International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319-6734, ISSN (Print): 2319-6726
www.ijesi.org ||Volume 10 Issue 3 Series I || March 2021 || PP 14-23

Optimization of Cost 231 HATA Model For Propagation Path Loss Measurements in Lagos

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ABSTRACT : *This study focuses on optimizing COST 231 Hata model that will best predict the path loss of the received signal power from global system for mobile communication (GSM) base stations located in the Lagos metropolis using a comparative approach. A site survey was carried out and the areas classified as rural, suburban and urban. Propagation measurements were taken at 1800MHz with a BK Precision Spectrum Analyzer, personal computer and a GPS unit to accurately track the location of mobile equipment from the fixed base station. The test locations were within a propagation distance of 2km, starting from a reference distance (do) of 100m. On the average, over 1200 measurement results were taken at about 120 measurement locations from six GSM base station sites. Average power received was calculated to estimate the path loss corresponding to each measurement. Least squares (LS) regression analysis was used to determine the path loss exponent. The optimization was done by subtracting the calculated mean square error mean square error (MSE) between the measured and the predicted path loss for each location. The developed model was found to predict the measured path loss with acceptable mean square errors of 2.30dB in rural, 3.64dB in suburban and 5.25dB in urban area of Lagos. The mean square error reduction translates to improved signal power.*

KEYWORDS –*measurement, mean square error****,*** *Optimization, propagation, signal power,*

Date of Submission: 21-02-2021 Date of Acceptance: 04-03-2021

I. INTRODUCTION

As mobile radio systems become more present, a basic understanding of radio frequency (RF) propagation for the purpose of RF planning becomes very important. In wireless mobile communications, the information that is transmitted from one end to another propagates in the form of electromagnetic (EM) wave. Reflection, diffraction and scattering are responsible for incurring path loss as electromagnetic waves propagate from source to destination during information transmission. Electromagnetic effects such as power attenuation, deep fading and so on are the major causes of dropped calls in cellular networks [1]. Path loss is the gradual attenuation and fading of signals along their propagated path. Hence accurate estimation of propagation path loss is a key factor for the good design of mobile systems. In order words, the coverage reliability of a wireless network design depends on the accuracy of the propagation model [2].

Propagation models applied for GSM mobile systems have built-in-error of the order 7-10dB standard deviation and as such most empirical propagation models used to predict radio signal in a place do not correctly predict the radio signal fading [5}. Again the performance of any radio system depends largely on the signal power, topology and morphology of the propagation environment. To reduce the effects of these factors in signal propagation, a well-defined model which appropriately covers all propagation phenomena in a given environment will require an accurate computation of the mean or median path loss to further reduce the error margin < 7dB and additional attenuation that is likely to occur. This research work is set to develop such a model which best predicts the path loss of measured data in the investigated environment.

1 Aim and Objectives of the Study

The aim of this study is to develop a suitable model for optimized RF propagation Path Loss Measurements which best predicts the path loss of measured data in Lagos Metropolis.

To achieve this, the following objectives were set;

- To compare the mean power received in dB in rural area (Ifako), suburban areas (Gbagada and Oshodi) and urban areas (Saka Tinubu, Victoria Island, and Osborne in Ikoyi) against predictions made by free space model.
- To take measurements at the operating frequency with a Spectrum Analyzer in the Lagos environment to be compared with existing propagation models using computing tool in MATLAB.

- To select, modified and optimize the most suitable existing free space models for path loss prediction in the investigated areas by computing the MSE in dB.
- To evaluate the optimized path loss model through a validation process by comparing the calculated path loss to the existing acceptable standard in dB in the chosen locations in Lagos GSM Network

II. METHODOLOGY

A radio frequency (RF) site survey is the first step in the deployment of a wireless network and the most significant step to ensure preferred operation. A site survey is a meticulous process by which the researcher studies the facility to know the RF behavior, ascertain RF coverage areas, check for RF interference and determines the appropriate placement of wireless devices. Investigation based on computer simulation is totally different from measuring real-world interference and blockage at a site. Only on-site measurements and surveys can give a complete and detailed picture of the environment investigated. An access point and survey utility are the basic requirements for conducting a site survey. In this study, a site survey was carried out to know the location of the base stations, accessibility of line of sight (LOS) and non-line of sight (NLOS) propagation paths and areas to be classified as rural, suburban and urban

1 Experimental Setup

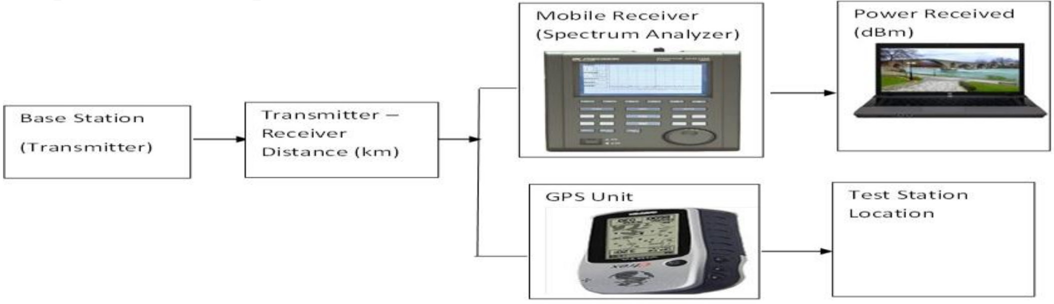

Fig. 1 THE BLOCK DIAGRAM SHOWING THE EXPERIMENTAL SET-UP [1]

2 COST -231 Hata Model

A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model [5]. Given the limitation of the Hata model to 1.5GHz and below, as well as the interest in personal communications systems operating near 1.9GHz, this model was devised as an extension to the Hata-Okumura model. The COST -231 Hata model is designed to be used in the frequency band from 500MHz to 2000MHz. It also contains corrections for urban, suburban and rural (flat) environments. Apart from availability of correction factors for the categories of environments under investigation, the COST-231 Hata model is very simple and easy to use for path loss prediction. The basic (1) for the path loss in dB predicted by this model is;

$PL_{COST} = 46.3+33.9\log_{10} f - 13.82 \log_{10} h_b - ah_m + [44.9 - 6.55\log_{10} h_b)] \log_{10} d + C_m$ (1) [5]

Where, f = frequency in MHz

d = distance between transmitter and receiver in km

h_b= Base station antenna height above ground level in meters.

The parameter C_m is defined as 0dB for suburban or open environments and 3dB for urban environments and the parameter ah_m is defined for urban environments as;

$ah_m = 3.20 [\log_{10}(11.75h_r)]^2 - 4.97$ for $f > 400MHz$ (2)

And for suburban or rural environments,

$ah_m = (1.1 \log_{10} f - 0.7) h_r - (1.56 \log_{10} f - 0.8)$ (3)

Where, h_r is the mobile antenna height above ground level? Observation of (2) to (3) reveals that the path loss exponent of the predictions made by the COST-231 Hata model is given by, $n_{COST} = \frac{[44.9-6.55\log_{10}(h_b)]}{10}$ (4) [5]

In order to evaluate the applicability of the COST-231 Hata model for the 1800MHz band, the model predictions are compared against field measurements from three different environments namely; rural, suburban and urban in Lagos. To show the COST-231 Hata model in a simpler form, the model is expressed by [11] as;

$PL = L_o + n \log_{10} f - 13.82 \log_{10} h_b - CH + [\sigma - 6.55 \log_{10} h_b]] \log_{10} d + C$ (4) [11]

Where PL = Median path loss in decibel (dB), f = Frequency of transmission in MHz

h_b= Base station antenna height in meters (m), CH = Mobile station antenna height correction factor, Lo = 46.3, σ = 44.9 , C = {0dB for rural and suburban areas, 3dB for urban areas}

3 Mean Square Error Analysis.

In [9], it is shown that for any value of d, the reference path loss $PL(d_o)$ is a random variable with a log-normal distribution about the mean value of measured path loss *PLm(d)* in dB due to shadowing. In order to compensate for shadow fading, the path loss beyond the reference distance (d_o) can be represented by;

$$PLm\,(d) = PL(d_o) + 10n \log\,(d/d_o) + S_f; \quad d \geq d_o \qquad (5)\ [9]$$

Where *Sf* is the shadow fading variation about the linear relationship and it has an rms value that best minimizes the error given by [18] and [29] as shown in (5). This is the mean square error (MSE) and it is defined as the square root of the summed square of the difference between measured and predicted path loss per number of measured data points;

$$\text{MSE} = \sqrt{\sum_{i=1}^{k} \frac{[\text{PLm(d)} - \text{PLr(d)}]^2}{k}} \qquad (6)\ [18]$$

Where PLm(d) = Measured Path Loss (dB)
PLr(d) = Predicted Path Loss (dB)
k = 20 (Number of Measured Data Points).

III. SYSTEM MODELLING

The numerical values showing the measured path loss and the existing path loss of each propagation model used in this study were gotten from the feed measurement. Applying (6) to these numerical values give the MSEs for rural, suburban and urban areas as shown in Table [1].

Table 1 Mean Square Error (MSE) Estimates [1]

Mean Square Error (MSE) in Db			
Path Loss Model	**Rural Areas**	**Suburban Areas**	**Urban Areas**
Free Space	31.46	34.33	40.22
Egli	28.25	23.73	29.25
COST-231 Hata	5.22	4.80	4.41
Ericsson	22.78	14.77	15.90
ECC -33	-	22.29	14.62
SUI	3.96	31.18	48.07
COST 231 W-I	59.83	8.36	3.44

The mean power received as shown in Table [2] was determined for each measurement location of the areas under study. The data in Table [2] are analyzed using a computing tool in MATLAB.

Table 2 Mean Power Received in Rural, Suburban and Urban Areas. [2]

Mean Power Received P_r (dBm)			
Distance (km)	Rural Area	Suburban Area	Urban Area
0.1	-45.8	-54.3	-61.3
0.2	-52.3	-60.5	-64.8
0.3	-55.2	-65.4	-59.7
0.4	-59.7	-62.8	-70.0
0.5	-62.0	-67.3	-68.9
0.6	-69.2	-70.7	-73.4
0.7	-66.4	-74.7	-76.2
0.8	-73.7	-72.3	-77.3
0.9	-71.3	-77.3	-84.1
1.0	-76.1	-75.9	-81.4
1.1	-78.4	-78.1	-86.4
1.2	-79.9	-79.6	-87.9
1.3	-81.2	-84.5	-89.6
1.4	-80.8	-80.8	-91.2
1.5	-82.3	-85.9	-93.2
1.6	-84.2	-88.0	-91.7
1.7	-85.6	-87.2	-95.4
1.8	-87.5	-87.8	-96.3
1.9	-87.0	-89.7	-97.0
2.0	-88.8	-90.2	-99.5

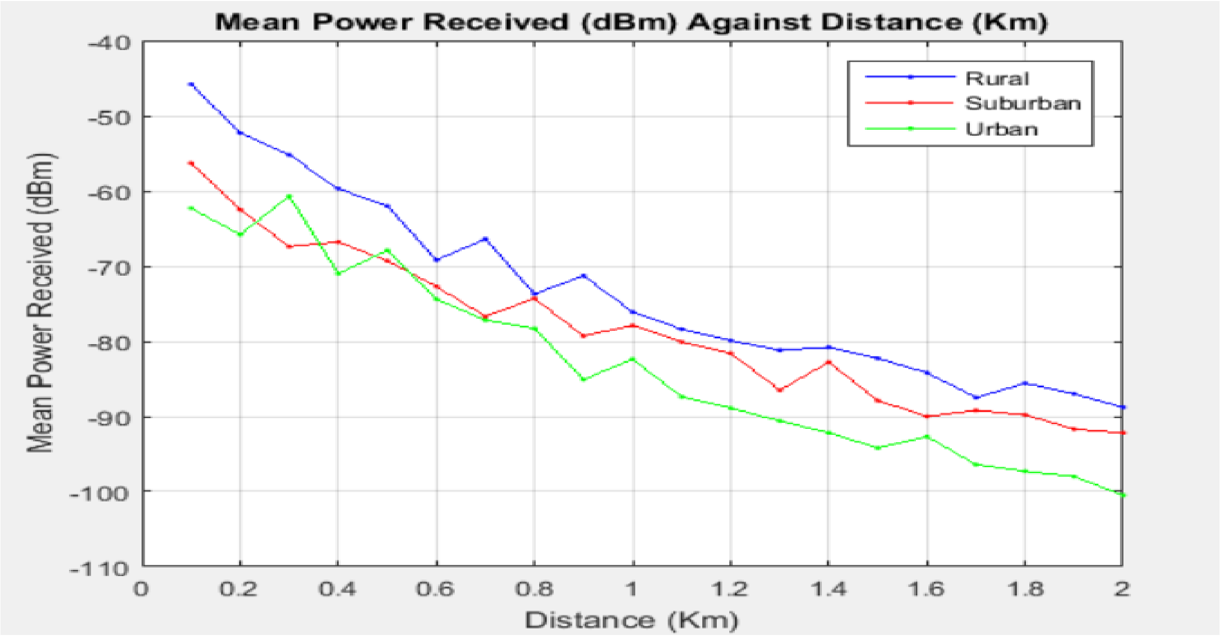

Figure 2 Mean power received in rural, suburban and urban area [2]

1 Modification of COST 231 Hata Model for the Investigated Environment

From the mean square error calculated in Table [1], it was observed that among the existing empirical propagation models compared against propagation measurements taken at 1800KHz in the Lagos environment, the Standford University Interim (SUI) model and COST 231 W-I showed a satisfactory performance in the rural and Urban area with an MSE of 3.96dB and 3.44dB as shown in Table 4.16. However, these models obviously over predicted the path loss in the rural, suburban and urban areas with MSEs of 59.83dB, 8.36dB, 31.18dB and 48.07dB respectively. As a result of these over predictions, they were not selected as the best models. Likewise, the Egli, Ericsson, and ECC-33 models generally over predicted the path loss in the tested areas with MSEs higher than the acceptable range of up to 6dB as stated by [18]. Hence, they were not also selected as most suitable for the investigated environments. In all, the COST 231 Hata model showed the best performance in the rural, suburban and urban areas with MSEs of 5.22dB, 4.80dB and 4.41dB respectively. The model was selected for modification for better signal prediction with lower values of MSEs on the average. The path loss predicted by the COST 231 Hata model as stated in (1) is;

$\mathrm{PLCOST} = 46.3+33.9 \log_{10} (\mathrm{f}) - 13.82\log_{10}(\mathrm{h_b}) - \mathrm{ah_m} + [44.9 - 6.55\log_{10}(\mathrm{h_b})] \log_{10} \mathrm{d} + C_m$

Where, f = frequency in MHz

d = distance between transmitter and receiver in km,

$\mathrm{h_b}$ = Base station antenna height above ground level in meters.

The parameter Cm is defined as 0dB for suburban and rural environments and 3dB for urban environments. Similarly, the parameter $\mathrm{ah_m}$ is defined for urban environments as;

$\mathrm{ah_m} = 3.20 [\log_{10}(11.75 h_r)]\ 2 - 4.97$ for f > 400MHz.

For suburban or rural environments,

$\mathrm{ah_m} = (1.1\log_{10}{}^{f} - 0.7)h_r - (1.56 \log_{10}{}^{f} - 0\text{-}8)$

Where, h_r is the mobile antenna height above ground level in meters.

The modification of (1) was done by subtracting the calculated MSE between the measured and the predicted path loss for each environment as stated in Table 4.16 from the COST 231 Hata model. Therefore, (1) becomes;

$\mathrm{PLCOST}_{Modified} = 46.3 + 33.9 \log_{10} (\mathrm{f}) - 13.82\log_{10}(\mathrm{h_b}) - \mathrm{ah_m} + [44.9 - 6.55\log_{10}(\mathrm{h_b})] \log_{10} \mathrm{d} + C_m - \mathrm{MSE}$

The MSEs of 5.22dB, 4.80dB and 4.41dB for rural, suburban and urban areas respectively, aids the desired modifications and the new models obtained are subsequently referred to as the modified models. The logarithmic curves showing the measured path loss, the COST 231 Hata model and the modified models for rural, suburban and urban areas are as shown in Fig. 3, Fig.4 and Fig.5 respectively.

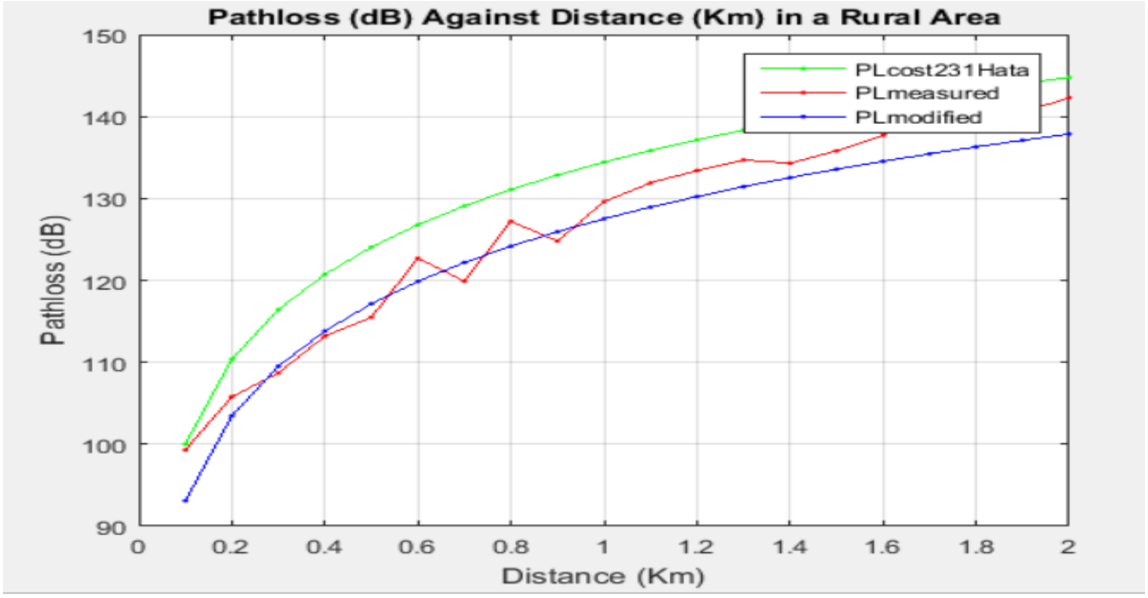

Figure 3 Modification of COST 231 Hata Model for a Rural Area. [3]

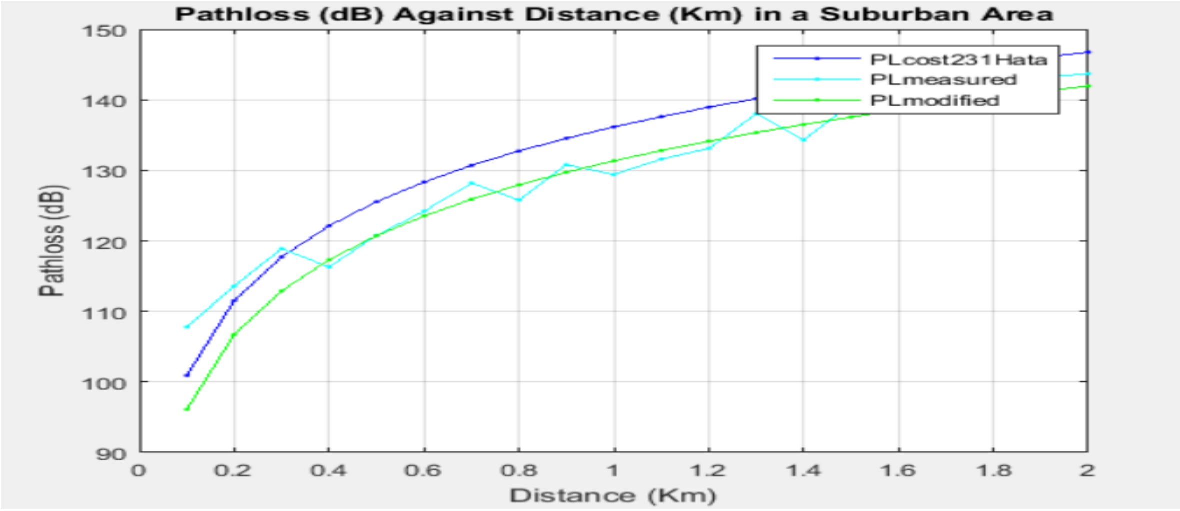

Figure 4 Modification of COST 231 Hata Model for a Suburban Area. [4]

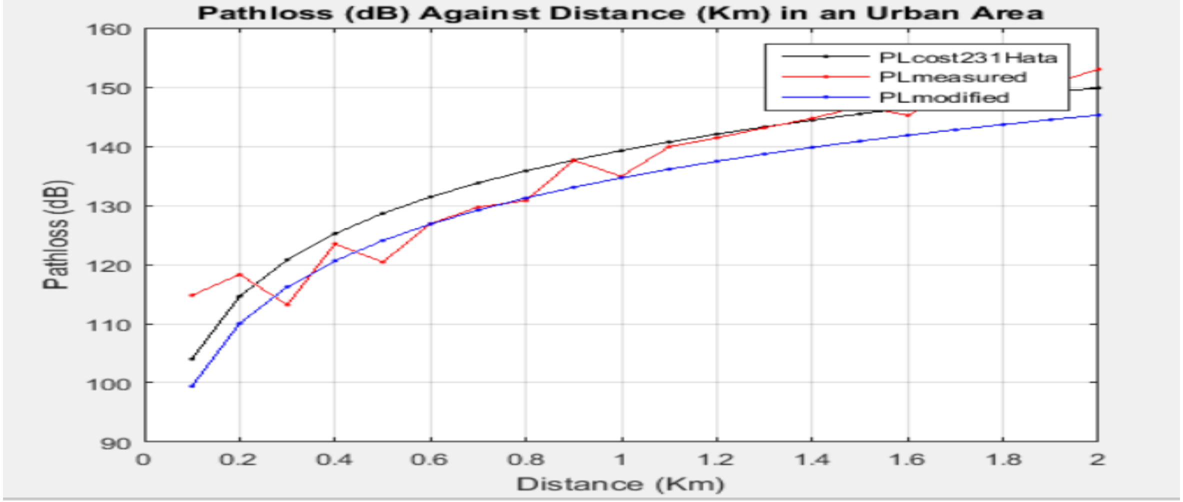

Figure 5 Modification of COST 231 Hata Model for an Urban Area. [5]

2 The New Model Using Modified COST 231 Hata Model

The modified models are developed based on the available network statistics such as operating frequency of 1800MHz, mobile antenna height of 1.5m and base station antenna heights of 40m for rural areas and 30m for suburban and urban areas.

The COST 231 Hata model expressed in (1) can be grouped into the three basic elements of any empirical model as stated by [17] ; the initial offset parameter $\boldsymbol{P_o}$, the initial system design parameter $\boldsymbol{D_{sys}}$ and the slope of the model curve $\boldsymbol{M_{slope}}$ defined by;

$\boldsymbol{P_o} = 46.3 - \mathrm{ah_m} + C_m$ (7) [17]

$\boldsymbol{D_{sys}} = 33.9\,Log_{10}(f) - 13.82\,Log_{10}(\mathrm{h_b})$ (8)

$\boldsymbol{M_{slope}} = [44.9 - 6.55\,Log_{10}(\mathrm{h_b})]\ Log_{10}\mathrm{d}$ (9)

The total path loss is given by;

$\mathrm{PL\ (dB)} = \boldsymbol{P_o} + \mathbf{r}\boldsymbol{D_{sys}} + \boldsymbol{M_{slope}}$ (10)

The least square algorithm in conjunction with the basic fitting function of the computing tool in MATLAB to fit linear models to the logarithmic curves provided by the COST 231 Hata, measured path loss and the modified COST 231 Hata models for rural, suburban and urban areas in Fig.3, 4 and 5. The linear models fitted to the logarithmic curves were presented.

Table 3 Initial Offset Parameters for Modified COST 231 Hata Model [3]

Area	$\boldsymbol{P_o}$	**b**	$\boldsymbol{D_{sys}}$	New $\boldsymbol{P_o}$= **46.3 – MSE – ah**$_\mathbf{m}$**+** $\boldsymbol{C_m}$
Rural	$46.3 - \mathrm{ah_m} + C_m$	104.66	88.21	$41.08 - \mathrm{ah_m} + C_m$
Suburban	$46.3 - \mathrm{ah_m} + C_m$	107.96	89.94	$41.50 - \mathrm{ah_m} + C_m$
Urban	$46.3 - \mathrm{ah_m} + C_m$	111.26	89.94	$41.89 - \mathrm{ah_m} + C_m$

By substituting (8), (9) and the values of New $\boldsymbol{P_o}$ for rural, suburban and urban areas in Table [3] into (10), the path loss models obtained as shown in (11), (12) and (13) are hereby referred to as the **developed models for rural, suburban and urban areas respectively**.

$\mathrm{PL\ (dB)} = 41.08 + 33.9\mathrm{Log}_{10}(\mathrm{f}) - 13.82\mathrm{Log}_{10}(\mathrm{h_b}) - \mathrm{ah_m} + [44.9 - 6.55\mathrm{Log}_{10}(\mathrm{h_b})]\ \mathrm{Log}_{10}\mathrm{d} + C_m$ (11)

$\mathrm{PL\ (dB)} = 41.50 + 33.9\mathrm{Log}_{10}(\mathrm{f}) - 13.82\mathrm{Log}_{10}(\mathrm{h_b}) - \mathrm{ah_m} + [44.9 - 6.55\mathrm{Log}_{10}(\mathrm{h_b})]\ \mathrm{Log}_{10}\mathrm{d} + C_m$ (12)

$\mathrm{PL\ (dB)} = 41.89 + 33.9\mathrm{Log}_{10}(\mathrm{f}) - 13.82\ \mathrm{Log}_{10}(\mathrm{h_b}) - \mathrm{ah_m} + [44.9 - 6.55\mathrm{Log}_{10}(\mathrm{h_b})\ ]\mathrm{Log}_{10}\mathrm{d} + C_m$ (13)

Where, f = Frequency in MHz

d = Distance between transmitter and receiver in km,

$(\mathrm{h_b})$ = Base station antenna height above ground level in meters.

The parameter Cm is defined as 0dB for suburban and rural environments and 3dB for urban environments. Similarly, the parameter $\mathrm{ah_m}$ defined for urban environments as;

$\mathrm{ah_m} = 3.20\ [\ \mathrm{Log}_{10}(11.75hr)]^2 - 4.97$ for f > 400MHz.

For suburban and rural environments,

$\mathrm{ah_m} = (1.1\mathrm{Log}_{10}\mathrm{f} - 0.7)\ h_r - (1.5\ \mathrm{Log}_{10}\mathrm{f} - 0.8)$

Where, h_r is the mobile antenna height above ground level in meters?

By substituting f = 1800MHz, $(\mathrm{h_b})$ = 30m for suburban and urban areas, $(\mathrm{h_b})$ = 40m for rural areas and h_r = 1.5m into (11) , (12) and (13), the simplified forms of the developed models are obtained as shown in (14), (15) and (16) for rural, suburban and urban areas respectively. The path loss predicted by these models is analyzed as shown in Fig.6, using a computing tool in MATLAB. Also, the measured and the predicted path loss on the basis of the developed models for rural, suburban and urban areas are compared as shown in Fig.7.

For rural area,

$\mathrm{PL\ (dB)} = 129.25 + 33.9\ \mathrm{Log}_{10}(1800) - 13.82\ \mathrm{Log}_{10}(40) - 0.04277 + [44.9 - 6.55\ \mathrm{Log}_{10}(40)]\ \mathrm{Log}_{10}\mathrm{d} + 0$

$\mathrm{PLrural\ (dB)} = 129.25 + 34.41\ \mathrm{Log}_{10}\mathrm{d}$ (14)

For suburban area,

$\mathrm{PL(dB)} = 41.50 + 33.9\ \mathrm{Log}_{10}(1800) - 13.82\ \mathrm{Log}_{10}(30) - 0.04277 + [44.9 - 6.55\ \mathrm{Log}_{10}(30)]\ \mathrm{Log}_{10}\mathrm{d} + 0$

$\mathrm{PLsuburban\ (dB)} = 131.40 + 35.22\ \mathrm{Log}_{10}\mathrm{d}$ (15)

For urban area,

$\mathrm{PL\ (dB)} = 41.89 + 33.9\mathrm{Log}_{10}(1800) - 13.82\mathrm{Log}_{10}(30) - (-0.000919) + [44.9 - 6.55\ \mathrm{Log}_{10}(30)]\ \mathrm{Log}_{10}\mathrm{d} + 3$

$\mathrm{PLurban\ (dB)} = 134.83 + 35.22\ \mathrm{Log}_{10}\mathrm{d}$ (16)

Where d = 0.1, 0.2… 2.0 km in rural, suburban and urban areas.

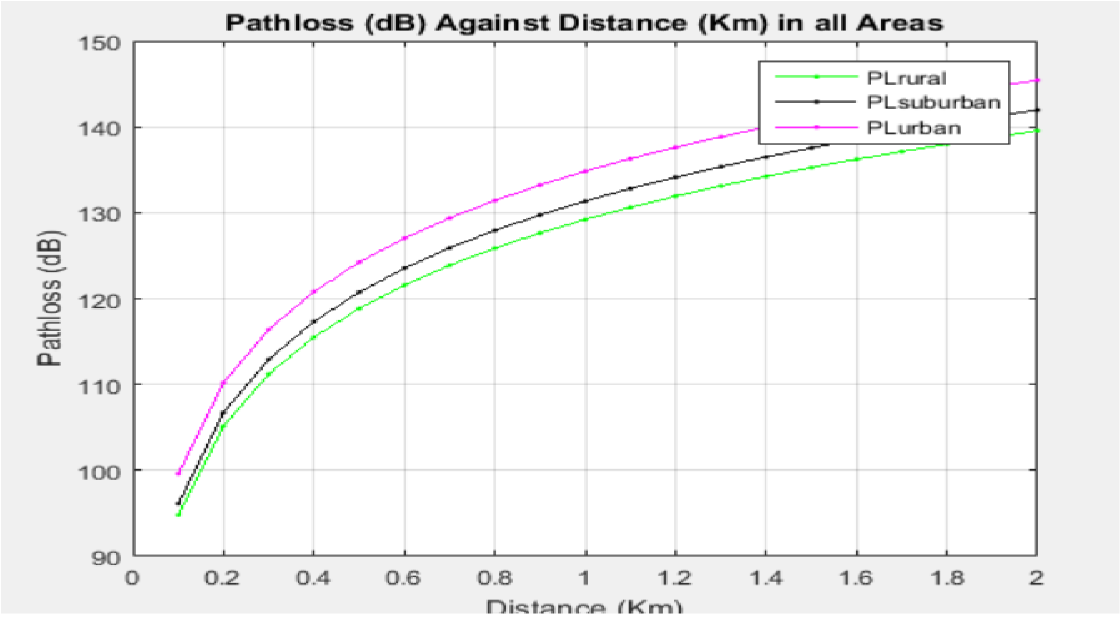

Figure 6 Developed Models for Rural, Suburban and Urban Area [6]

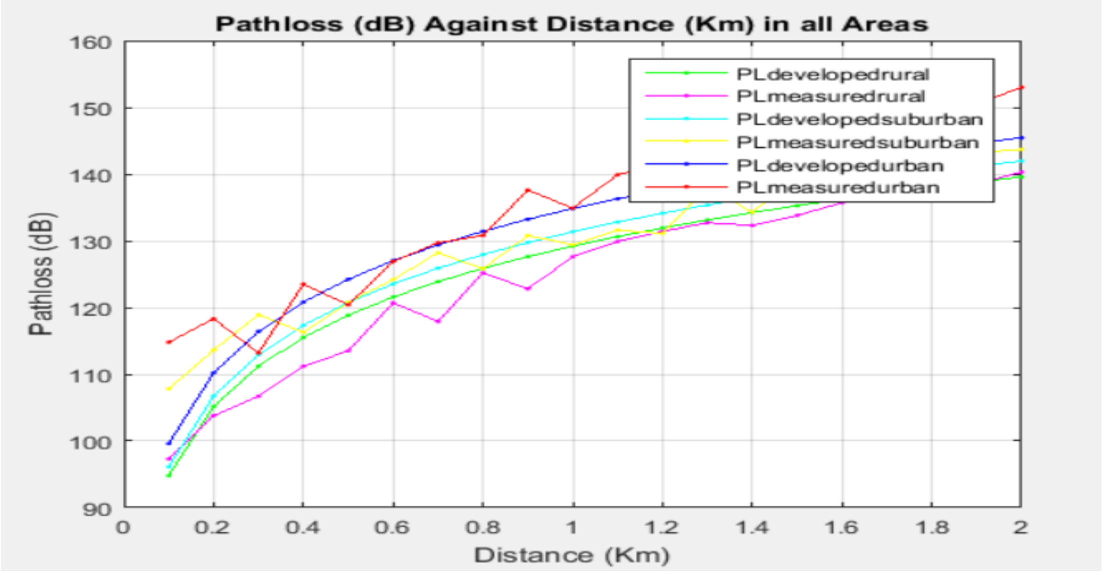

Figure 7 Comparison of Developed Models with Measured Path Loss in Rural, Suburban and Urban areas. [7]

Table 4 MSE from the developed Model in a Rural Area [4]

d(km)	PLm(dB)	PLr(dB)	$[PLm - PLr]^2$
0.1	99.3	94.8	20.25
0.2	105.8	105.2	0.36
0.3	108.7	111.3	6.76
0.4	113.2	115.6	5.76
0.5	115.5	118.9	11.56
0.6	122.7	121.6	1.21
0.7	119.9	123.9	16.0
0.8	127.2	125.9	1.69
0.9	124.8	127.7	8.41
1.0	129.6	129.1	0.25
1.1	131.9	130.7	1.44
1.2	133.4	132.0	1.96
1.3	134.7	133.2	2.25
1.4	134.3	134.3	0.01
1.5	135.8	135.3	0.25
1.6	137.7	136.3	1.96
1.7	141.0	137.2	14.44

1.8	139.1	138.0	1.21
1.9	140.5	138.8	2.89
2.0	142.3	139.6	7.29

Table 5 MSE from the developed Model in a Suburban Area [5]

d(km)	PLm(dB)	PLr(dB)	$[\mathbf{PLm} - \mathbf{PLr}]^2$
0.1	107.8	96	136.89
0.2	113.6	107	43.56
0.3	118.9	113	34.81
0.4	116.3	117	0.49
0.5	120.8	121	0.49
0.6	124.2	124	0.04
0.7	128.2	126	4.84
0.8	125.8	128	4.84
0.9	130.8	130	0.64
1.0	129.4	131	2.56
1.1	131.6	133	1.96
1.2	133.1	134	0.81
1.3	138.0	135	9.00
1.4	134.3	136	2.89
1.5	139.4	138	1.96
1.6	141.5	139	6.25
1.7	140.7	139	2.89
1.8	141.3	140	1.69
1.9	143.2	141	4.84
2.0	143.7	142	2.89

Table 6 MSE from the developed Model in an Urban Area [6]

d(km)	PLm(dB)	PLr(dB)	$[\mathbf{PLm} - \mathbf{PLr}]^2$
0.1	114.8	99.6	207.36
0.2	118.3	110.2	65.61
0.3	113.2	116.4	10.24
0.4	123.5	120.8	7.29
0.5	120.4	124.2	14.44
0.6	126.9	127.0	0.01
0.7	129.7	129.3	0.16
0.8	130.8	131.4	0.36
0.9	137.6	133.2	19.36
1.0	134.9	134.8	0.01
1.1	139.9	136.2	13.69
1.2	141.4	137.6	14.44
1.3	143.1	138.8	18.49
1.4	144.7	139.9	23.04
1.5	146.7	141.0	32.49
1.6	145.2	142.0	10.24
1.7	148.9	142.9	36.01
1.8	149.8	143.8	36.00
1.9	150.5	144.6	34.81
2.0	153.0	145.4	57.76

The mean square error from (6) is given as; $\mathrm{MSE}=\sqrt{\sum_{i=1}^{k}\frac{[\mathrm{PLm}-\mathrm{PLr}]^2}{k}}$

Where PLm = Measured Path Loss (dB)
PLr = Predicted Path Loss (dB) on the basis of the developed model for rural, suburban and urban areas.
k = Number of Measured Data Points = 20.

From Table [4] for a rural area, $\mathrm{MSE} = \sqrt{\frac{105.91}{20}} = 2.30$

From Table [5] for a suburban area, $\mathrm{MSE} = \sqrt{\frac{264.34}{20}} = 3.64$

From Table [6] for an urban area, $\mathrm{MSE} = \sqrt{\frac{550.64}{20}} = 5.25$

The calculated MSEs on the basis of the developed model for rural, suburban and urban areas are presented in Table [7]. Also, these MSEs are compared with the MSEs obtained on the basis of the COST 231 Hata model as shown in Table [8]

Table 7 MSEs for the Developed Models [7]

Area	**Developed Model MSE (dB)**
Rural	2.30
Suburban	3.64
Urban	5.25

Table 8 Mean Square Errors (MSEs) Comparison of COST 231 Hata Model and Developed Model [8]

Area	**COST 231 Hata Model MSE (dB)**	**Developed Model MSE (dB)**
Rural	5.22	2.30
Suburban	4.80	3.64
Urban	4.41	5.25

IV. CONCLUSION

For radio network planning, deployment and optimization processes, these models will provide a platform for improved performance. These model is also very useful for predicting various coverage areas, interference analysis, frequency assignments and cell parameters which are the fundamental elements for network planning processes in mobile radio systems. This would pose great benefits for the Nigerian telecommunication providers; MTN, GLO, Airtel, Etisalat etc., to further improve their services in serving high signalled quality coverage for mobile users' satisfaction while improving coverage in rural areas and increasing capacity in suburban and urban areas in Lagos, Nigeria. A near constant mobile antenna height of 1.5m was used for propagation measurements. Future studies can compare the results of this study with field tests using other acceptable mobile antenna heights. Future research could also be directed towards optimizing the parameters of the SUI model to accommodate suburban and urban environments and finding more suitable parameters for the Ericsson and the COST -231 Walfisch-Ikegami models in rural areas. Finally, a comparative analysis of the measured data with test results from other environments having similar geographical characteristics with the investigated areas will further strengthens the reliability of the stated models.

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IMHOMOH E. LINUS (MNSE), et. al. "Optimization of Cost 231 HATA Model For Propagation Path Loss Measurements in Lagos.” *International Journal of Engineering Science Invention (IJESI)*, Vol. 10(03), 2021, PP 14-23. Journal DOI- 10.35629/6734