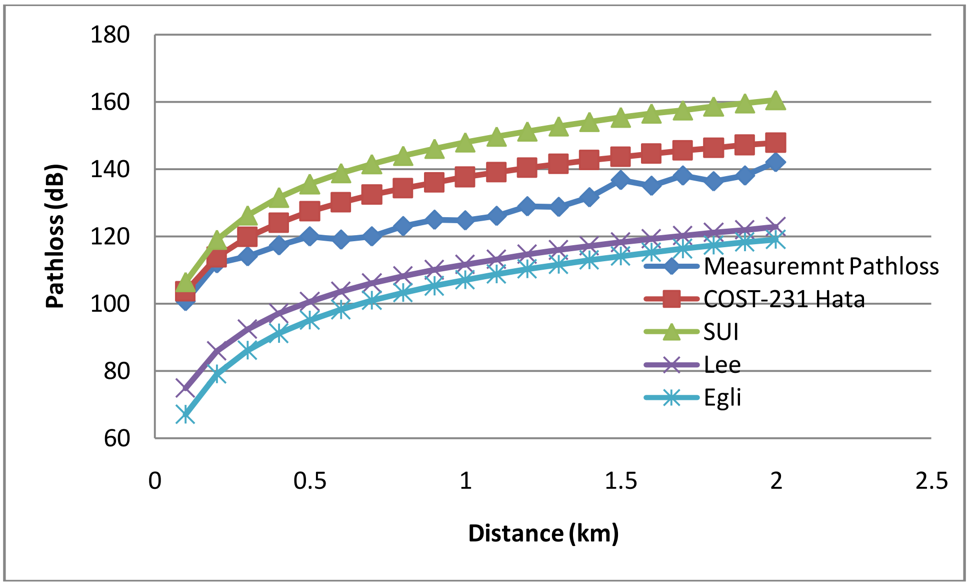

Figure 4: Comparative path loss model in BS 3

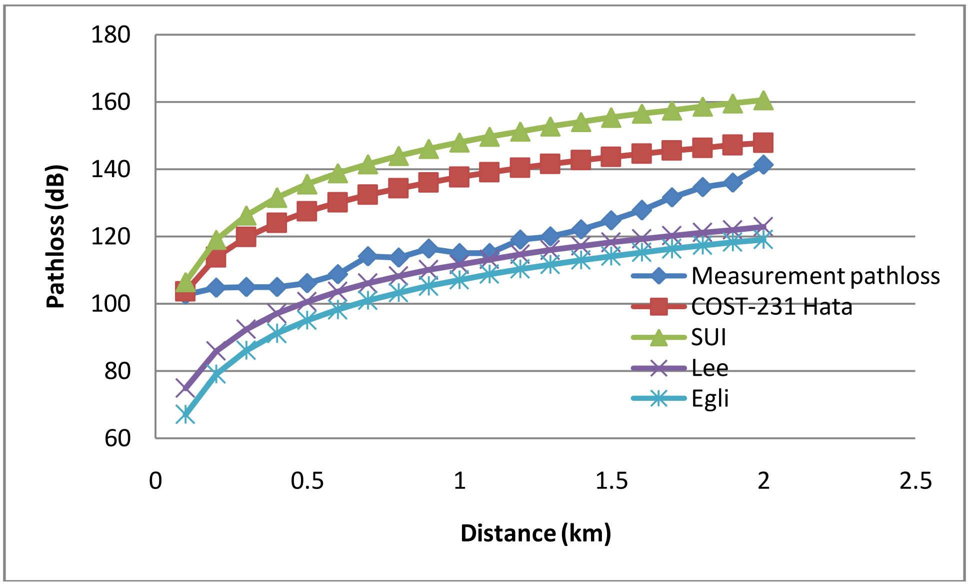

Figure 5: Comparative path loss model in BS 4

Path loss Model *Optimisation*

Path loss model optimisation is a process in which a theoretical propagation model is adjusted with the help of measured values obtained from test field data. The aim is to get the predicted field strength as close as possible to the measured field strength. Propagation path loss models optimized for different wireless technologies and environments are abundant in literature (e.g., [17]-[19]. Figure 5 below illustrates how measured path loss models have been optimised with Hata's model in this thesis.

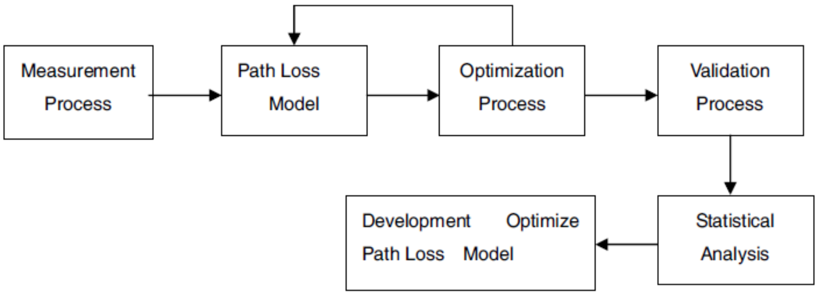

Figure 6: The flow chart of Path loss Optimisation process

Filtering Process and Best Model Selection

In order to obtain a specific path loss model for the operator in the four study sites, we took the average path loss PL = E [PL], of each of the operators, where E[·] denotes averaging operators. This approach is referred to as filtering the variations [19]**.** Table 3 below shows the results of the average path loss for each site.

Table 3. The path loss exponents found from the slopes of these graphs of measured data

BS Site	Path loss exponent	Intercept
BS 1	3.18	123.20
BS 2	2.52	122.40
BS 3	2.88	128.10
BS 4	2.82	120.40
Average	**2.85**	**123.53**

The path loss exponents found from the slopes of these graphs in figure 2-5 are summarized in table 4. From the tables, the following observations have been made. Hata's model gave a closest prediction to the measurement with a path loss exponent of 3.40. Based on closest agreement, the Hata model is selected as the best model for optimisation

Table 4: The path loss exponents and intercepts found from the slopes of these graphs

BS Site	1	2	3	4
$n_{measured}$	3.12	2.52	2.88	2.82
n_{COST}	3.41	3.41	3.41	3.44
n_{SUI}	3.82	3.83	3.82	3.90
n_{Lee}	3.68	3.68	3.68	3.68
n_{Egi}	4.00	4.00	4.00	4.00

Hata Model optimisation and Validation

In order to optimise and validate the effectiveness of the proposed model, the Mean error (ME), root mean square error (RMSE) and standard deviation (SD) were calculated between the results of the Hata model and the measured path loss data of each area. These errors and the standard deviation are defined by the expression in (14), (15) and (16), respectively.

$$ME = \frac{\sum(Pm - Pr)2}{N} \quad (14)$$

$$RMSE = \sqrt{\frac{\sum(Pm - Pr)2}{N}} \quad (15)$$

$$SD = \sqrt{\frac{\sum(Pm - \ddot{y})2}{N-1}} \quad (16)$$

where P_m = measured Path loss (dB)
Pr = Predicted Hata Path loss (dB)
N = Number of measured data points

The results of the error computation is given in table 1 below

The parameters of the Hata path loss model were adjusted using least square algorithm to fit to measured data using the following process. First, the residual between measured path loss, P_m, and the predicted value, Pr, by the Model is calculated for each location point which is a distance *d* from the base station by:

P_m - Pr = P_m -[*43.6+33.9 log fc –13.82 log hr– a(hr)+ (44.9-loght)log d]* (17)

where P_m and Pr are in dB and d is in km.

Second, the RMSE function computation of this residual is calculated based on the least squared algorithm which is used to determine the values of γ that minimizes the residual RMSE.

Thirdly, similar to the work by [18] and [19], the RMSE is then subtracted from the equation (13) of Hata model to obtain optimised path loss models for all BS sites in the location of study as given in equation (18).

$$L_P(opt) = 34.77 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) + A\ \log_{10} d - B + C \quad (18)$$

where

$$A = (44.9 - 6.55\log_{10}(h_b)) \quad (19)$$

$$B = 3.20\ (\log_{10}(11.75hr))^2 - 4.97, \quad (20)$$

$C = 0$ dB; medium-sized cities

$C = 3$ dB metropolitan areas

$$n_{COST} = (44.9 - 6.55\log_{10}(h_b))/10 \quad (21)$$

Performance analysis of Optimised Path loss model

Here, the optimized path loss model for each operator was applied for path loss calculation for other base stations in all the study location, to verify the accuracy and the suitability of this optimized path loss models. The result shows that all the base stations fit into the optimized model with lower ME, RMSE and standard deviation (see table 5 below). From these results as depicted in figure 7-10, it is shown that the optimized model does show a good agreement for the entire studied BS sites compared with Hata model. Thus the optimized model is successfully developed with proper optimized procedure.

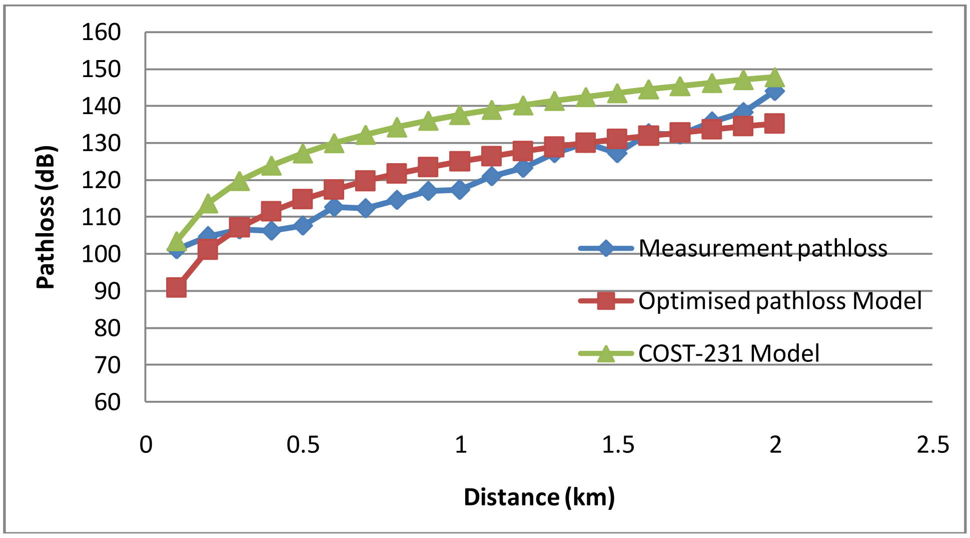

Figure 7: Optimised Hata path loss model with measurement data in BS 1

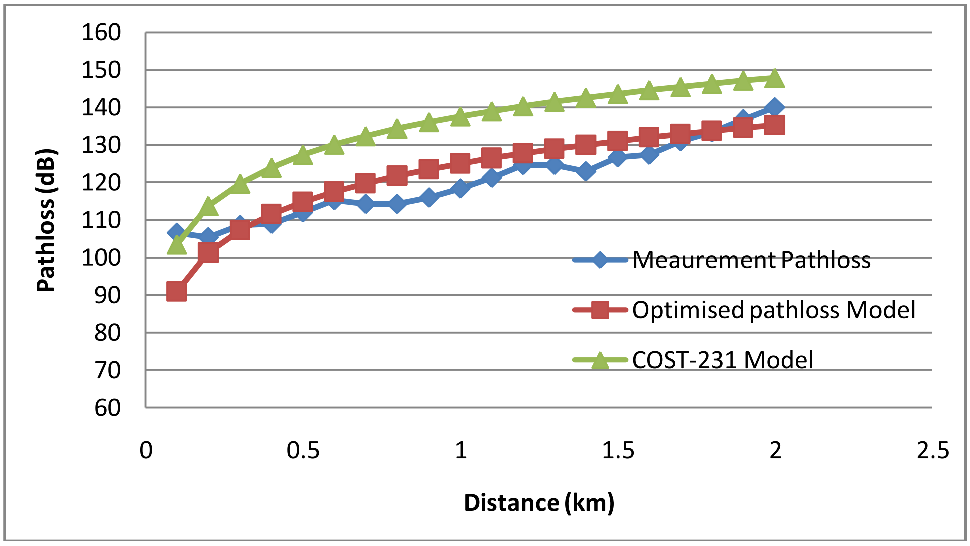

Figure 8: Optimised Hata path loss model with measurement data in BS 2

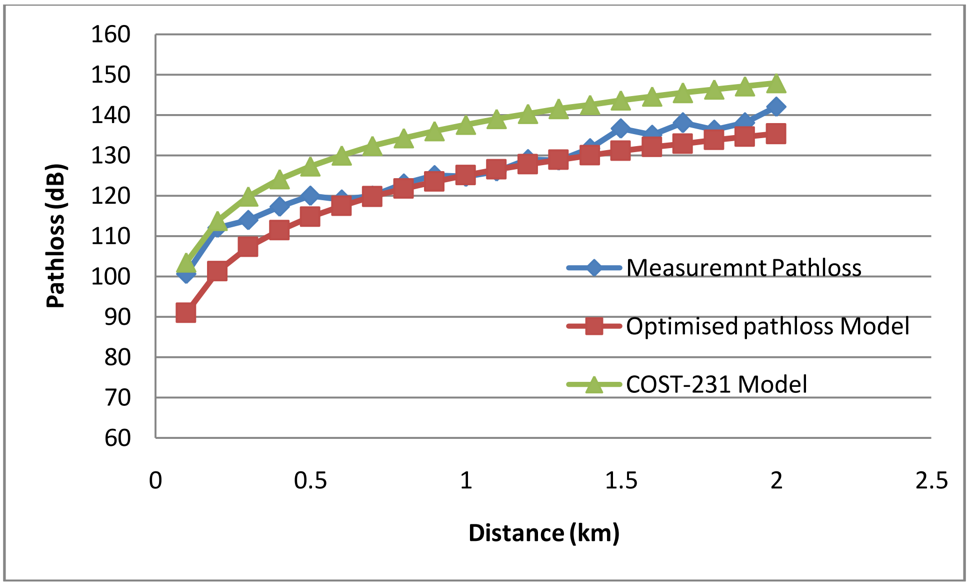

Figure 9: Optimised Hata path loss model with measurement data in BS 3

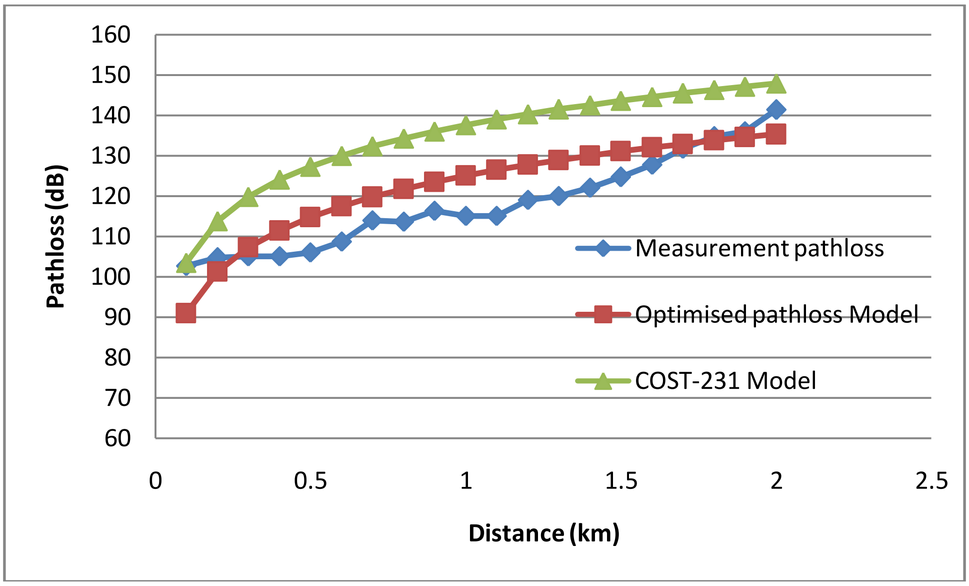

Figure 10: Optimised Hata path loss model with measurement data in BS 4

The results of the error computation is given in table 5 below

Table 5: Proposed model performance before and after optimisation

BS site	Before optimisation			After optimisation		
	ME	RMSE	SD	ME	RMSE	SD
1	12.57	12.88	3.54	0.14	1.87	2.13
2	15.93	16.05	4.08	0.14	2.03	2.02
3	16.48	16.61	4.22	0.02	1.79	1.79
4	15.77	15.89	3.74	0.01	1.81	1.02
Average	15.19	15.36	3.89	0.08	1.88	1.74

V. Conclusion

In this paper, the measured path losses in four cells are compared with theoretical path loss models: Hata, SUI, Lee and Egli. The measured path loss, when compared with theoretical values from the theoretical models, showed the closest agreement with the path loss predicted by the Hata model in terms of path loss exponent prediction and standard deviation error analysis. Based on this, an optimised Hata model for the prediction of path loss experienced by CDMA2000 signals in the 800MHz band in urban environment of South-south Nigeria is developed. The optimised model showed high accuracy and is able to predict path loss with smaller standard deviation errors as compared to the Hata model.

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