Statistical Tuning of Hata Model for 3G Communication Networks at 1.857 GHz in Porth Harcourt, Nigeria

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Abstract - *Erroneous path loss predictions before the siting of base stations cause over estimation or under assessment of coverage areas which subsequently lead to incessant call drops, cross talks and network congestions. The ever increasing demand to meet the diverse service requirements of various applications by mobile subscribers makes the consequence more pronounced, and this significantly influences efficiency of the cellular wireless system spectrum. In this paper, a drive test was conducted for the 3G Network at 1.857GHz in some selected urban areas of Port Harcourt, Nigeria viz: Rivers State University of Science and Technology (RSUST), Ikwerre road and D-line using Transmission Evaluation and Monitoring Systems (TEMS II), Global Positioning System (BU-353 GPS), HP laptop and ACTIX software analyzer. The measured path loss was determined from the collected field data. Three standard prediction models namely Hata COST 231 and LEE were implemented. The measured and predicted models were compared and Hata model was identified as the best suited model for the environment. In order to improve the prediction accuracy, Hata model was statistically tuned (optimized) by linear regression approach using the k factor model. Performance analysis of the optimized model and Hata was made using the Mean Absolute Percentage Error (MAPE). The MAPE of the optimized model and Hata model were 13.35 % and 15.0 % respectively. This result shows that the error is less for the optimized model compared to the standard Hata model and thus recommended for deployment for a better and accurate path loss prediction on the environment of study.*

Key Words*: *Statistical Tuning, Linear Regression, Propagation, Hata Model, Communications

1. INTRODUCTION

The nature of the radio channel causes wireless signal system to be more complex than the wired counterpart. During signal reception, radio signals radiated through a wireless channel experience unsystematic variation due to obstruction resulting from objects in the propagating path, which causes random variations of the received signal strength at a particular distance. This prevalence observed in wireless communications is called Path loss. This results to poor signal strength and reduction of power density of an electromagnetic wave as it propagates through the multipath propagation atmosphere.

Wideband Code Division Multiple Access (WCDMA) is the third generation (3G) mobile system intended to transmit high speed access to voice, data and video services to several users concurrently. The technology permits the use of this air- interface for free mobility of User Equipment (UE) though it causes severe challenges as a means for high speed communication.

Erroneous path loss predictions before the siting of most base stations result to over estimation or under assessment of coverage areas which consequently lead to persistent call drops, cross talks and network congestions. The effect is more evident where there are ever increasing demand to meet the diverse service requirements of various applications, which drastically influences efficiency of the cellular wireless system spectrum. Thus, the quality of signals delivered to the mobile users are affected which renders the services offered by the mobile operators defective and below expectation.

Path loss model optimization involves the statistical tuning of chosen parameters of a standard theoretical model with the aid of measured data obtained by field measurement aimed at minimizing the error between the measured and predicted signal strength for the environment under study. Many authors have worked in the optimization of propagation models. The authors in [1] researched on tuning of COST 231 model for radio wave propagation prediction. In [2], the authors worked on New Approach for Determination of Propagation Model Adapted to an Environment Based on Genetic Algorithm for the city of Yaoundé, Cameroun. The authors in [3] tuned the Okumura Hata model in urban and rural areas in Lituania at 160, 450, 900 and 1800 MHz bands. COST 231 model was optimized for 3G wireless communication signal in Suburban area of Port Harcourt, Nigeria in [4]. Authors in [5] optimized COST 231 Hata model to predict path loss for suburban and open urban environments in the 2360-2390 MHz.

In this work, a drive test was conducted for the 3G Network at 1.857GHz in some selected urban areas of Port Harcourt, Nigeria viz: Rivers State University of Science and Technology (RSUST), Ikwerre road and D-line. The measured path loss was determined from the collected field data. Three standard prediction models namely Hata, COST 231 and LEE were implemented. The measured and predicted models were compared and Hata model was identified as the best suited model for the environment. In order to improve the prediction accuracy, Hata model was optimized by linear regression approach using the k factor model.

2. STANDARD PATH LOSS MODELS

HATA MODEL

Hata model is a set of equations which are acquired from taking measurements and extrapolations acquired from curves that are developed by Okumura. According to [6] and [7], the Hata path loss prediction model is preferred since it is convenient for frequency range of 150-1500 MHz and for distance range of 1km - 20km. It demands that the base station antenna height be 30m and above while the receiving station antenna height will be 3m and above. Hata prediction model also gives room for correction factors addition.

The three categories of Hata prediction models according to [8], are as enlisted below:

- Open or rural Hata pathloss,
- Suburban Hata pathloss and
- Urban Hata pathloss.

Rural Hata pathloss

The rural Hata path loss is given by the expression:

$$PL = PL\,(Urban) - 4.78(\log_{10}(f)^2) + 18.33\log_{10}(f) - 40.98 \quad (1)$$

Where:
PL is the Path Loss, f is the frequency (MHz)

Urban Hata pathloss

The urban Hata path loss is given by the expression:

$$PL = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + C_m - a(h_m) \quad (2)$$

Where:
h_m is the height of the mobile antenna in meters, h_b is the height of the base station antenna in meters, $a(h_m)$ is the correction factor, C_m is a constant.

Surban Hata pathloss

The Sub-urban Hata path loss is given by the expression:

$$PL = PL(Urban) - 2((\log_{10} f/28))^2 - 5.4 \quad (3)$$

For the above three categories, the correction factor for the Mobile station antenna is given thus:

$$a(h_m) = 1.11\log_{10}(f) - 0.7)h_m - (1.56\log_{10}(f) - 0.8) \text{ dB} \quad (4)$$

It is worth noting that Hata propagation model does not consider terrain profile like hills that are found between transmitter and receiver [8].

According to [9], Hata model is based on measurements made in and around Tokyo in 1968 between 150 MHz and 1500 MHz. The author maintained that the model operates better under the following listed conditions;

- Carrier Frequency: 150 MHz ≤ fc ≤1500 MHz
- Base Station (BS) Antenna Height: 30 m ≤hb ≤200 m
- Mobile Station (MS) Antenna Height: 1 m ≤hm ≤10 m
- Transmission Distance: 1 km ≤d ≤20 km

COST-231 Model

COST-231 model uses suitable correction factors to improve the limitations of the Hata model. This COST-231 model uses four parameters in the prediction of propagation loss. These parameters include receiving antenna height, frequency, base station height, and distance between base station and receiving antenna.

According to [9], this model uses the Height Above Average Terrain (HAAT) along each radial to determine the attenuation. The equation for COST-231 model is written as,

$$Lp\,(dB) = A + B\log10\,(d) + C \quad (5)$$

Where;

$$A = 46.3 + 33.9\log10\,(fc) - 13.28\log10\,(h_b) - a\,(h_m) \quad (6)$$

$$B = 44.9 - 6.55\log10\,(h_b) \quad (7)$$

C= 0 for medium city and suburban areas and 3 for metropolitan areas [4]

Where: fc is the center frequency (MHz), h_m is the height of the mobile antenna in meters, h_b is the height of the base station antenna in meters, d is distance in meters.

LEE Model

LEE Model is used for forecasting the path loss in urban, suburban, rural and free space regions [10]. LEE Model is accepted among researchers and system engineers because the parameters of the model can be easily attuned to the local environment by additional field drive tests. This model is comprised of four key categories:

Category 1: Urban region

$$PL = 123.77 + 30.5\log_{10}(d) + 10n\log_{10}(f/900) - \alpha_o \quad (8)$$

Category 2: Suburban region

$$PL = 99.86 + 38.4\log_{10}(d) + 10n\log_{10}(f/900) - \alpha_o \quad (9)$$

Category 3: Rural region

$$PL = 86.12 + 43.5\log_{10}(d) + 10n\log_{10}(f/900) - \alpha_o \quad (10)$$

Category 4: free space region

$$PL = 96.92 + 20\log_{10}(d) + 10n\log_{10}(f/900) - \alpha_o \quad (11)$$

Where: n is an experimental value, α_o is the correction factor.

3. METHODOLOGY

Drive Test

In the course of this research work, drive test approach was adopted for data collection. The apparatus used include the following: HP Laptop with installed Transmission Evaluation and Monitoring System (TEMS) software, Global positioning System (BU-353 GPS), Galaxy S5 Mobile Phone with installed TEMS software, Power supply from external battery source and Car for mobility. This test was carried out in three (3) sites within Port-Harcourt (urban city) and a distance of 1.0 km was chosen from the routes as sample distance for analysis. On the start of each segment, the laptop was prompted to commence readings on the site by the tick of the cursor on the 'Record' button. Hence, the radio Propagation Simulator (TEMS installed Galaxy S5 Phone) initiates and terminates short calls (about 15 seconds each), the BU-353 GPS points coordinates (latitude and longitudes) of the environment, while the HP laptop registers the Received Signal Strength (RSS) and displays the log video on the screen [11].

The values of the parameters for the test network are tabulated in Table 1.

Table 1: Transmission Parameters for the Network

S/N	Transmission parameters	Values
1	Frequency of operation	1.857 GHz
2	Transmitter power	30W
3	Transmitter height	35m
4	Mobile Station height	1.5m
5	Gain of transmitter	18dBi
6	Gain of receiver	1.76db

4. RESULTS BEFORE STATISTICAL TUNING

Table 2.0 shows the pathloss values for the various predicted models and the measured data.

Figure 1 shows the graphical representation of the predicted and measured pathloss values against distance. The graph shows that pathloss varied with change in distance. Though the change in the measured pathloss values varied in a non-linear pattern, this could be attributed to factors affecting the propagation of signals within the environment. The MAPE (mean Absolute Percentage Error) was used to check the performance of the various models. The MAPE of the predicted models were calculated using equation (12) and compared with the measured data.

$$\text{MAPE} = \frac{100}{n}\sum_{t=1}^{n}\frac{|A_t - F_t|}{A_t}\% \qquad (12)$$

Where A_t are the actual values (measured), F_t are the predicted values (predicted models), n is the number of measured points.

The result shown in table 3 has it that Hata Okumura model performed better with MAPE value of 15.04% compared to COST 231 16.34% and LEE 19.31%. Based on the performance of Hata Okumura, there is need to tune the model to suit the environment of study.

Table 2.0 Pathloss value for various models and the measured model.

Distance (km)	Measured (dB)	Okumura-Hata (dB)	COST 231(dB)	LEE (dB)
0.10	112	126.3500	128.9100	86.4650
0.20	136	136.8217	139.3828	95.6464
0.30	135	142.9472	145.5089	101.0171
0.40	158	147.2934	149.8555	104.8277
0.50	121	150.6645	153.2270	107.7834
0.60	158	153.4189	155.9817	110.1985
0.70	114	155.7477	158.3108	112.2403
0.80	118	157.7650	160.3283	114.0091
0.90	128	159.5444	162.1079	115.5692
1.00	158	161.1362	163.6998	116.9648

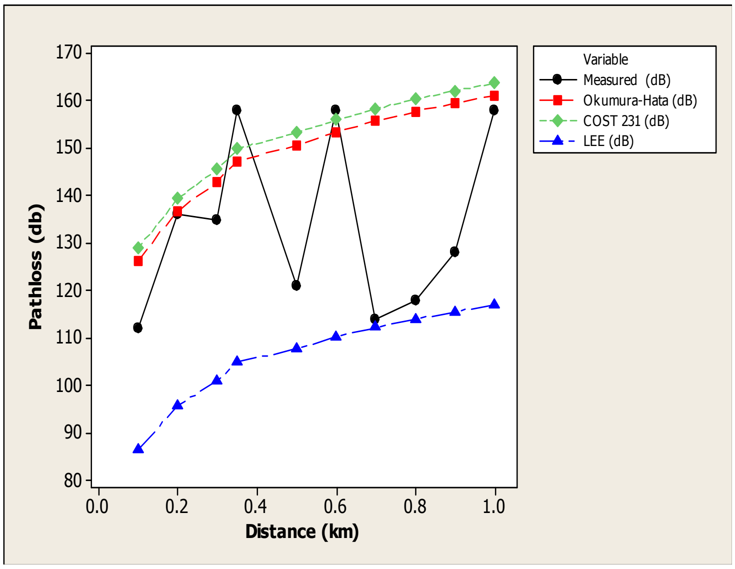

Figure 1. Graph showing predicted and measured Pathloss against distance

Table 3.0: Mean Absolute Percentage Error before optimization

Model	MAPE
Okumura Hata (dB)	15.044
COST 231 (dB)	16.34
LEE (dB)	19.31

5. TUNING OF HATA MODEL AT 1.857 GHZ

With differences in the environmental characteristics for which the model has been made, we adopt a tuning procedure the K factor model approach [12].

we present the Okumura Hata model used in this work as thus;

$$L_p = 69.55 + 26.16\log(f_c) - 13.82\log(h_b) + (44.9 - 13.82\log(h_b)) * log(d) - E \quad (13)$$

With $E = 32(\log(11.75h_m))^2 - 4.97$; For h_m=1.5;

$$E = 3.2(log(11.75 * 1.5))^2 - 4.97 \quad \text{For } f \geq 400\text{MHz} \quad (14)$$

$E = -9.190 \times 10^{-4}$ (Negligible),

Considering the following standard form given by equation (13),

$$L_p = k_1 + k_2 * \log(d) + k_3 * (H_m) + k_4 * \log(H_m) + k_5 * \log(H_b) + K_6 * \log(H_b) * \log(d) \quad (15)$$

With (15) it is possible to determine the Okumura Hata model Coefficients, K, as shown in Table 4

Equation (15) can also be rewritten as

$$L_p = [k_1 + k_3 * H_m + k_4 * \log(H_m) + k_5 * \log(H_b)] + [k_2 + k_6 * \log(H_b)] * \log(d) \quad (16)$$

Assuming,

$$A = k_1 + k_3 * (H_m) + k_4 * \log(H_m) + k_5 * \log(H_b)$$

$$B = k_2 + k_6 * \log(H_b)$$

Then,

$$L_p = [1 \quad \log(d)] * \begin{bmatrix} A \\ B \end{bmatrix} \quad (17)$$

Once we get the measured propagation loss L_1 for N points at different distances d_1, (17) can be written in matrix form as:

$$\begin{bmatrix} L_1 \\ \vdots \\ L_N \end{bmatrix} = \begin{bmatrix} 1 & \log(d_1) \\ \vdots & \vdots \\ 1 & \log(d_N) \end{bmatrix} * \begin{bmatrix} A \\ B \end{bmatrix} \quad (18)$$

Eq. (17) can be re arranged in a compact form as [13]:

$$L = M_o * T \quad (19)$$

The optimization process consists of minimizing the Euclidian distance between the prediction values contained in the vector L and the measured propagation loss L_M.

Let E= $\frac{1}{N}\| L_M - M_o * T\|^2$ be the mean squared error, E is minimal if its gradient relatively to T is null, that is $\frac{\partial E}{\partial T} = 0$ and then

$$\frac{\partial E}{\partial T} = 0 => \Delta E = \frac{1}{N}(2M_o^T M_o^T - 2M_o^T L_M)$$

$$=> \frac{1}{N}(2M_o^T M_o^T - 2M_o^T L_M) = 0$$

Finally the solution is:

$$T^* = (M_o^T M_o)^{-1} M_o^T L_M = \begin{bmatrix} A^* \\ B^* \end{bmatrix} \quad (20)$$

Therefore for K3, K4, K5 and K6 constants, we get:

$$K_1 = A^*(K_3 * h_m + K_4 * \log(h_m) + K_5 * \log(h_b)) \quad (21)$$

$$K_2 = B^* - K_6 * \log(h_b) \quad (22)$$

Table 4: Okumura Hata model coefficients

Model	K1	K2	K3	K4	K5	K6
Okumura Hata	133.72	44.9	0	0	-13.82	-6.55

6. RESULT AFTER STATISTICAL TUNING

The MAPE of the optimized model was calculated and found to be 13.35%. Figure 2.0 presents a graphical representation of predicted, optimized models and measured values. The optimized hata model showed better performance compared to the predicted and measured values in this environment. This was ascertained through a Mean Absolute Error Analysis which showed that the optimized model had improved by 13.35% compare to an earlier value of 15.04%. With this the optimized model has the potential of performing better upon deployment.

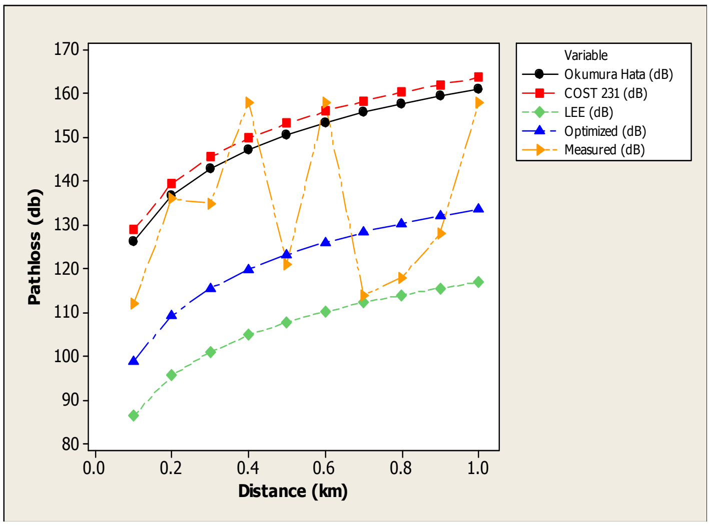

Figure 2: the plot of predicted models, measured data and optimized data

Figures 3 and 4 shows plots from the regression analysis on the optimized and Okumura Hata models respectively.

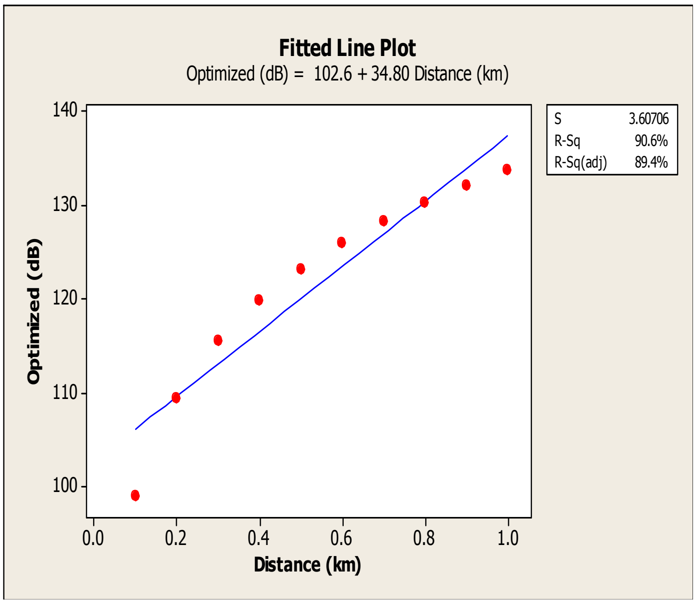

Figure 3: Regression analysis on the optimized model

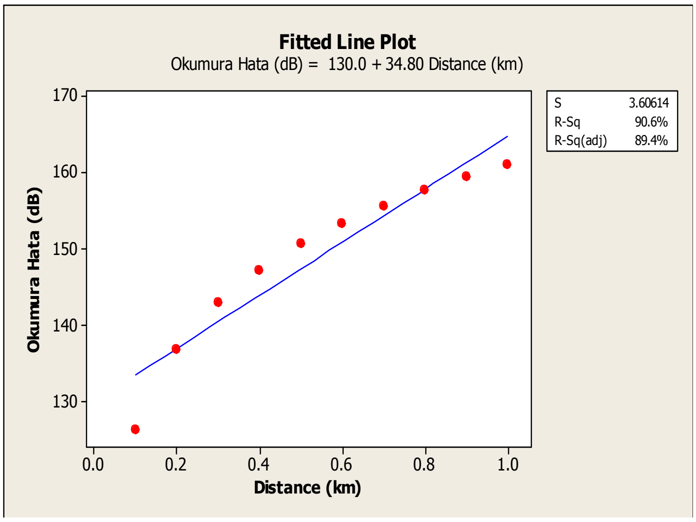

Figure 4: Regression analysis on Okumura Hata model

7. CONCLUSION

This research did not emphasize on any propagation model, rather optimized the best performing model to suit the environment of propagation in a specific frequency. The K factor model has the advantage of being used to achieve this, as almost all existing statistical propagation models on a specific frequency could be written in the form of Equation (14). The optimized Hata model has shown potential to be recommended for use as a propagation model at 1.857 GHz in the environment of study.

REFERENCES

[1]. Chhaya Dalela,etal, tuning of Cost231 Hata model for radio wave propagation prediction, Academy & Industry Research Collaboration Center, May 2012.

[2]. Deussom E. and Tonye E, New Approach for Determination of Propagation Model Adapted To an Environment Based On Genetic Algorithms: Application to the City Of Yaoundé, Cameroon, IOSR Journal of Electrical and Electronics Engineering, Volume 10, pages 48-49, 2015.

[3]. Medeisis and Kajackas, The tuned Okumura Hata model in urban and rural zones at Lituania at 160, 450, 900 and 1800 MHz bands, Vehicular Technology Conference Proceedings, VTC 2000-Spring Tokyo. IEEE 51st Volume 3 Pages 1815 – 1818, 2000.

[4]. Akujobi Ekeocha, Nosiri Onyebuchi, Lazarus Uzoechi and Gordon Ononiwu, Optimization of Cost 231 Model for 3G Wireless Communication Signal in Suburban Area of Port Harcourt, Nigeria, International Journal of Engineering Sciences & Research Technology, vol.5 issue 5, pages 83-88, May 2016.

[5]. Mardeni and Priya , Optimized COST-231 Hata model to predict path loss for suburban and open urban environments in the 2360-2390MHz, Progress In Electromagnetics Research C, Vol. 13, 91-106, 2010.

[6]. Ubom, E. A, Idigo, V.E., Azubogu, A.C.O., Ohaneme, C.O., and Alumona, T.L. (2011), "Pathloss Characterization of Wireless Propagation for South – South Region of Nigeria". International Journal of computer theory and Engineering, vol.3, N03, Pg 360 - 364.

[7]. Ogbulezie, J.C, onuu, M.U., Bassey, D.E and Etienam-Umoh, S. (2013), "Site specific measurements and propagation models for GSM in three cities in northern Nigeria". American Journal of scientific and industrial Research, Vol.4, Issue 2, pp 238 – 245.

[8]. Alsami, M.A, Arslan, T., Thompson, J. and Erdogan, A.T.(2011), "Frequency Analysis of path loss models on WiMAX". Computer science and Electronic Engineering conference (CEEC).

[9]. Singh, Y. (2012), "Comparison of Okumura, Hata and COST-231 Models on the Basis of Path Loss and Signal Strength". International Journal of Computer Applications. Volume 59, No.11

[10]. Biebuma, J.J. and Omijeh, B.O. (2013). Path Loss Model Using Geographic Information System (GIS). International Journal of Engineering and Technology Vol. 3, No. 3, pp 269 – 275.

[11]. Chinedu Anyanwu, Nkwachukwu Chukwuchekwa and Cosmas Agubor. (2017). Development of a Pathloss Model For 3G Networks at 1.857 GHz in Port Harcourt Nigeria, International Journal of Engineering Sciences & Research Technology, 6(5), 423-433.May 2017.

[12] Deussom Djomadji Eric Michel and Tonye Emmanuel "Optimization of Okumura HATA Model in 800 MHz

based on Newton Second Order algorithm. Case of Yaounde, Cameroon" IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE). Volume 10. Issue 2 Pages 16-24, 2015.

[13]. Deussom Djomadji Eric Michel and Tonye Emmanuel, "New Propagation Model Optimization Approach based on Particles Swarm Optimization Algorithm" International Journal of Computer Applications (0975 – 8887) Volume 118 – No. 10, May 2015.