Journal of Engineering and Applied Sciences 13 (9): 2521-2529, 2018
ISSN: 1816-949X

Suburban Area Path Loss Propagation Prediction and Optimization at 900 and 1800 MHz

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Abstract: Radio frequency optimization is an important process in verifying and monitoring the performance of any GSM radio network already deployed in an area. It is a periodic activity that is done to maintain a good radio quality of service and enhance end user's perception. This study describes a study on radio frequency attenuation path loss behavior in suburban and rural coverage of Ekiti State in Nigeria. The objective of this study is to develop and optimize a path loss model based on the existing path loss model and outdoor measurement using at 900 and 1800 MHz Measurements of received signal strength were taken in some base stations in the 16 local governments of the state along the propagation paths. Specifically, five path loss prediction models namely free space, Hata, COST-231 Hata, Ericsson and Egli were used to predict path losses. The Hata Model and COST-231 Hata Model were 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 at 900 and 1800 MHz, respectively.

Key words: Radio frequency optimization, Hata Model, path loss, propagation mechanisms, exponent, measured

INTRODUCTION

In the past few decades, cellular radio communication systems have been witnessing extensive development and cellular phones that were initially means of communications in defense quarters and services of dispatch nature are now being used for commercial purposes and are fast becoming more of status symbols (Shittu, 2006). Wireless communication systems like the Global System for Mobile communication (GSM) has become part of us in nearly all our daily activities. The services rendered are but not limited to data transmission, internet usage, e-Banking, tele-medicine, security networking, tele-education (Ojo *et al.*, 2008). The introduction of cellular communication systems in Nigeria using GSM and Code Division Multiple Access (CDMA) technologies brought a brighter light to mobile communication scenario in this part of tropical regions. Mobile communication was first introduced to Nigeria in 1999, it heralded in a great switch from fixed telephony to mobile telephony; today it has a joint subscriber base of over 100 million and still counting (Ojo *et al.*, 2008).

In wireless communications, the information that is transmitted from one end to another propagates in the form of Electromagnetic (EM) wave. All transmitted information incur path loss as electromagnetic waves propagate from source to destination due to reflection, diffraction and multipath scattering (Rappaport 1996; Jemilohun and Walker, 2015). Propagation path loss models are mathematical tools used by engineers and scientists to plan and optimize w ireless 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 (Jadhav and Kale, 2014). The quality of coverage of any 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 Received Signal Strength (RSS) and co-channel interference is low (Freeman, 2006). 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 (Jadhav and Kale, 2014). 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 (Rappaport, 1996). The accuracy of propagation path loss model helps to determine the optimum base station location and with appropriate propagation path loss model, the coverage area of a mobile

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communication system, the signal-to-noise ratio as well as the carrier-to-interference ratio can be easily determined (Jadhav and Kale, 2014; Freeman, 2006; Ajay, 2004). The optimization process should be an on-going process to increase the efficiency of the network leading to revenue generation from the network (Ajay, 2004).

In this study, the Hata Model adopted in predicting the path loss for signals in the 900 and 1800 MHz frequency bands respectively. The optimized path loss models is developed based on the Received Signal Strength (RSS) measurements taken in this band in MHz and the estimated path loss. The Hata Model and COST-231 Model was selected because they have closest values to the measured path loss in terms of path loss exponent as compared to other prediction models in the 900 and 1800 MHz frequencies, respectively.

The comparative studies of three propagation models namely COST 231, ECC33 and the Lee path loss mode for UMTS based cellular systems was conducted in (Ekpenyong *et al*., 2010) while by Alotaibi and Ali (2006), a received signal level prediction model based on measurement in Riyadh urban area was presented. Seasonal variation of propagation signal at 900 MHZ for Oman city was presented by Nadir (2011). This work modified and adopted the Hata Model for prediction of the path loss in Oman. Also by Gupta *et al*. (2009), Hata Model was modified for Meluwala Deliradun. In (Bakinde *et al*., 2012), a comparison of propagation models for GSM 1800 and WCDMA systems was presented in selected urban area of Nigeria. However, the research was limited to urban area and the result cannot be generalized for suburban and rural area. In this study, the results of propagation profile at 900 and 1800 MHz for suburban and rural area of Ekiti State, Nigeria is presented. The measured data was compared with some predictive models and optimization was conducted using the model with the closest path loss exponent.

Propagation models

Free space model: Path loss in free space defines how much strength of signal is lost during propagation from transmitter to receiver. Free space model is diverse on frequency and distance. It is calculated as:

$$P_L(dB) = 32.48+20\log_{10}(d)+20\log_{10}(f) \quad (1)$$

Where:
f = Frequency (MHz)
d = Distance between transmitter and receiver (km)

Hata Model: The Hata Model is a set of equation obtained on measurements and extrapolations taken from curves that are derived by Okumura. It is an empirical formula for graphical path loss. Hata Model is the most popular model that have been extensively used in Europe and North America. The model was developed by Y. Okumura and M. Hata (Popoola *et al*., 2009; Ndife *et al*., 2013) and is based on measurements in urban and suburban areas. Validity range of the model is between 150 and 1500 MHz, transmission height of $h_b$between 30 and 200 m, reception height h_m of between 1 and 10 m and a distance of 1-20 km between the transmitter and the receiver. The empirical calculation method is used to predict the model at GSM frequency of 900 MHz. However, Hata Model does not consider terrain profile like hills that are found between transmitter and receiver. According to Obot and Afolayan (2011), Mogensen *et al*. (1991), Blackard *et al*. (1992) Hata path loss can be determined by:

$$P_L = 69.55+26.16\log_{10}(f)-13.82\log_{10}(hB)-a(hM)+ [44.9-6.55\log_{10}(hB)\log_{10}(d) \quad (2)$$

And:

$$a(h_M) = 3.2[\log_{10}(11.75h_M)]2-4.97$$

For large city, FC = 300 MHz

The COST 231 Model: The European co-operative for scientific and technical research formed the COST 231 committee to develop an extended version of the Hata Model such that applicability to 2 GHz range will be possible. The COST-231 Hata Model is designed to be used in the frequency band from 500-2000 MHz It also contains corrections for urban, suburban and rural (flat) environments. Path loss is calculated in dB for COST 231 Model by Sharma and Singh (2010), Jemilohun and Walker (2014), Moinuddin and Singh (2007); Shalangwa and Singh (2010) as follows:

$$P_L = 48.5+35.9\log_{10}(f)-14.84\log_{10}(hb)- ahm+(45.8-6.58\log_{10}(hb))\log_{10}d+C_m \quad (3)$$

The parameter C_m has different values for different environments like 3 dB for urban areas.

Ericsson Model: To predict the path loss, software is provided for network planning engineers developed by Ericsson Company. So, it is called as Ericsson Model. The path loss according (Neskovic *et al*., 2000, Rautiainen *et al*., 2002; Bhuvaneshwari *et al*., 2013) to this model is given by the equation:

$$P_L = a_0+a_1.\log_{10}(d)+a_2.\log_{10}(hb)+ a_3.\log_{10}(hb)\log_{10}(d)-3.3(\log_{10}(11.78hr)^2)+g(f) \quad (4)$$

Table 1: Definition of parameters for various terrain

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12	0.1
Sub-urban	43.2*	68.93*	12	0.1
Rural	45.95*	100.6*	12	0.1

*Significant valus

Where g (f) is defined as:

$$g(f)=44.51\log_{10}(f)-4.79(\log_{10}(f))^2)$$

The default values of these parameters (a_0-a_3) for different terrain are given in Table 1.

Egli Model: The Egli Model is a terrain model for radio frequency propagation. Egli Model was first introduced by John Egli in 1957 (Nadir, 2011). This prediction model is applicable at frequency from 40-900 MHz and the linking range is <60 km. It predicts the total path loss for a point-to-point link.

The formulas for the Egli's propagation loss prediction model are as follows (Adebayo and Edeko, 2006). For:

$$h_m = 10$$

$$Lt(dB) = 20\log10fc+40\log10R¡20\log10hb+76:3¡10\log10h_m \quad (5)$$

For:

$$hm = 10$$

$$Lt(dB) = 20\log10fc+40\log10R-20\log10hb+85:9-10\log10h_m \quad (6)$$

Where:

h_b = Height of the base station antenna (m)
h_m = Height of the mobile station antenna (m)
R = Distance from base station antenna (m)
fc = Frequency of transmission (MHz)

MATERIALS AND METHODS

Description of the measurement environment: Ekiti is a state in Southwest Nigeria with Ado Ekiti as the state capital with geographical coordinates: 7°37′16″N 5°13′17″E, total land area: 293 km^2, elevation: 455 m. The state has sixteen local government areas. Measurement was carried out in at least one base station in all the sixteen local government area of the state.

Measurement equipment and parameters: Experimental measurements were collected in both scenarios with the use of a field strength meter software (network cell info Android App.). It is capable of measuring received signal power in decibel miliwatts (dBm). The equipment has the facility to indicate the particular base station whose signal strength is being measured.

Table 2: Parameters of the of the base station

Variables	GSM GSM signal	WCDMA WCDMA signal
Antenna height (m)	30-36	30-36
Transmitting power (W)	80	430
Transmitting power (dB)	19.03	26.33
Antenna gain (dB)	18	18
EIRP (dBm)	65.38	72.68

During measurements, readings of received signal powers were taken for both 3G (where available) and 2G by trekking away from the serving base stations. Care was taking not to enter into the serving regions of a next base station transmitting antennas.

Received power values were recorded at various distances from each of the base stations. The parameters of the base station considered are as shown in Table 2.

RESULTS AND DISCUSSION

Analysis of data obtained through measurements is carried out. Comparison is then made with computed values using the free-space, Hata, COST 231, Ericson, Egli Models respectively. These models are then modified with appropriate mean error (μe) and RMSE (ρ_e) to obtain the optimized network model for the specific environments under investigation. Figure 1-6 show the plots of path losses against distances for 2G networks for the predictive models and the measured path losses for some selected base stations across the state. It can be observed from the figures that the Egli Model extremely over estimated the path loss in all the based stations considered. Also, COST 231 Model and Ericsson model is seen to overestimate the path loss in all the base station considered. It is also observable from the plots that the Hata Model provides a close estimate of the path loss aside the free space path loss model which doesn't consider topology in its estimation. In all, the path loss is seen to increase with distance away from the base station. In some cases, there is overlapping estimate of the path loss from the measured data with that of the free space path loss. It is also observed in some instances that the measure path loss is uneven. This may be due to the topography of the sites as the state is hilly in terrain.

Figure 7-12 show the plots of path loss against distances for 3G network for the measured data and predictive models for some base stations where 3G network is available. It can be observed form the figures that the Egli Model extremely over estimated the path loss in all the based stations considered. Also, Ericsson Model is seen to overestimate the path loss in all the base station considered. It is also observable from the plots that the COST 231 Model provide a close estimate of the path loss aside the free space path loss model which doesn't

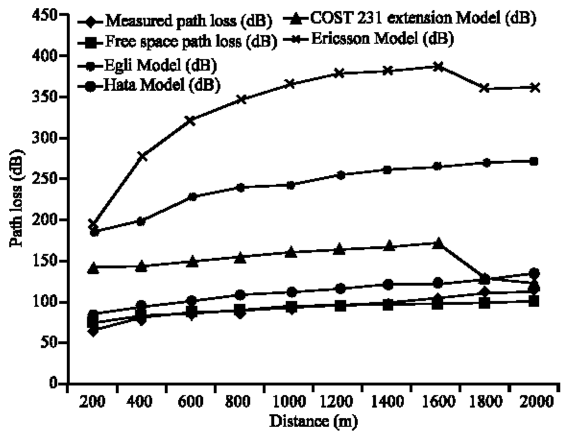

Fig. 1: Comparison of measured and predicted path loss for Iyin base station of 2G network

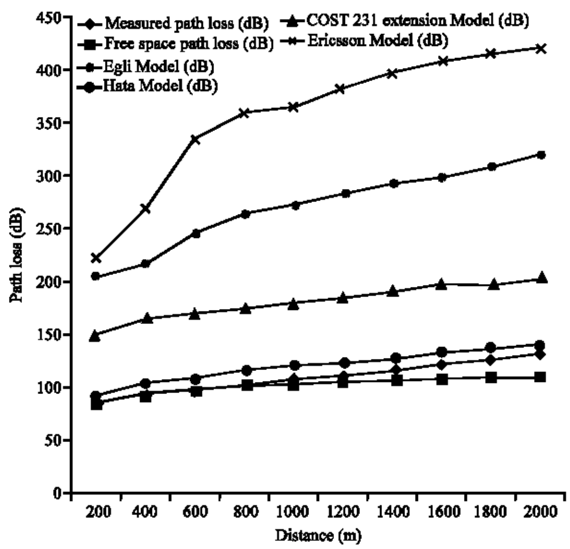

Fig. 2: Comparison of measured and predicted path loss for Igede base station strength of 2G network

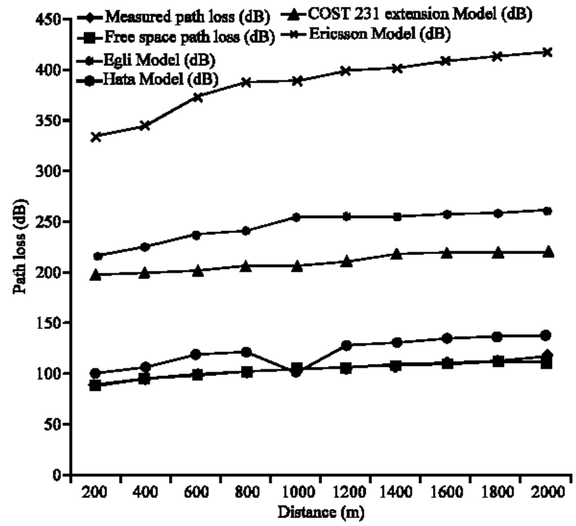

Fig. 3: Comparison of measured and predicted path loss for Oke Ayedun base station of 2G network

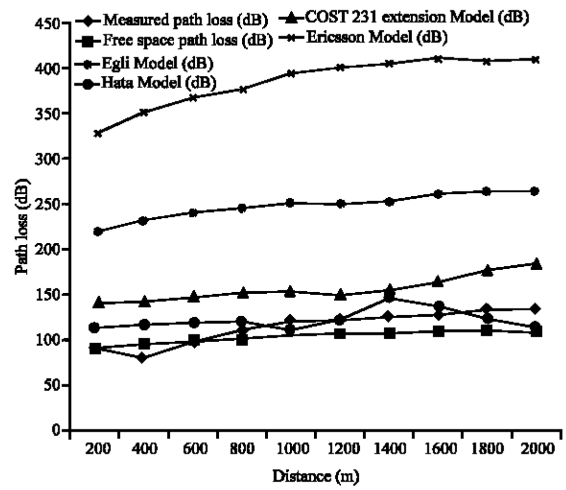

Fig. 4: Comparison of measured and predicted path loss for Oja Ikole base station of 2G network

consider topology in its estimation. In all, the path loss is seen to increase with distance away from the base station. In all the base station considered, the free space is said to overestimate the pathloss at a distant of <1 km while it under estimate the path loss at distance >1 km.

Path loss model optimization for 900 and 1800 MHz: Path loss model optimization 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.

In order to optimize the proposed model, the condition of a best fit of the theoretical model curve with a given set of experiment data would be met if the function of sum of deviation squares is minimum.

For the prediction of path loss in suburban environment, i.e., new optimization Hata and COST-231 Models in suburban environment is shown in Eq. 7:

$$PL_{new} = 23.648+33.9\log10f-13.82\log10h_b-ahm+44.9-6.55\log10h_b\log10_d+Cm \quad (7)$$

The path loss predicted by the Hata optimized models are plotted against measured and COST 231 Hata predicted path losses as shown in Fig. 13-20.

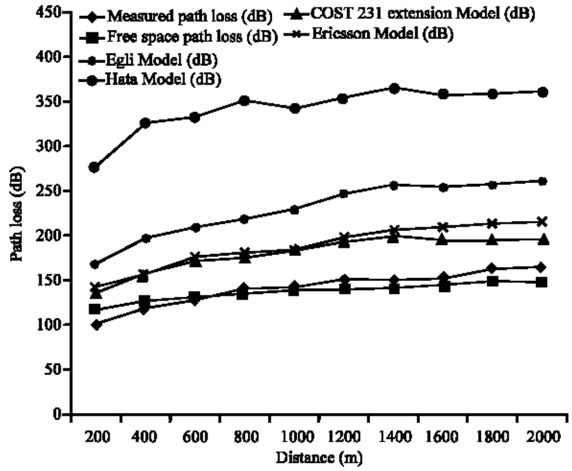

Fig. 5: Comparison of measured and predicted path loss for Ifelodun Street, Darlimore with 900 MHz GSM frequency

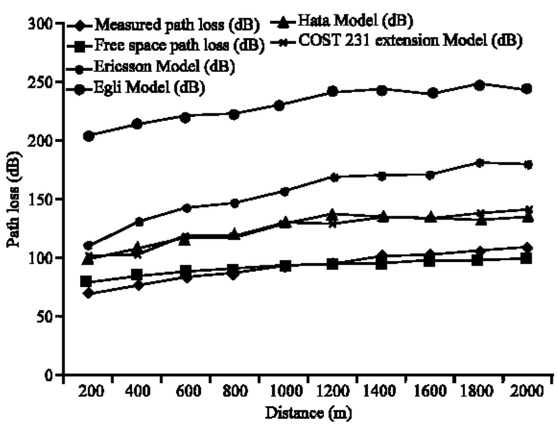

Fig. 6: Comparison of measured and predicted path loss for Adeatunramu street, Ado-Ekiti with 900 MHz frequency

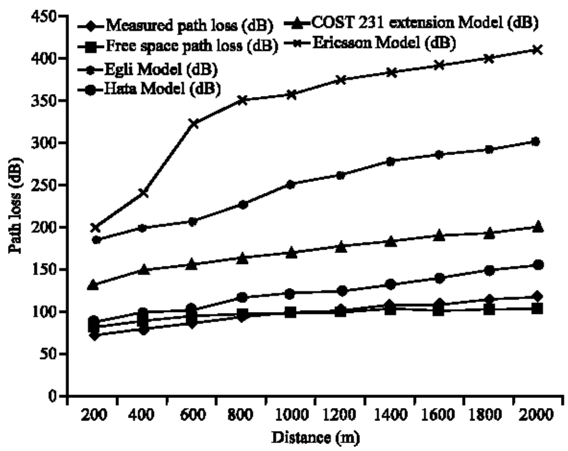

Fig. 7: Comparison of measured and predicted path loss for Iyin base station of 3G network

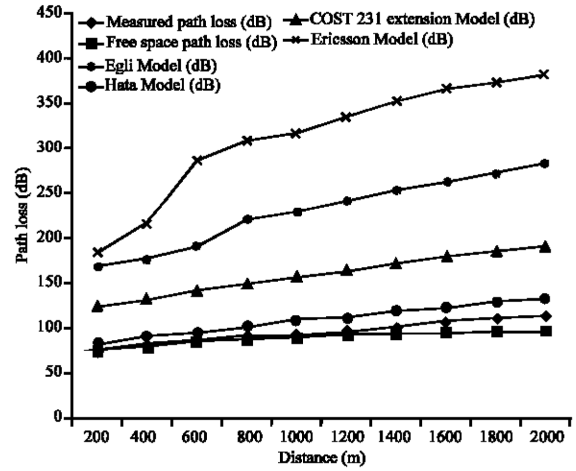

Fig. 8: Comparison of measured and predicted path loss for Igede base station of 3G network

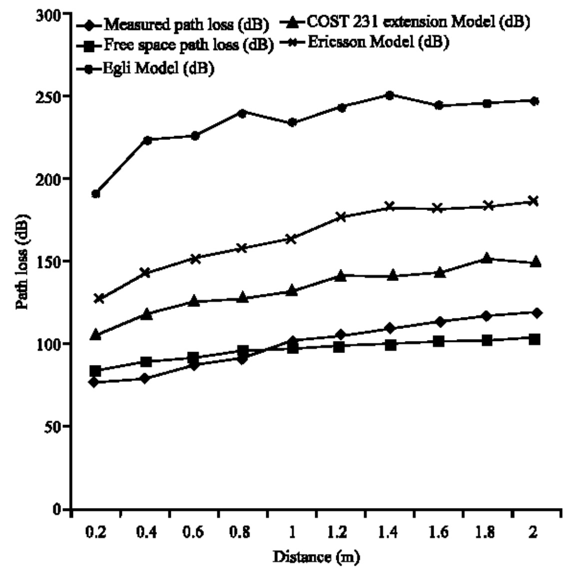

Fig. 9: Comparison of measured and predicted path loss for Ifelodun Street, Darlimore in the 1800 MHz

In order to optimize and validate the effectiveness of the proposed model, the Mean error (μe) and RMSE (ρ_e) were calculated between the results of the proposed closest model and the measured path loss data of each area. These mean error (μ_e) and root mean square error RMSE (ρ_e) are defined by the expressions below:

$$\mu e = \frac{1}{N}\sum(\text{PL measure-PL predicted}) \tag{8}$$

$$\rho e = \sqrt{\frac{\mu e^2}{N}} \tag{9}$$

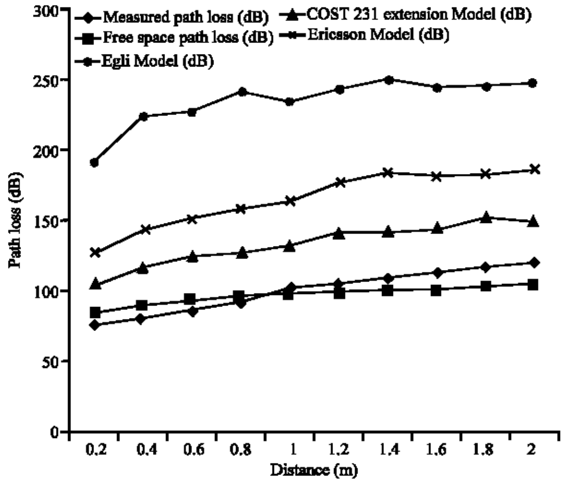

Fig. 10: Comparison of measured and predicted path loss for Adeatunramu Street, Adebayo in the 1800 MHz

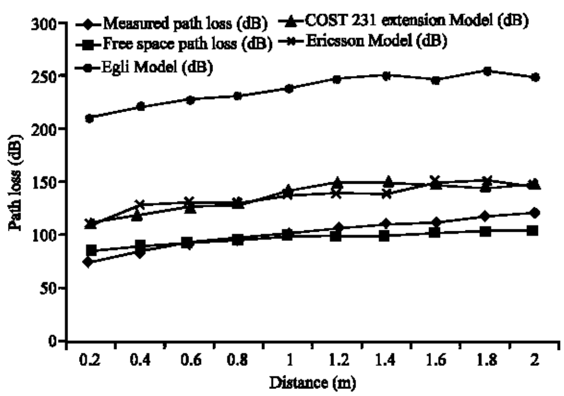

Fig. 11: Comparison of measured and predicted path loss for Olora quarters, Ado-Ekiti in the 1800 MHz

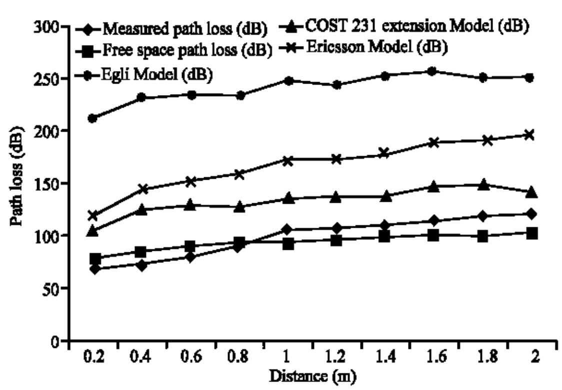

Fig. 12: Comparison of measured and predicted path loss for MFM road, opopogbooro, Ado Ekiti in the 1800 MHz

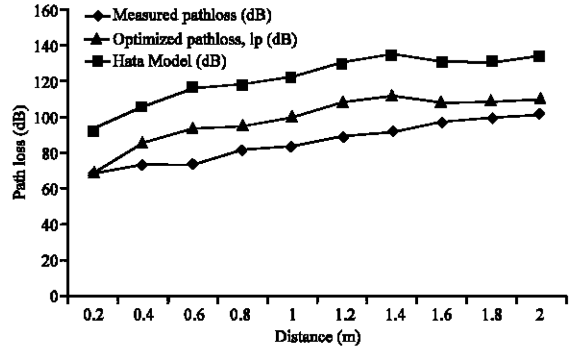

Fig. 13: Comparison of the optimized Hata Model with prediction model for Ifelodun Street, Darlimore in the 900 MHz

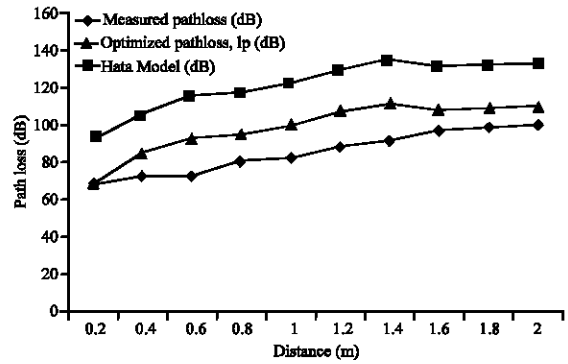

Fig. 14: Comparison of the optimized Hata Model with prediction model for Adeatunramu Street, Adebayo, Ado-Ekiti in the 900 MHz

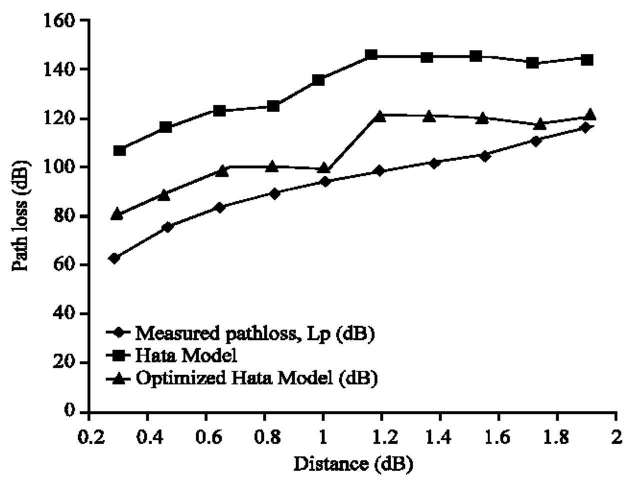

Fig. 15: Comparison of the optimized Hata Model with prediction model for Olora quarters, Ado-Ekiti in the 900 MHz

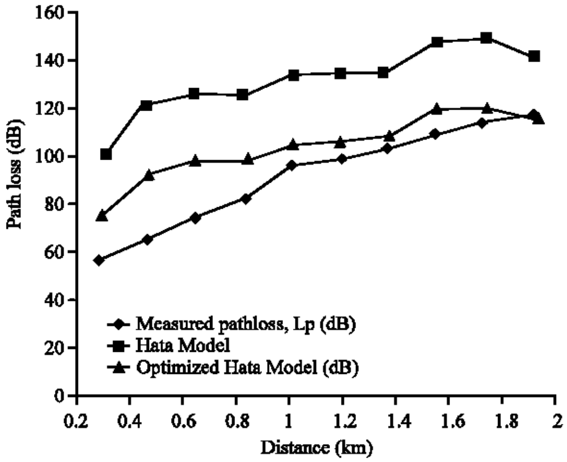

Fig. 16: Comparison of the optimized Hata Model with prediction model for MFM road, Opopogbooro, Ado-Ekiti in the 900 MHz

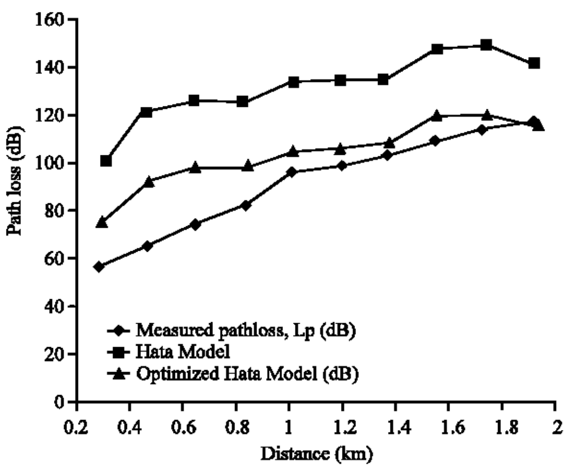

Fig. 17: Comparison of the optimized cost 231 Hata Model with prediction models for Ifelodun Street, darlimore in the 1800 MHz

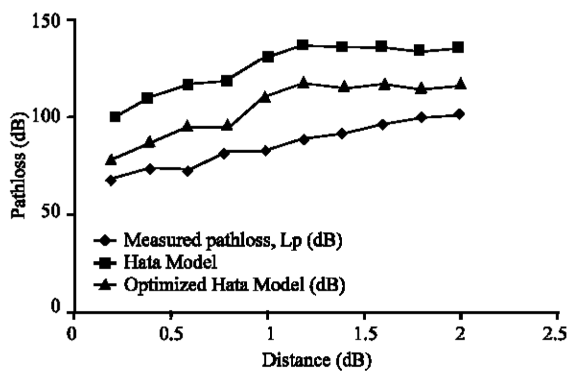

Fig. 18: Comparison of the optimized COST 231 Hata Model with prediction models for Adeatunramu Street, Adebayo in the 1800 MHz

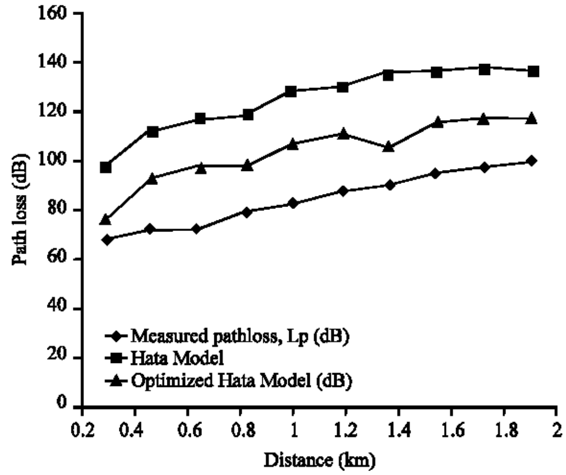

Fig. 19: Comparison of the optimized COST 231 Hata Model with prediction models for olora quarters, Ado-Ekiti in the 1800 MHz

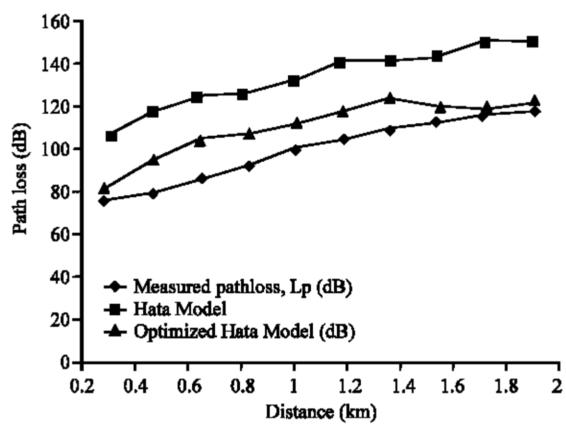

Fig. 20: Comparison of the optimized COST 231 Hata Model with prediction models 4 for MFM road, Opopogbooro, Ado-Ekiti in the 1800 MHz

Where:

$PL_{Measured}$ = Measured Path loss (dB)

$PL_{Predicted}$ = Predicted path loss (dB) and N is number of measured data points

Performance analysis of optimized 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. From these results, 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.

Summary of results: Firstly, we discovered that the Okumura-Hata and COST-231 Hata Models were very good at giving a good estimate of the path-loss at the areas under consideration in the GSM 900 and 1800 MHz frequencies respectively. The accuracy of the path-loss gotten through this models when compared with the free-space model only got better as the distance from the base station is increased. It is also very close to the measured path-loss obtained from measurements.

This shows us that the Okumura-Hata and COST-231 Hata Models can be used as an alternative to calculate for the path-loss in this areas if the cost of carrying out experiments and the time involved is not acceptable.

CONCLUSION

In line with the aim of this study, it has been proven practically, through this study, that the Okumura-Hata Model is very accurate in its prediction of the path-loss in Ado-Ekiti and its environs. It is to be noted that despite the accuracy of this model in predicting the path loss in this environment, the results obtained in this research is subject to changes due to the ever changing nature of our environment. Secondly, it was observed that the measured path-loss as seen from the graph, usually settles for the same value as the Okumura-Hata Model as the distance increases. This also adds to the already high reliability of these stated models. The measured path losses in four cells are compared with theoretical path loss models: Hata, COST 231, Ericson 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 Models in terms of path loss exponent prediction and root mean square error analysis.

The optimized models showed high accuracy and are able to predict path loss with smaller root mean square errors as compared to the Hata and COST-231 Hata Models, respectively. These changes can be natural or man-made, permanent or temporary, instant or gradual. It should also be noted that these five models are not the only models that can be used to predict the path-loss in an environment like Ado-Ekiti. The Okumura-Hata Model has proven to be very reliable and accurate in its prediction of path-loss encountered and it is recommended as a suitable replacement to taking exact measurements if the cost in time, money and effort is too great to bear.

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