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Adjustment of Cost 231 Hata Path Model For Cellular Transmission in Rivers State

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Abstract: *Path loss prediction models are essential tools in radio network planning for cellular transmission as they are used for received signal strength estimation, link budget design and analysis, cell size estimation, and interference optimization. This paper presents empirical path loss models developed for WCDMA microcells operating at 2100MHz on live radio Globacom Node Bs in the urban, suburban, and rural areas in Rivers state. The performance of COST 231 Hata model, Stanford University Interim, and Electronic Communication committee 33 were compared with measured field data. COST 231 Hata model gave a better prediction but with high RMSE and SD which are outside the acceptable value for a good radio signal propagation. COST 231 Hata model was for adjustment based on Linear Least Square Algorithm (LLSA). After adjustment and simulations, the adjusted COST 231 Hata model gave better predictions with minimum MSE and SD that are within the acceptable values. The adjusted COST 231 Hata can accurately be used for predicting the radio characteristic of Rivers State.*

Keywords*: Path loss prediction, cellular transmission, COST -231 Hata model, Mean Square Error, Standard Deviation, Linear Least Square Algorithm.*

I. Introduction

As the demand to meet the heterogeneous service requirements of different applications for cellular wireless services increases, the needs for high quality and high capacity network become extremely important.

For more coverage design of modern cellular networks the signal strength measurements must be taken into consideration. Path loss models are mathematical tools used daily by the Engineers and Network planners for proper determination of the received signal strength at certain location from the Node B. Path loss is defined as the difference in dB between effective transmitted power and the received power [1]. There are lots of different path loss models described by various research experiments. It is important to know that the result of each experiment depends on the environmental conditions under which an experiment was carried out. Each model can be useful for some specific environments, terrain and climate. Therefore, there is no general algorithm that is globally accepted as the best propagation model. Choosing an accurate and realistic path loss model for signal predictions, depends on the fit between the parameters available for the area concerned and parameters required by the model. Therefore, Predictions must be verified by measurements taken from the field survey and the model adjusted accordingly. In this paper, a classical propagation model is adjusted in agreement with field measured data in order to generate predictions with minimal error. The paper is organized as follows. Section 2, presents an overview of the four common existing path loss model considered. The procedure and tools used for obtaining the measured data are described in section 3. Section 4 presents the data obtained from field measurements. The measured results are compared with the results from the three existing models considered in section 5. Model adjustments are presented in section 6.

II. Existing Path loss models

2.1 Log-normal Shadowing Path loss model

This model describes the random shadowing effects that occur over a large number of measurement locations with the equal separation distance between the transmitter and the receiver. The path loss model is given as [3]:

$$L\ (dB) = L(d) + 10r\log\left(\frac{d}{do}\right) + X\sigma \qquad (1)$$

L(dB) is random and log-normally distributed about the distance Where, $X\sigma$ is a zero mean Gaussian distributed random variable (in dB).

2.2 COST 231 Hata model

COST 231 Hata model is an empirical model used for calculating path loss in cellular mobile system. This model is an extension of the Okumura-Hata model designed to cover frequency ranges from 1700Mz to 2300MHz with receiving antenna heights up to 10m and transmitting antenna heights of 30m-200m. COST 231

Hata model contains correction factors for urban, suburban, and rural areas. The equation for COST 231 Hata path loss model is expressed as [3]:

$$L_{COST231Hata}=46.3+33.9\log_{10}(f_c)-13.82\log_{10}(h_t)-a(h_m)+[44.9-6.55\log_{10}(h_t)]\log_{10}(d)+C_m \quad (2)$$

Where, d is the link distance in Kilometres, f_c is the frequency in MHz, h_t is the effective height of the transmitting antenna in meters, h_r is the effective height of the receiving antenna in meters, C_m is the correction factor and is defined 0dB for rural or suburban and 3dB for urban area.
For rural or suburban area,
Correction factor for receiver antenna height:

$$a(h_m) = (1.11*\log_{10} f_c-0.7)h_t - (1.5*\log_{10} f_c - 0.8)$$

For Urban:

$$a(h_m) = 3.2 (\log_{10}(11.75h_m))^2 - 4.79$$

2.3 Stanford University Interim (Sui) Model

The Stanford University Interim was developed by the working group of Institute of Electrical Electronic Engineers (IEEE 802.16) for path loss prediction in all three macro-cellular environments. The model is formulated to operate based on an operating frequency above 1900MHz and a cell radius of 0.1km to 8km, base station antenna height 10m to 80m, and receiver antenna height of 1m to 10m. This model is divided into three categories of terrains namely A, B, C. The terrain category A is associated with maximum path loss, and densely populated region. Moderate path loss is captured in terrain category B. The terrain category C is associated with minimum path loss and flat terrain with light tree densities.

The basic path loss formula for SUI model is expressed as [3]:

$$L_{SUI} = A+10r\log_{10}(d/d_o) +X_f + X_h+ S \quad (3)$$

For $d > d_o$, and d_o=0.1Km
The parameter for Free space attenuation, A is expressed as:

$$A=20\log_{10}(4\pi d_o/\lambda)$$

r is the path loss exponent, h_t is the effective base station height, the constants used for a, b, and c are given in Table 1.

Table1: Numerical values for the SUI Model Parameters

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

X_f is the frequency correction factor: $X_f=6.0\log_{10}\left(\frac{f_c}{2000}\right)$

X_h is the correction factor for receiving antenna height is defined as:

$$X_h=\begin{cases} -10.8\log 10\left(\frac{H_R}{2000}\right), \text{for categories A, B and B} \\ -20\log 10\left(\frac{H_R}{2000}\right) \text{for terrain category C}\end{cases}$$

s is the correction for shadow fading factor, and is defined between 8.2dB and10.6dB.
where f_c is the operating frequency in MHz, and h_r is the receiver antenna height in meters.

2.4 ECC-33 model

The Electronic Communication Committee 33 model was developed by Electronic Communication Committee. This model is designed to predict path loss at higher frequency greater than 3GHz. In this model, path loss is given by [4]:

$$L_{ECC-33}= A_{fs} + A_{bm} - G_t - G_r \quad (4)$$

where,

A_{fs} is the free space attenuation (dB), A_{bm} is the basic median path loss (dB), G_t is the transmitter antenna height gain factor, G_r is the receiver antenna height gain factor.
where, the free space attenuation:

$$A_{fs} = 92.4 + 20\log_{10}(d)+ 20\log_{10}(f_c),$$

Basic median path loss:

A_{bm}=20.41+9.83$\log_{10}$(d)+7.894 $\log_{10}$(f_c)+9.56[$\log_{10}$(f_c)]^2,
Transmitter antenna height gain factor:
G_t=$\log_{10}$(h_t/200){13.958+5.8[$\log_{10}$(h_r)]}^{2} The receiver antenna height gain factor, Gr for medium cities is expressed as:
G_r= [42.57+13.7$\log_{10}$ (f_c)][$\log_{10}$(h_r)-0.585]

III. Data collection method and procedure

To predict path loss model for cellular transmission, practical data from the field measurement are required. Downlink data were collected at various distances on live radio Globacomm WCDMA Node Bs at transmits frequency of 2100MHz. A drive test tools used for collecting data include a laptop equipped with drive test Ericsson software, Map info software (professional version 8.0), a communication Network Analyser software (ACTIX analyser 4.05), Garmin GPS 12XL receiver, Two C702 Sony Ericsson TEMS phone for idle and dedicated mode, an inverter and extension board. The test was carried out on three different locations in Rivers State:

Rumukoro, with co-ordinate (4°48′52″N 7°12'6E″) is selected as urban area, Finima, Bonny Island with co-ordinate (4°26'12.8″N 7°10'25.5″E) selected as sub-urban area, and Borokiri (Creek road) coordinates (4°45'50.5″N 7°1 '26.4″E) selected as rural area.

The two Sony Ericsson UEs, GPS receiver and the Dongle probe were coupled to a laptop placed in a car. The laptop was powered on in order to launch TEMS investigation software. All the equipment were connected and detected on TEMS interface. The routes and the Node Bs were identified before setting out for the drive test. The car was driven around through a predefined route in the direction of the Active Sector (AS) of the directional antenna away from the site until it got to the coverage border. The car was driven at an average speed of 30Km/h. Two modes of configurations for the handsets were used for the monitored software during this drive–test. These were the idle and dedicated modes. M_1 was set at idle mode and M_2 was set at dedicated mode. M_2 was preset automatically to make a continuous call to a fixed destination number. The received signal power is measured using Ericsson handset and transferred to the TEMS log file in the laptop. The GPS receiver gave the location and distance from the Node B synchronously with the received power level reading and was recorded on the laptop. The experimental data were taken at distances ranging from 100meters to 1kilometer. Measurements were carried out between and October and November, 2012.

Table 2: Simulation Parameters.

Parameters	Values
Antenna type	S-wave 0809-65-15DV14
Operating frequency	2100MHz
Node B transmitter	43dBm in urban, 46dBm in sub-urban, 48dBm in rural.
Node B antenna height	30m in urban, 34m in suburban, 38m in rural
UE antenna height	1.5m
Node B antenna gain	18dB
UE antenna gain	0dB
Connector loss	2dB
Cable loss	1.5dB
Duplexer loss	1.5dB
Body loss	3dB

IV. Data analysis

The field measurement and the corresponding path loss values are given in Tables (3)-(5).

L(dB) =10$\log_{10}\frac{P_t}{P_r}$ (6)

Table 3: Measured path loss for urban area

Distance between the Node B and the UE, d (Km)	Mean received level (dBm)	Measured Pat Loss, (dB)
0.10	-69	115
0.20	-74	120
0.30	-79	125
0.40	-80	126
0.50	-82	128
0.60	-85	131
70	-89	135
0.80	-93	139
0.90	-97	143
1.00	-99	145

Table 4: Measured Path Loss for Suburban area.

Distance between the Node B and the UE, d (Km)	Mean Received Level (dBm)	Measured Path Loss, (dB)
0.10	-62	110
0.20	-68	116
0.30	-71	119
0.40	-75	123
0.50	-77	125
0.60	-81	129
0.70	-83	131
0.80	-85	133
0.90	-87	135
1.00	-89	137

Table 5: Measured Path Loss for Rural area

Distance between the Node B and the UE, d (Km)	Mean Received Level (dBm)	Measured Path Loss, (dB)
0.10	-60	110
0.20	-62	112
0.30	-67	117
0.40	-71	121
0.50	-74	124
0.60	-77	127
0.70	-79	129
0.80	-81	131
0.90	-83	133
1.00	-85	135

The values of the reference path loss and the path loss exponent for urban, suburban and rural areas are obtained from the measured values given in Tables (3) - (5) using linear regression [5]; Excel program. Considering other losses, the resultant Path Loss model for field measurement estimated for the three locations (urban, suburban, and rural areas) is expressed as:

$$L_{estimated}(dB) = L(d) + 10 * r * \log_{10}\left(\frac{d}{d_o}\right) + X_\sigma + (G_T + G_R) - (L_R + L_T) \quad (7)$$

V. Comparison of measured path loss with existing path loss model

The path loss values for the three existing models investigated are estimated using equations (2)-(5).The results were compare with the path loss from the field measurements for the three locations and the results given by Figs (1)-(3) .It is necessary to know that ECC-33 model is not applicable to rural environment.

VI. Result and analysis

From the above plots, Figs (1)- (3) showed that ECC-33 model overestimated the measured path loss and have the highest predictions for the three environments, followed by SUI model. COST 231 Hata model under estimated measured path loss with high prediction values (Table 6). The comparisons were based on MSE and SD between the measured path loss and predictions by ECC-33, SUI, COST 231 Hata, models, and they are expressed as [6]:

$$MSE = \sqrt{\frac{\sum_{i=1}^{n}(P_m - P_r)^2}{n-1}} \quad (8)$$

$$\sigma = \sqrt{\frac{(\sum_{i=1}^{n}(P_m - P_r)^2}{n}} \quad (9)$$

Where, P_m Where, $P_{m\,=}$ the measured path loss (dB), P_r is the predicted path loss (dB), and n is the number of measured data points. The results are tabulated in Table (6).

Table (6): Statistical evaluation of MSE and SD for COST 231 Hata, SUI and ECC-33 models before model adjustment

Verification items	COST 231 Hata model		SUI model		ECC-33 model
	MSE	SD	MSE	SD	MSE
Urban	20.440	19.391	37.185	35.277	162.646
Suburban	17.156	16.276	36.284	38.247	169.379
Rural	14.759	14.002	36.786	38.776	118.751

The acceptable limit for good signal propagation is 6dB [6]. COST 231 Hata model has the least MSE and SD for the three environments and was selected for adjustment using linear iterative method based on Least Square Algorithm.

VII. Model adjustments

According to [7], a general radio path loss model based on COST 231 Hata model is defined as:

$$L(\cos)=K_1+K_2\log_{10}d+K_3\log_{10}h_t+K_4\log_{10}h_t*\log_{10}d-K_5\log_{10}f-a(hm), \quad (10)$$

where K_1-K_5 are model adjustable parameters for the model, d is the link distance, f_c is the frequency in MHz, h_t is the effective height of the transmitting antenna in meters, h_r is the effective height of the receiving antenna in meters.

The parameters (K_1 and K_2) of the model are adjusted using Linear Least Square Algorithm .The accuracy of the proposed COST 231 Hata models in different environments depend on the proper adjustment of these parameters and the results are presented in Table (7).

The path loss formula for proposed adjusted COST 231 Hata model is given as:

$$L(adj) = K_1+K_2\log_{10}d+K_3\log_{10}h_t+K_4\log_{10}h_t*\log_{10}d-K_5\log_{10}f-a(h_m)+C_1+C_2\log_{10}d$$
$$=(K_1+C_1)+(K_2+C_2)\log10d+K_3\log_{10}h_t+K_4\log_{10}h_t*\log_{10}d-K_5\log_{10}f-a(h_m) \quad (11)$$

where K_1+C_1 is the K_1 after model adjustment ,
K_2+C_2 is the K_2 after model adjustment, while other parameters remain constant.

Table (7): Parameters of COST 231 Hata model after adjustment

Parameter	Urban		Sub urban		Rural	
Before adjustment		After adjustment	Before adjustment	After adjustment	Before adjustment	After adjustment
C1		17.269		13.51		11.098
C2		-5.923		-7.57		-7.853
K1	46.3	63.57	46.3	59.81	46.3	57.40
K2	44.9	3897	44.9	37.33	44.9	37.05
K3	-13.82					
K4	-6.55					
K5	33.9					

The adjusted COST 231 Hata model is validated by applying it to the experiment areas in order to obtain accurate predictions closer to the field measurements for these areas. The performance of the adjusted COST 231 Hata model is compared with the classical COST 231 Hata model and the measured path loss by comparing the predicted path loss values with the measured values using MSE and SD. The result is shown in Table (8).

Table (8): Statistical verification of adjusted model

Verification items	**Urban**	**Suburban**	**Rural**
MSE	3.1601	0.124	0.123
SD	2.9979	O.118	0.116

The results in Table (8), show the MSE and SD for the proposed model. The proposed adjusted COST 231 Hata models showed better agreement with the measured values, since its MSE and SD are within the acceptable value. Figs (4)-(6) shows the comparison between the proposed adjusted COST 231 Hata model and classical COST 231 Hata model.

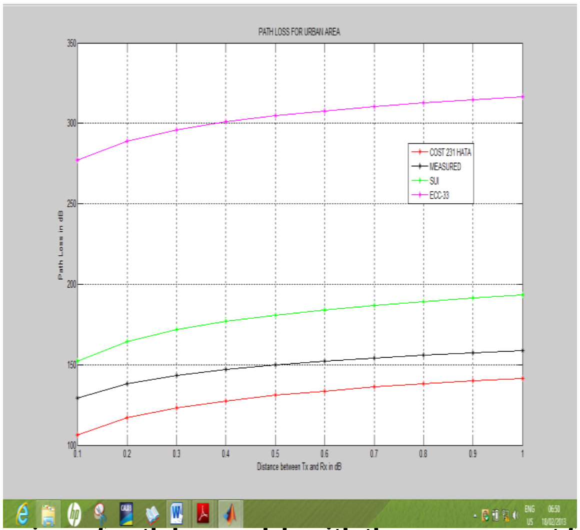

Figure 1: Comparison of path loss models with the measurement from urban area

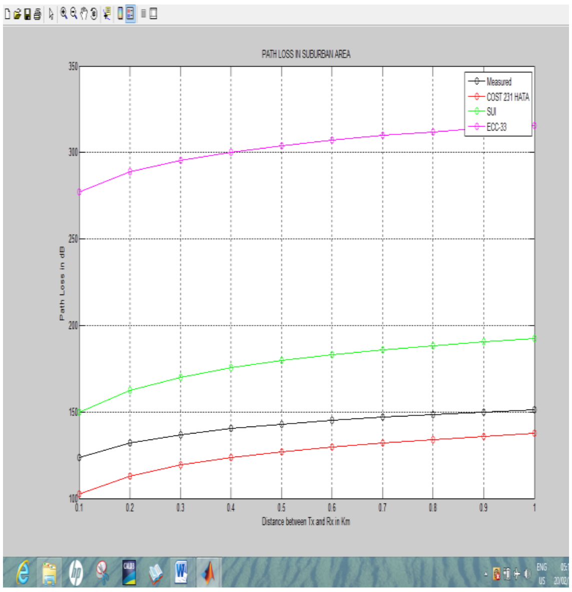

Figure 2: Comparison of path loss models with measurement from suburban area

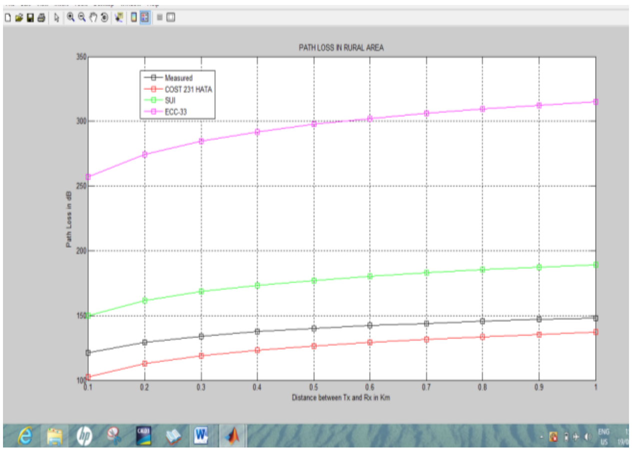

Figure 3: Comparison of path loss models with measurement from rural area

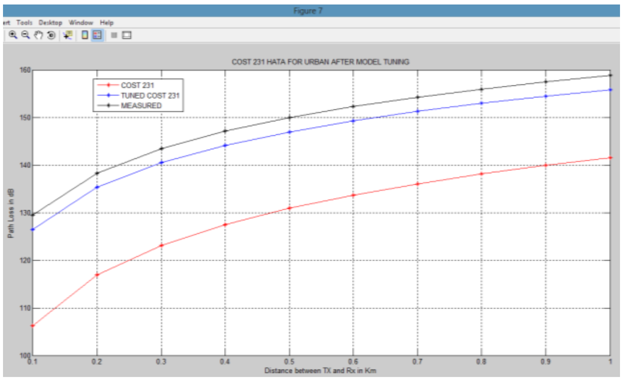

Figure 4: Path loss comparison of Cost 231 model before and after model adjustment for urban area.

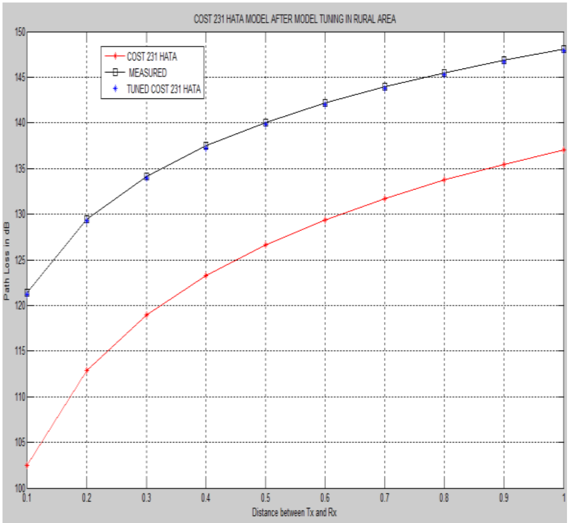

Figure 5: Path loss comparison of Cost 231 model before and after model adjustment for suburban area

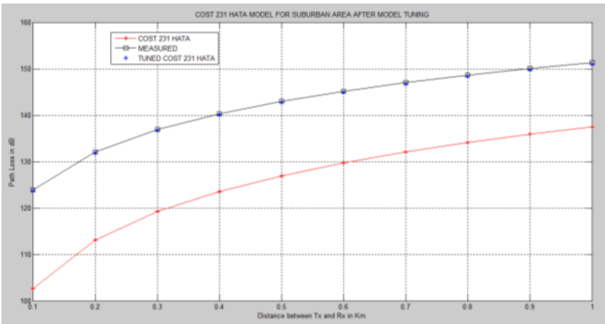

Figure 6: Path loss comparison of Cost 231 model before and after model adjustment for rural area

VIII. Conclusions

This paper presents a statistically adjusted COST 231 Hata model for link budget design and analysis using a simple Linear –iterative Least Square algorithm based on existing path loss model. The outdoor measurements of the received signal power have been collected through drive tests in urban, suburban, and rural areas in Rivers state for comparison with the existing path loss models. The Results of the plots between the proposed adjusted COST 231 Hata model and the measured path loss showed better performance of the adjusted model in these environments. The adjusted model was found suited in these environments, and can be used to predict the signal strength of mobile phone. COST 231 Hata model appears to strike the balance between simplicity and accuracy. But with the adjusted proposed model, Network provider can improve their service for better capacity and better user satisfactions.

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