Assessment of Path Loss Prediction Models for Wireless Propagation Channels at L-Band Frequency over Different Micro-Cellular Environments of Ekiti State, Southwestern Nigeria

C. I. Abiodun, S. O. Azi, J. S. Ojo, P. Akinyemi

Abstract—The design of accurate and reliable mobile communication systems depends majorly on the suitability of path loss prediction methods and the adaptability of the methods to various environments of interest. In this research, the results of the adaptability of radio channel behavior are presented based on practical measurements carried out in the 1800 MHz frequency band. The measurements are carried out in typical urban, suburban and rural environments in Ekiti State, Southwestern part of Nigeria. A total number of seven base stations of MTN GSM service located in the studied environments were monitored. Path loss and break point distances were deduced from the measured received signal strength (RSS) and a practical path loss model is proposed based on the deduced break point distances. The proposed two slope model, regression line and four existing path loss models were compared with the measured path loss values. The standard deviations of each model with respect to the measured path loss were estimated for each base station. The proposed model and regression line exhibited lowest standard deviations followed by the Cost231-Hata model when compared with the Erceg Ericsson and SUI models. Generally, the proposed two-slope model shows closest agreement with the measured values with a mean error values of 2 to 6 dB. These results show that, either the proposed two slope model or Cost 231-Hata model may be used to predict path loss values in mobile micro cell coverage in the well-considered environments. Information from this work will be useful for link design of microwave band wireless access systems in the region.

Keywords—Break-point distances, path loss models, path loss exponent, received signal strength.

I. INTRODUCTION

SINCE 1999, the introduction of the Global System for Mobile Communication (GSM) and the Code Division Multiple Access (CDMA) technologies has brought a big thrust to wireless communication systems in Nigeria. The last few years have witnessed a tremendous growth in the wireless industries, both in terms of mobile technology and its subscribers. There has been a shift from the fixed to mobile cellular telephony. By the end of 2011, there were over five times more mobile cellular subscriptions than fixed telephone lines [1].

In the light of the above, to maintain the upward growth, the need to make accurate path loss predictions for optimum performance of wireless network services cannot be over emphasized. This will not only enhance optimization but also to meet the massive subscriber's expectations as well as customer level agreements (CSLAs).

In the present study, GSM radio measurements at L -band frequencies utilizing the MTN cellular network in urban, suburban and rural environments of Ekiti state, Nigeria has been investigated. Path loss values were calculated from the measured RSS values and path loss exponents as a function of distance have been deduced. Break point distances have also been deduced. We finally proposed a path loss model based on the break point distances and make comparison with measured path loss values and some existing empirical models.

II. EXPERIMENTAL SITE AND RESEARCH METHODOLOGY

With GSM frequency of L-band (1800 MHz) RF signals, measurements were performed during June to July of 2017. The measurement campaign consisted of three slightly various environments in Ekiti State, Southwestern part of Nigeria. The field measurement survey was performed on Adebayo road, Oja-Oba and Mary hill at 1800 MHz in Ado-Ekiti, the capital of Ekiti State. The sites represent typical urban environments that are typified with blocks of densely constructed buildings, building height between 3-15 meters, market places, hills, mountains and trees of average height. Typically, more than 70% of the area is filled with houses constructed with concrete, blocks and tiles. The second measurement survey was performed in Ajebamidele and Oye-Ekiti representing a typical suburban environment of Ekiti State. These sites consist of lightly constructed buildings of height between 3 and 10 meters, a market place, hills and distributed tall trees. Around 55% of the areas is filled with houses constructed with concrete and blocks. The third measurement survey was performed in Ilupeju and Ayegbaju. These sites reflect a typical rural environment consisting of sparsely constructed buildings, thick vegetation of tall trees and open areas. They

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are also characterized by some sequence of houses built with muds and planks with less than 45% of houses made of concrete. The Google map and environmental view of the environments are shown in Figs. 1-3

A test drive was conducted to measure the RSS levels of GSM base station transmitters using a Sony Ericsson TEMS phone. 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 mobile receiver and the transmitter [2]. In each of the sites, measurements were carried out at distances ranging between 100 and 1,200 meters along each sector of a base transmitter station. Measured data were also recorded in a log file for each of the sites. The transmitting power of the transmitter at 1800 MHz is 40 dBm while the sensitivity of the receiver is -110 dBm and height 1.2 meters. Detailed base station features and the characteristics of each of the sites are shown in Table I.
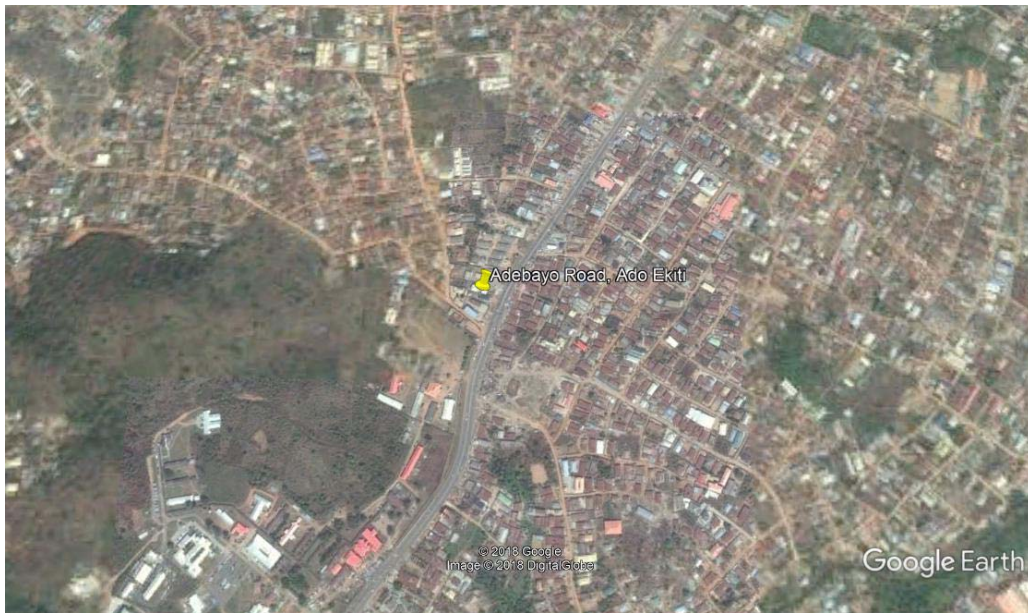

Fig. 1 Map showing one of the Investigated Urban Environments

Fig. 2 Photograph of one of the rural environment paths

Fig. 3 Photograph of one of the Suburban environment Paths

A. Path Loss Calculation

The path loss in dB is calculated from the measured RSS using [2]-[10]:

$$P_L = P_t + G_t + G_r - L_C - RSS \qquad (1)$$

where P_L is the path loss, P_t is the transmitting antenna power, G_t is transmitting antenna gain, G_r (2 dB) is the receiving antenna gain, L_C (10 dB) is the cable loss.

B. Brief Overview of Cellular Propagation Models

Radio propagation model is made to provide empirical formulation for radio wave propagation scenario. The model must be relevant to the macro-cellular radio networks as a function of distance, frequency and some other atmospheric conditions [2].

Adequate modeling of path loss evaluation depends upon many details. Among such are knowledge of the location, dimension and constitutive specifications of every tree, buildings and terrain features in the covered area. This is practically very difficult to implement and would lead to too many excessive details. One suitable way to account for these difficult effects is through statistically based empirical models [4]. Some of the existing empirical models are the Okumura-Hata model, Ericsson model, Cost 231-Hata model and

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Standard University Interim (SUI) model [3]. The Hata model based on the Okumura's field test results is the widely used model; it predicted various equations for path loss with different types of clutter. It is a well suited model for the Ultra High Frequency band and built up areas [4]. To relate predicted coverage capacities with physical propagation processes, a statistical-based propagation model is proposed and used for comparison with other physical empirical models in this research.

TABLE I
DETAILS OF THE BASE STATIONS AND CHARACTERISTICS OF EACH OF THE SITES

Name of base station	Cell identity code	Coordinate (Lat°N/Long°E)	Elevation (m)	Environment type	Antenna height (m)	Antenna type	Frequency (MHz)	Tx antenna gain (dB)
Adebayo road	EK4400	7.648095 5.224616	426	Urban	31	Sectorial	1800	15
Oja-Oba	EK2244	7.620755 5.224661	441	Urban	30	Sectorial	1800	15
Maryhill	EK2225	7.629275 5.231178	547	Urban	36	Sectorial	1800	15
Ajebamidele	Ek2340	7.570890 5.194455	440	Suburban	34	Sectorial	1800	15
Oye-Ekiti	EK3470	7.798732 5.333036	550	Suburban	34	Sectorial	1800	15
Ilupeju	EK3471	7.802552 5.358431	629	Rural	31	Sectorial	1800	15
Ayegbaju	EK3767	7.795668 5.298276	557	Rural	31	Sectorial	1800	15

III. RESULTS AND DISCUSSION

The measured values of the path loss for all the base stations have been deduced for each sector for distances ranging from 100 to 1200 meters. In all the sectors, a general increase in path loss with distance was observed.

A. Breakpoint Distances

In [4], empirical measurement studies have shown that the path loss exponent of measurement of path loss changes after a certain distances. In this study, path loss exponent values have been computed from the deduced values of path loss at various distances up to 1200 meters using (2):

$$Pl_m(dB) = Pl_0(dB) + 10n \log_{10}(\frac{d_i}{d_0}) \qquad (2)$$

where Pl_m is the measured path loss deduced for various distances, Pl_0 is the path loss at 100 m reference distance (d_0), d_i is the distance in meters. From [5], Pl_0 can also be estimated by (3):

$$Pl_0(dB) = 20 \log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \qquad (3)$$

where λ is the wavelength corresponding to 1800 MHz for this study, n is the path loss exponent deduced with distance between base stations (BS) and mobile station (MS) for each BS considered. The path loss exponent is known to be critical in establishing the coverage of any cellular network [2]. It is assumed to be 2 in free space and when there are obstructions between transmitter and receiver, it assumes larger values. Based on (2), various path loss exponents of all the sectors and for all the BS investigated in 50 meters interval were computed

Fig. 4 is a typical exponent value variation for a BS in Maryhill (urban environment), with the cell identity code

EK2225 and antenna height of 36 meters over the three sectors monitored. We observed path loss exponent values of the order of 1.8 to 2.5 for distances closer to the transmitter. This indicates that, at distances closer to the transmitter, the effects of obstructions between the transmitter and receiver are minimal. This is an indication of the existence of line of sight (LOS) in the signal path. This order rises from an exponent value of 2.5 to 3.3 from a distance of about 350 meters and maintains a steady increase to about 4.6 for the remaining distances. Higher path loss exponents, at distances far away from the transmitter may be as a result of high density of obstructions in the signal path, hilly topography and degradation of electromagnetic wave with distance. It may also be due to the nonexistence of line of sight (NLOS) in the environment. Fengyu and Yan [6] had earlier observed the same trend in the study carried out in Beijing, China. They observed exponent values of 2.4 at distances closer to the transmitter and 3.8 at farther distances away from transmitter. Erceg et al. [5] also deduced exponent values of order of 2.3 to 4.5 at antenna heights of 30 to 40 meters in New Jersey at 1.9 GHz frequency band.

Fig. 5 also presents typical exponent value variations for a BS in a typical suburban environment, Oye-Ekiti with cell identity code EK3470 and an antenna height of 34 m. The same trend was observed in path loss exponent value but with an order of 2.2 at distances closer to the transmitter. The variation increases steeply to a value of about 3.0 from a distance of about 400 m and maintains a steady step for the remaining distance to a value of 3.5. Other environments considered also show similar trend, but with different path loss exponent values. The results are presented in Table II. Similar break point distances were observed by Ojo et al. [2] in urban and suburban environments of Akure, Ondo State, Nigeria at 1.8 GHz frequency band.
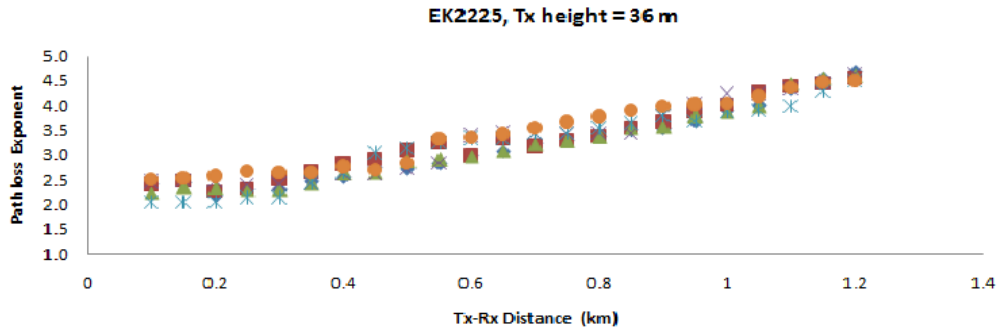
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EK2225, Tx height = 36 m

Fig. 4 A typical variation of path loss exponent with distance for Maryhill Ado- Ekiti, (EK2225) BS
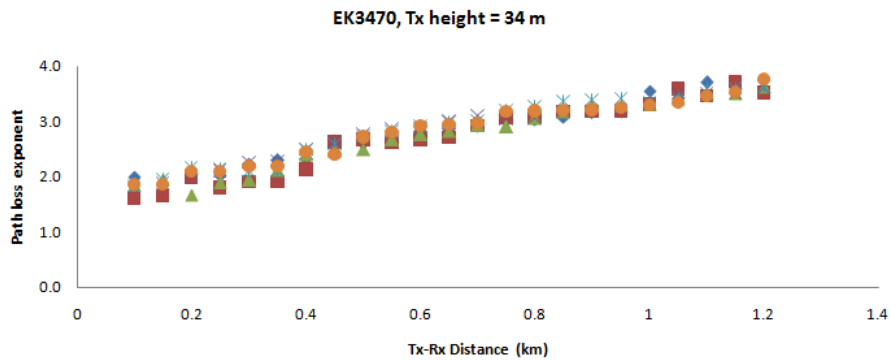
EK3470, Tx height = 34 m

Fig. 5 A typical variation of path loss exponent with distance for Oye-Ekiti (EK3470) BS

TABLE II
BREAK POINT DISTANCE OF SIGNAL ALONG THE PROPAGATION PATHS

Name of BS	Cell identity code	Environment type	Antenna height (m)	Observed signal break Point d_c (m)
Adebayo road	EK4400	Urban	36.0	410.0
Oja-Oba	EK2244	Urban	36.0	400.0
Maryhill	EK2225	Urban	36.0	360.0
Ajebamidele	Ek2340	Suburban	34.0	420.0
Oye-Ekiti	EK3470	Suburban	34.0	400.0
Ilupeju	EK3471	Rural	31.0	450.0
Ayegbaju	EK3767	Rural	31.0	420.0

IV. IV. SIMULATIONS AND PATH LOSS MODELING.

A two slope path loss model [6] was chosen for predicting the distance of reliable communication between the transmitter and the MS. In the two slope model, two separate path loss exponents are used to characterize the propagation together with a distance break point where propagation changes from one regime to the next [6]. In this case, the two slope path loss model is modified as:

$$P_L(d) = \begin{cases} PL(d_0) + 10n_1 \log_{10}(\frac{d_i}{d_o}) \ for \ d_i < d_c \\ PL(d_c) + 10n_2 \log_{10}(\frac{d_i}{d_c}) + c + X_\sigma, \ for \ d_i \ge d_c \end{cases} \quad (4)$$

where the path loss parameters are; $PL(d)$ is the mean path loss value, $PL(d_0)$ is the measured or predicted reference path loss at distance d_0 which is 50 m from the BS. The reference path loss value is obtained by field measurement at distance d_0 [3]. The n_1 and n_2 are the path loss exponents before and after the break point regions, these describe how quickly the signal attenuates as a function of distance (steepness of the path loss curve). Typical values for the path loss exponents are found by investigation to be around $n_1 = 2$ and $n_2 = 4$, with break point distances of 200-500 m [6]. But these values vary greatly between individual measurements and environments.

Variable X_σ is the random variable which describes the shadow fading deviation from the mean path loss value. This variable is present due to the fact that two different locations having the same transmitter-receiver distance may undergo totally different kinds of propagation paths. Therefore, measured values may differ greatly in their mean predicted signal strengths. Field measurements have shown this variation to be dependent on the type of environment and are distributed log normally [7]. Variable c is the offset correction factor and it describes the offset between the reference model and the measured values after the break point distance. The path loss exponents values n_1 and n_2 before and after the break point for a particular site are obtained from the measured data by linear regression. This indicated that the difference between the measured and the predicted path loss is minimized in a mean square sense [8].

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The path loss model in (4) was adjusted by finding proper values for path loss exponent n_1 and n_2 and the correction factor c. The path loss curve can be regarded as a two-slope model. For this model, the LOS path between the transmitter and receiver is strong, and the contributions from the entire scatter are small in a short distance. However, beyond the breakpoint distance, the scatter starts to play an important role and the path loss is assumed to correspond to the measured base-mobile environment characteristics.

Figs. 6 and 7 show the path loss curves for Maryhill base station, an urban environment and the base station in Oye-Ekiti a suburban environment respectively. The solid curves indicate the path loss fit with the correction factor in the far field. The broken lines indicate the reference models without the correction factor c. The dark blue markers show the measured path loss values.

In Maryhill environments, the path loss exponent values are 2.5 for n_1 and 4.5 for n_2 and the correction factor is 16.0 dB. In Oye-Ekiti environments, the path loss exponent values are 1.8 for n_1 and 3.5 for n_2 with a correction factor of 11.0 dB. Similarly, path loss parameters were also obtained for other environments investigated. Table III presents the path loss parameters for the model under study for all the BS monitored.

The two slope behaviors of the base to the mobile propagation environment can be observed in Figs. 6 and 7 in Maryhill and Oye-Ekiti BS. Approximate values of all reference path losses and break point path loses for urban, suburban and rural environments are also shown in Table III: These values are based on the observed path loss values analysis. The difference between the measured values and the reference model might be due to terrain influences and obstacles in the paths of the signal in higher distances. At Maryhill, the offset correction factor c and the path loss exponent values are high; this may be due to the hilly terrain and cluster of buildings within the environment. This may also account for the shorter break point distance of 360 m observed.
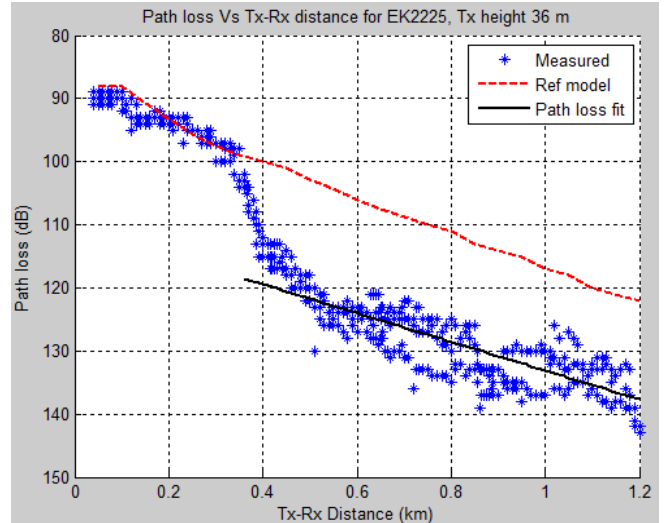

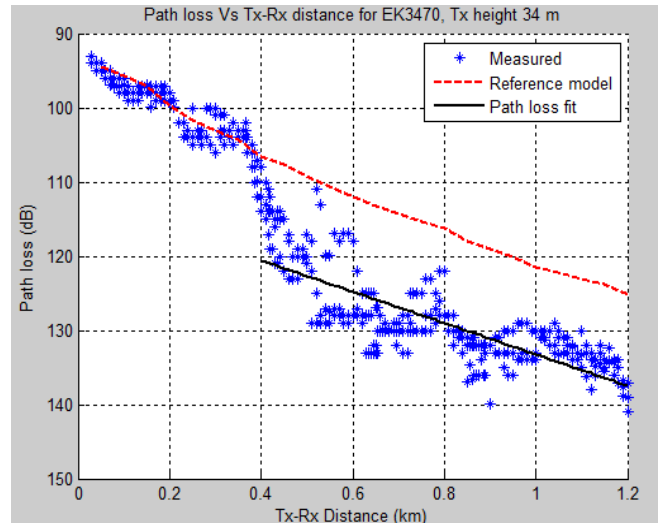Fig. 6 A path loss curve for one of the urban environments (Maryhill, EK2225)

Fig. 7 A path loss curve for one of the suburban environments (Oye-Ekiti, EK3470)

TABLE III
PATH LOSS PARAMETERS FOR THE PROPOSED MODEL

Cell code	Path loss exponent		Correction factor c (dB)	Shadowing STD (dB)	Reference path loss (dB)	Break point path loss (dB)	Environmental type
	n_1	n_2					
EK4400	2.0	3.9	9.7	7.5	90.0	107.0	Urban
EK2244	2.5	4.3	12.0	5.0	90.0	107.0	Urban
EK2225	2.5	4.5	16.0	3.7	90.0	107.0	Urban
Ek2340	1.9	3.4	9.0	7.0	92.0	103.0	Suburban
EK3470	1.8	3.5	11.0	2.2	92,0	103.0	Suburban
EK3471	1.8	3.2	7.0	4.0	90,0	98.0	Rural
EK3767	1.7	3.0	6.5	5.5	90,0	98.0	Rural

The equation of the proposed two slope path loss model with standard deviation (σ) for Maryhill (EK2225) environment is modeled with the path loss parameters as:

$$P_L(d) = \begin{cases} 90 + 25\, log_{10}(\frac{d_i}{d_o}) \; for \; d_i < 360\, m \\ \qquad\qquad\qquad X_\sigma = 3.7\, dB \\ 123 + 45\, log_{10}(\frac{d_i}{d_c}), \; for \; d_i \geq 360\, m \end{cases} \quad (5)$$

Also, the equation of the proposed two slope path loss model

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with standard deviation for Oye-Ekiti (EK3470) environment is modeled as:

$$P_L(d) = \begin{cases} 92 + 18\,log_{10}(\frac{d_i}{d_o}) \;\; for \;\; d_i < 400\,m \\ \qquad\qquad\qquad X_\sigma = 2.2\,dB \qquad (6) \\ 113 + 35\,log_{10}(\frac{d_i}{d_c}), \; for \;\; d_i \geq 400\,m \end{cases}$$

Fig. 8 shows the comparison of measured path loss values with the proposed model and SUI, Cost-231 Hata, Ericson and Erceg models for EK2225 Maryhill BS.

At distances close to the transmitter, we observed measured path losses of about $90\,dB$ to $110\,dB$ with estimated measurement error of $1.54\,dB$. Considering the effective isotropic radiated power of the transmitter of 40 dBm and a receiver sensitivity of -110 dBm, the mean measured path loss is about $139.5\,dB$ while the best measured path loss value is 145 dB. Both the Cost-231-Hata and Erceg models overestimated the measured path loss values by $12\,dB$ to $30\,dB$ at close distances to the transmitter. The Cost-231 models have closer values to the measured values at higher distances from 400 m than Erceg model. However, the Ericson model overestimated the measured values between $22\,dB$ and $32\,dB$ at closer distances and $10\,dB$ at higher distances. SUI model overestimated the measured path loss values at all distances.

The two-slope model has a better prediction of the measured values at all distances than the other existing empirical models considered. The regression line has also been plotted on Fig. 8 with its coefficients deduced. General increase in received signal strength with distance was observed in all the base station (BS) monitored.

Similar results seen could be observed for all the remaining six BS. Consecutively, path loss exponent values as a function of distances, path loss parameters values and comparison of observed values with proposed values were also estimated. The figures of these stations are not presented in this work due to space reduction and repetition of results.

Table IV presents the statistical evaluation of the mean error and standard deviations of the proposed two-slope model when compared with the specified models. The standard deviations exhibited by the proposed model and regression line are low. The values range between $4\,dB$ and $9\,dB$ when compared with Cost 231-Hata, Erceg, Ericson and SUI models. Similar trends have been observed in macro cells operating at 900 MHz over longer distances by [9]. Further result revealed that; the standard deviation of about $6\,dB$ to 14 dB was recorded for Cost 231-Hata model. This value is slightly less than Erceg model which ranges between $6\,dB$ and 16 dB. SUI model exhibited the highest value of about $36\,dB$ indicating a wide range of deviations. In the case of Ayegbaju BS with id code EK3767, Cost 231-Hata model exhibited a standard deviation value of $6.5\,dB$. It is evident that the value is much less than that of Erceg, Ericson and SUI models but closer to the proposed two slope model. The trend continued for other BS with Cost231-Hata model exhibiting lesser standard deviations than Erceg, Ericson and SUI models. Although each of the base station exhibited different values of standard deviation for all the six models considered, the proposed two-slope models, Cost 231-Hata and Erceg models have positive correlation and are consistent with the measured path loss values.
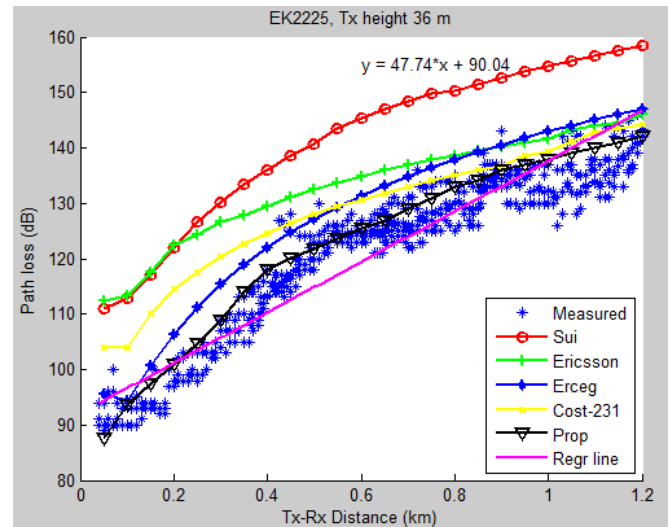

Fig. 8 Comparison of observed path losses in urban environment with proposed two slope, SUI, Ericson, Cost 231-Hata and Erceg models

TABLE IV
MEAN ERROR AND STANDARD DEVIATION OF PREDICTION MODELS IN THE STUDIED ENVIRONMENTS

Cell Code	Environment Type	Mean Error (dB)						Standard Deviation (dB)					
		Cost231-Hata	Ericson	Erceg	SUI	Two slope	Regr line	Cost231-Hata	Ericson	Erceg	SUI	Two slope	Regr line
EK4400	Urban	13.02	17.50	10.40	32.70	5.15	6.50	12.10	15.10	12.40	35.6	4.50	5.00
EK2244	Urban	15.50	18.00	12.50	35.70	6.10	6.55	13.50	16.80	15.50	37.00	5.20	7.55
EK2225	Urban	10.10	14.72	10.54	34.26	2.20	9.00	11.03	17.88	13.41	36.09	4.00	9.50
Ek2340	Suburban	8.50	12.00	9.25	31.00	4.00	4.55	9.00	13.00	7.54	30.10	5.70	9.50
EK3470	Suburban	4.82	7.96	4.98	29.71	1.70	2.00	5.34	15.92	6.23	30.00	3.61	9.22
EK3471	Rural	7.20	8.00	9.75	28.00	4.20	5.70	7.50	11.00	10.25	29.05	6.50	8.55
EK3767	Rural	5.20	11.00	7.00	30.50	5.70	6.90	8.80	13.55	9.00	31.40	7.00	6.24

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V. Conclusion

In this study, investigation of radio channel behavior and prediction of propagation model based on the path loss measurement in the 1800 MHz frequency have been investigated. The investigation has been carried out over urban, suburban and rural environments in Ekiti State, Southwestern Nigeria. A two slope path loss model based on the deduced reference and break point distances has been proposed with practical path loss values derived for accurate wireless prediction. The measured path loss has been compared with the proposed model and four other existing propagation models, namely; the Erceg model, Cost-231-Hata model, SUI model and Ericsson model. Some metric measures were also performed with the proposed model exhibiting the lowest standard deviation followed by Cost-231-Hata and Erceg models when compared with the other two models. Path loss exponents of around 1.8 to 2.5 were observed at distances closer to the transmitter. This order steeply increases to 3 at 350 m to 400 m distances. A steady increase of up to 4.5 was also seen at higher distances in urban environments. The same trend was observed in suburban and rural environments, but with a lower order of path loss exponent values and higher breaker point distances. Generally, the proposed model shows the closest agreement with the measured values followed by Cost 231-Hata model then Erceg model. However, turning of Cost-231-Hata model is necessary for a better agreement with the measured path loss values and minimize the prediction error. Information from this research will be useful to researchers and practicing communication engineers in estimating coverage areas. The results will also be applicable for prediction of reliable links for base-mobile propagation systems in the well-considered region.

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