A Measurement-Based Model For The Analysis Of Pathloss In A Given Geographical Area

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Abstract*—Through the use of Transmission Evaluation and monitoring system (TEMS) equipment, Global positioning system (GPS) and laptop, a drive test was carried out along the major streets in owerri metropolis. From the experimental data collected, a measurement-based path loss model was developed for Owerri Metropolis, Imo State Nigeria. The results from the MatLab software simulation showed a considerable drop in the Received Signal Level (RSL) in some of these studied areas which were as a result of multipath fading, inefficient call hand over scheme, among others. There was every indication from the results that there was no much deviation of the standard models (Hata and Cost 231) from the predicted path loss model as represented in figure 4.1. However, the slope of the Cost 231 plot is closer to the predicted model than that of Hata; hence, cost 231 model will best describe the path loss experienced in the Owerri MTN network than the Hata model.

***Keywords*— transmission; signal; model; multipath; level; measurement**

I. Introduction

II. THE STUDY WHICH EVALUATES THE PATH LOSSES AND THE STRENGTH OF RECEIVED SIGNAL WITHIN OWERRI IS VERY ESSENTIAL IN DETERMINING THE REDUCTION IN POWER OF AN ELECTROMAGNETIC WAVE AS IT PROPAGATES THROUGH SPACE. THIS LOSS CONSIST A MAJOR COMPONENT IN ANALYSIS AND DESIGN OF LINK BUDGET OF A SYSTEM COMMUNICATION MODEL (1). THIS SYSTEM MODEL IS DEPENDENT ON ANTENNA HEIGHT, FREQUENCY, LINK DISTANCE, AMONG OTHER FACTORS. THIS STUDY HELPS TO ASCERTAIN THE ACTUAL ANTENNA HEIGHT, LINK DISTANCE AND SO ON, THAT WILL ENSURE OPTIMUM SIGNAL PROPAGATION. HENCE, THE WASTE OF DEVICES AND COST IS MINIMIZED. HATA PROPAGATION 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 formular for graphical path loss.(2), (1).

Hata presented the prediction area into three divisions: Open, suburban and urban areas. This model is appropriate for frequency range of 150-1500 MHz (UHF) and for distance of 1km-20km. However, Hata model does not consider terrain profile like hills that are found between transmitter and receiver. (1)

In the words of (3), Hata model for calculation of path loss are used in three situations namely:

Situation1: Urban Hata pathloss

$PL = 69.55 + 26.16log_{10}(f) - 13.82log_{10}(hb) + (44.9 - 6.55log_{10}(hb))log_{10}(d) + s\text{-a}(hm)$ ….1

Situation 2: Surban Hata pathloss

PL=PLUrban-2((log_{10}f/28))^2-5.4 ….2

Situation 3: Rural Hata pathloss

PL=PLUrban – $4.78(log_{10}(f)^2) + 18.33log_{10}(f) - 40.98$ ….3

Where the MS (Mobile station) antenna correction factor for the entire above situation is:

$a(h_m)=1.11log_{10}(f) - 0.7)h_m - (1.56log_{10}(f) - 0.8)$ in dB ….4

f is the frequency in MHZ

h_m is the height of the mobile antenna in meters

h_b is the height of the base station antenna in meters (2), (3), (4)

III. Cost-231 Propagation model

This stands for Co-operative for Scientific and Technical research. It is an enhanced version of the Hata propagation model. That is, it employs suitable correction factors to improve the limitations of the Hata model(2). Cost-231 model makes use of four variables in predicting propagation loss. The variables are Frequency, height of base station, height of receiver's antenna and distance between base station and receiver antenna.

(1).

The Cost hata Path loss equation is given by

$PL(dB) = 46.3 + 33.9log(f_c) - 13.82log(h_b) - a(h_m) + (44.9 - 6.55log(h_b))log_{10}(d) + c_M$ 5

Where;

C_M may be 0 for suburban city or 3 for metropolitan city (5)

IV. PROPOSED MODEL AND FIELD DATA COLLECTION

In order to determine the Path Loss within Owerri Metropolis, the data obtained from the field experiment on the path loss is collected and has its validity tested in order to derive an appropriate model that best predict the signal pathloss within Owerri. Table 4.1 below indicates the median values of the measured Received Signal Levels (RSL) and corresponding values of Path Losses for specified distances, 0.05km≤ di ≤1.00km.

Equation 4.1 below is the standard model for predicting the Path loss. Substituting the values obtained from the field measurements into equation 4.1 below gives the path loss of Owerri Metropolis.

$$Lp = Lp(d_0) + 10nlog\left(\frac{d_i}{d_0}\right) + X\delta \text{ ....6}$$

Where;

Lp=Path loss,

Lp (di) = Measured Path Loss

Lp (do)= Predicted Path Loss

n=Path loss exponent (Path Loss exponent shows the rate at which Path Loss varies with distance)

Table 1: Median Receive Signal Levels (RSL) for the measured routes

Distance(km)	Median RSS (dBm)
0.05	-51
0.10	-58
0.15	-64
0.20	-66
0.25	-69
0.30	-67
0.35	-69
0.40	-69
0.45	-68
0.50	-70
0.55	-71
0.60	-73
0.65	-73
0.70	-76
0.75	-79
0.80	-80
0.85	-82
0.90	-82
0.95	-81
1.00	-82

Making n (the path loss exponent) the subject of the equation 6 above produces equation 7 ;

$$n = \frac{Lp - Lp(d_0)}{10\,log\left(\frac{d_i}{d_0}\right)} \text{ .... 7}$$

For k number of data points, equation 7 is modified thus;

$$n = \frac{\sum_{i=1}^{k} Lp - Lp(d_0)}{\sum_{i=1}^{k} 10\,log\left(\frac{d_i}{d_0}\right)} \text{ .... 8}$$

Where n remains the path loss exponent.

From table 1 above, the estimate of the average power received at the closest distance is given thus;

$$\text{Power}(Rx_{av}) = \text{Pr}(dBm) = -51dBm \text{ ....9}$$

$$10logP_r = -51$$

$$logP_r = -5.1$$

$$P_r = 10^{-5.1} = 7.9X10^{-6}dB$$

And;

$$P_t = 40w = 16.02dB$$

$$Lp(d0) = 10\log\left(\frac{p_t}{p_r}\right) \text{ ....10}$$

For i=1,

$$Lp(d1) = 10\log\left(\frac{16.02}{7.9X10^{-6}}\right) = 63dB$$

$$for\ i = 2$$

$$Pr = 10^{-5.8} = 1.59 \times 10^{-6}dB$$

$$Lp(d2) = 10\log\left(\frac{16.02}{1.59 \times 10^{-6}}\right) = 70dB$$

$$for\ i = 3$$

$$Pr = 10^{-6.4} = 3.98 \times 10^{-7}dB$$

$$Lp(d3) = 10\log\left(\frac{16.02}{3.98 \times 10^{-7}}\right) = 76dB$$

$$for\ i = 4$$

$$Pr = 10^{-6.6} = 2.51 \times 10^{-7}dB$$

$$Lp(d4) = 10\log\left(\frac{16.02}{2.51 \times 10^{-7}}\right) = 78dB$$

$$for\ i = 5$$

$$Pr = 10^{-6.9} = 1.26 \times 10^{-7}dB$$

$$Lp(d4) = 10\log\left(\frac{16.02}{1.26 \times 10^{-7}}\right) = 81dB$$

$$for\ i = 6$$

$$Pr = 10^{-6.7} = 2.0 \times 10^{-7}dB$$

$$Lp(d5) = 10\log\left(\frac{16.02}{2 \times 10^{-7}}\right) = 79dB$$

$$for\ i = 7$$

$$Pr = 10^{-6.9} = 1.26 \times 0^{-7}dB$$

$$Lp(d7) = 10\log\left(\frac{16.02}{1.26 \times 10^{-7}}\right) = 81dB$$

$$for\ i = 8$$

$$Pr = 10^{-6.9} = 1.26 \times 10^{-7}dB$$

$$Lp(d8) = 10\log\left(\frac{16.02}{1.26 \times 10^{-7}}\right) = 81dB$$

$for\ i = 9$

$Pr = 10^{-6.8} = 1.59 \times 10^{-7} dB$

$$Lp(d9) = 10\log\left(\frac{16.02}{1.59 \times 10^{-7}}\right) = 80dB$$

$for\ i = 10$

$Pr = 10^{-7} = 1 \times 10^{-7}$

$$Lp(d10) = 10\log\left(\frac{16.02}{1 \times 10^{-7}}\right) = 82dB$$

$for\ i = 11$

$Pr = 10^{-7.2} = 7.94 \times 10^{-8} dB$

$$Lp(d11) = 10\log\left(\frac{16.02}{7.94 \times 10^{-8}}\right) = 83dB$$

$for\ i = 12$

$Pr = 10^{-7.3} = 5.01 \times 10^{-8} dB$

$$Lp(d12) = 10\log\left(\frac{16.02}{5.01 \times 10^{-8}}\right) = 85dB$$

$for\ i = 13$

$Pr = 10^{-7.3} = 5.01 \times 10^{-8} dB$

$$Lp(dB) = 10\log\left(\frac{16.02}{5.01 \times 10^{-8}}\right) = 85dB$$

$for\ i = 14$

$Pr = 10^{-7.6} = 2.51 \times 10^{-8}\ dB$

$$Lp(d14) = 10\log\left(\frac{16.02}{2.51 \times 10^{-8}}\right) = 88dB$$

$for\ i = 15$

$Pr = 10^{-7.9} = 1.26 \times 10^{-8} dB$

$$Lp(d15) = 10\log\left(\frac{16.02}{1.26 \times 10^{-8}}\right)\ 91dB$$

$for\ i = 16$

$Pr = 10^{-8} = 1 \times 10^{-8}\ dB$

$$Lp(d16) = 10\log\left(\frac{16.02}{1 \times 10^{-8}}\right) = 92dB$$

$for\ i = 17$

$Pr = 10^{-8.2} = 6.31 \times 10^{-9} dB$

$$Lp(dB) = 10\log\left(\frac{16.02}{6.31 \times 10^{-9}}\right) = 94dB$$

$for\ i = 18$

$Pr = 10^{-8.2} = 6.31 \times 10^{-9} dB$

$$Lp(d18) = 10\log\left(\frac{16.02}{6.31 \times 10^{-9}}\right) = 94dB$$

$for\ i = 19$

$Pr = 10^{-8.1} = 7.94 \times 10^{-9} dB$

$$Lp(d19) = 10\log\left(\frac{16.02}{7.94 \times 10^{-9}}\right) = 93dB$$

$for\ i = 20$

$Pr = 10^{-8.2} = 6.31 \times 10^{-9} dB$

$$Lp(d20) = 10\log\left(\frac{16.02}{6.31 \times 10^{-9}}\right) = 94dB$$

Table 2 below represent the tabulated values for the median received power and measured path loss for the distances, 0.05km<di<1.00km.

Table 2: Median Receive Signal Levels (RSL) and the measured path loss for the measured routes

Distance(km)	Median RSS (dBm)	Measured pathloss, Lp(di) [dB]
0.05	-51	63
0.10	-58	70
0.15	-64	76
0.20	-66	78
0.25	-69	81
0.30	-67	79
0.35	-69	81
0.40	-69	81
0.45	-68	80
0.50	-70	82
0.55	-71	83
0.60	-73	85
0.65	-73	85
0.70	-76	88
0.75	-79	91
0.80	-80	92
0.85	-82	94
0.90	-82	94
0.95	-81	93
1.00	-82	94

To estimate the rate at which path loss increases with distance, the path loss exponent is thus calculated using the data from the field measurement and substituting the values into equation below;

$$Lp(di) = Lp(d0) + 10nlog\left(\frac{di}{d0}\right) \quad ....11$$

Where the Lp(d0) is 63dB at close- in distance (d0) of 0.05km. Hence, the predicted pathloss at various specified distances are;

$for\ i = 1$

$di = d1 = 0.05km = d0$

$$Lp(di) = 63 + 10nlog\left(\frac{0.05}{0.05}\right) = 63$$

$for\ i = 2$

$di = d2 = 0.10km\ and\ d0 = 0.05km$

$$Lp(d2) = 63 + 10nlog\left(\frac{0.10}{0.05}\right) = 63 + 3.0n$$

$for\ i = 3$

$di = d3 = 0.15km\ and\ d0 = 0.05km$

$$Lp(d3) = 63 + 10nlog\left(\frac{0.15}{0.05}\right) = 63 + 4.8n$$

$for\ i = 4$

$di = d4 = 0.20km$

$$Lp(d4) = 63 + 10nlog\left(\frac{0.20}{0.05}\right) = 63 + 6.0n$$

$for\ i = 5$

$di = d5 = 0.25km$

$$Lp(d5) = 63 + 10nlog\left(\frac{0.25}{0.05}\right) = 94 + 7.0n$$

$for\ i = 6$

$di = d6 = 0.30km$

$$Lp(d6) = 63 + 10nlog\left(\frac{0.30}{0.05}\right) = 63 + 7.8n$$

$for\ i = 7$

$di = d7 = 0.35km$

$$Lp(d7) = 63 + 10nlog\left(\frac{0.35}{0.05}\right) = 63 + 8.5n$$

$for\ i = 8$

$di = d8 = 0.40km$

$$Lp(d8) = 63 + 10logn\left(\frac{0.40}{0.05}\right) = 63 + 9.0n$$

$for\ i = 9$

$di = d9 = 0.45km$

$$Lp(d9) = 63 + 10\log\left(\frac{0.45}{0.05}\right) = 63 + 9.5n$$

$for\ i = 10$

$di = d10 = 0.50km$

$$Lp(d10) = 63 + 10\log\left(\frac{0.50}{0.05}\right) = 63 + 10.0n$$

$for\ i = 11$

$di = d11 = 0.55km$

$$Lp(d11) = 63 + 10logn\left(\frac{0.55}{0.05}\right) = 63 + 10.4n$$

$for\ i = 12$

$di = d12 = 0.60km$

$$Lp(d12) = 63 + 10logn\left(\frac{0.60}{0.05}\right) = 63 + 10.8n$$

$for\ i = 13$

$di = d13 = 0.65km$

$$Lp(d13) = 63 + 10logn\left(\frac{0.65}{0.05}\right) = 63 + 11.1n$$

$for\ i = 14$

$di = d14 = 0.70km$

$$Lp(d14) = 63 + 10logn\left(\frac{0.70}{0.05}\right) = 63 + 11.5n$$

$for\ i = 15$

$di = d15 = 0.75km$

$$Lp(d15) = 63 + 10logn\left(\frac{0.75}{0.05}\right) = 63 + 11.8n$$

$for\ i = 16$

$di = d16 = 0.80km$

$$Lp(d16) = 63 + 10logn\left(\frac{0.80}{0.05}\right) = 63 + 12.0n$$

$for\ i = 17$

$di = d17 = 0.85km$

$$Lp(d17) = 63 + 10logn\left(\frac{0.85}{0.05}\right) = 63 + 12.3n$$

$for\ i = 18$

$di = d18 = 0.90km$

$$Lp(d18) = 63 + 10logn\left(\frac{0.90}{0.05}\right) = 63 + 12.6n$$

$for\ i = 19$

$di = d19 = 0.95km$

$$Lp(d19) = 63 + 10logn\left(\frac{0.95}{0.05}\right) = 63 + 12.8n$$

$for\ i = 20$

$di = d20 = 1.00km$

$$Lp(d20) = 63 + 10logn\left(\frac{1.00}{0.05}\right) = 63 + 13.0n$$

Table 3: Median Receive Signal Levels (RSL), measured path loss and predicted path loss for the measured routes

Distance(km)	Median RSS (dBm)	Measured pathloss, Lp(di) [dB]	Predicted Pathloss Lp(do)[dB]
0.05	-51	63	63
0.10	-58	70	63+3.0n
0.15	-64	76	63+4.8n
0.20	-66	78	63+6.0n
0.25	-69	81	63+7.0n
0.30	-67	79	63+7.8n
0.35	-69	81	63+8.5n
0.40	-69	81	63+9.0n
0.45	-68	80	63+9.5n
0.50	-70	82	63+10.0n
0.55	-71	83	63+10.4n
0.60	-73	85	63+10.8n
0.65	-73	85	63+11.1n
0.70	-76	88	63+11.5n
0.75	-79	91	63+11.8n
0.80	-80	92	63+12.0n
0.85	-82	94	63+12.3n
0.90	-82	94	63+12.6n
0.95	-81	93	63+12.8n
1.00	-82	94	63+13.0n

Given that;

$$\sum_{i=1}^{k}\left[L_p(d_i) - L_p(d_0)\right]^2 = 1{,}927n^2 - 8{,}612n + 9{,}362$$

$$\frac{\partial e(n)}{\partial n} = 2[1927n] - 8612 = 0$$

$$3854n = 8612$$

$$n = 2.24$$

Substituting this path loss exponent value (2.23) into equation 6, we obtain the value in equation below,

$$Lp = Lp(d_0) + 10\ (2.23) log\left(\frac{d_i}{d_0}\right) + X\delta\ \ldots.12$$

$$Lp = Lp(d_0) + 22.3\ log\left(\frac{d_i}{d_0}\right) + X\delta\ \ldots.13$$

To obtain the standard deviation, δ of the path loss distribution in table 4.1, a MatLab program of equation 4.6 below is written as shown in Appendix N;

$$\sigma = \sqrt{\sum \frac{(Lp(d_i) - Lp(d_0))^2}{N}}\ \ldots.14$$

(Nwalozie, et al., 2014)

Where;

$Lp(d_i)$= measured path loss values

$Lp(d_0)$= predicted path loss value

=63 dB

σ = standard deviation

X = constant

N=Number of data points =20

The value for the standard deviation obtained from the output of the program as shown in appendix k is:

$\sigma = 6.9318$, which approximated to $\sigma = 7dB$.

Hence, the resultant path loss model for Owerri Metropolis is given thus;

$$Lp = 63dB + 10 * 2.23\ log\left(\frac{d_i}{d_0}\right) + 7dB\ \ldots.15$$

$$Lp = 70 + 22.3\ log(D)\ \ldots.16$$

Where;

$$D = \frac{d_i}{d_0}$$

To obtain the Mean Square Error, e of the distribution, equation 17 is used;

$$e = \frac{\sigma}{N}\ \ldots.17$$

Hence,

$$e = \frac{7}{20} \approx 0.35\ \ldots.18$$

These simulations were carried out on the measured values obtained during the drive test conducted on the major street/ roads of the Owerri metropolis. These major routes include: Akanchawa-world bank-new Owerri road, Imo state government house-works layout-okigwe road, wetheral road-Royce- world bank road- Tetlow road, Owerri- Obinze express road, and FUTO - Ihiagwa.

To give room for comparison, the path loss models: Hata model and COST-231 models of equation (2.3) and (2.17) were also simulated using the MatLab software tools as plotted in figure 4.1 below. The codes were written on the M -files of the MatLab program.

V. RESULT

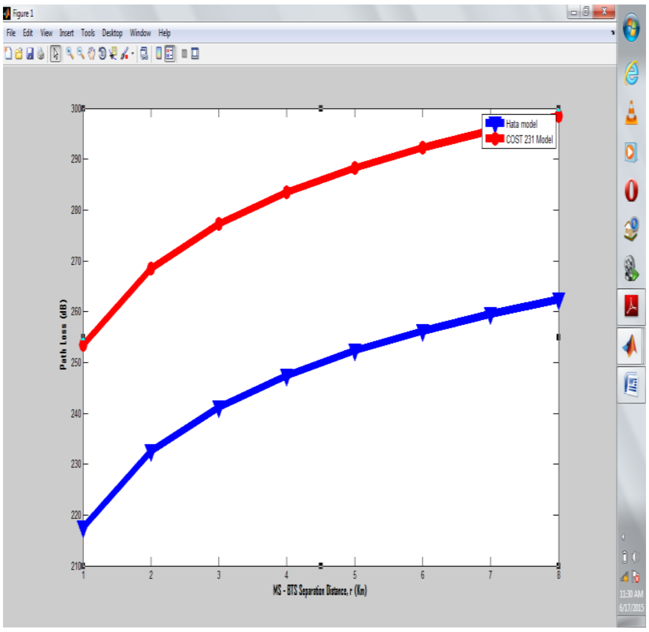

Figure 1: Simulated Plots of Hata Model and Cost-231 Model at a frequency of 2100MHz.

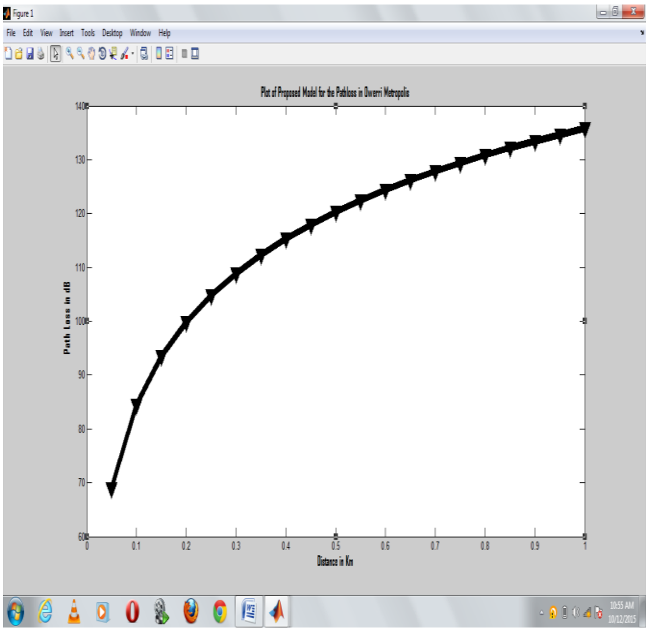

Figure 2: Plot of Proposed Model for the Pathloss in Owerri Metropolis

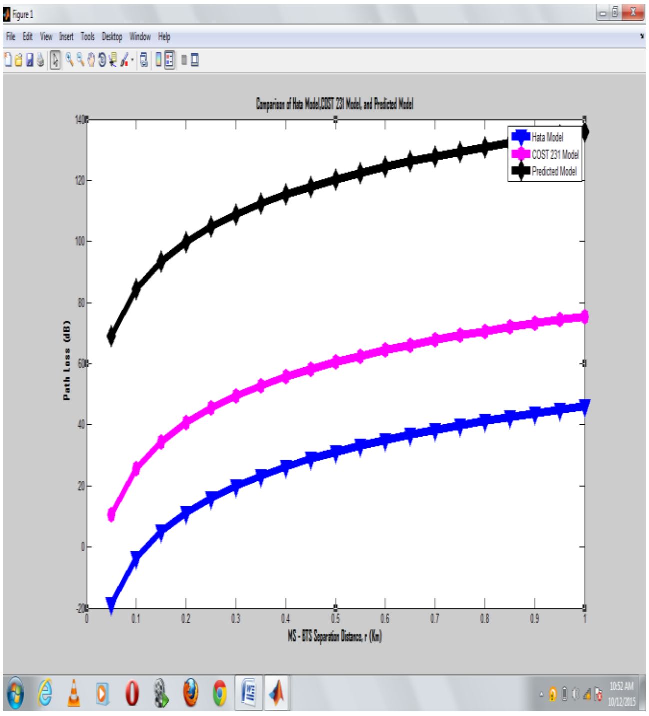

Figure 3: Comparison of Hata Model, COST 231 Model, and Predicted Model

Figure 1 represents the simulated models of Hata and cost-231 at a frequency of 2100MHz.It is a plot of the received signal level against the distance of separation between the mobile station (MS) and Base transceiver station (BTS). The plot shows that as the distance between the Base Transceiver station increases, the strength of the received signal diminishes.

It can be seen from all the routes that there was no much deviation of the standard models (Hata and Cost 231) from the predicted path loss model as represented in figure 1. The slope of the Cost 231 plot is closer to the predicted model compared to that of Hata; hence, cost 231 model will best describe the path loss experienced in the Owerri MTN network than the Hata model.

CONCLUSION

The results that were obtained via measurement undertaken during the drive test carried along the major routes in Owerri city were used to compute the path loss and the level of the strength of received signal thereafter; these values were compared with respect to Hata and COST 231 model findings/predictions. From all indication, these classical models did not over estimate the path loss and the received signal level within the Owerri metropolis, and they also make provision for some attenuation like rain encountered within. The result clearly demonstrated that the strength of signal reduction depends not only on distance of separation between the mobile station (MS) and the Base Transceiver station (BTS) but also on the height of the base station and frequency of signal radiated as witnessed in the computer programs formulated and simulated in MATLAB.

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