Path Loss Characterization of 3G Wireless Signal for Urban and Suburban Environments in Port Harcourt City, Nigeria.

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Abstract - ***The characteristic effects of propagation environment on wireless communication signals are significant on the transmitted and received signal quality. The study focused on investigative analysis of the effects of propagation environment on the wireless communication signals within some geographical domains in Port Harcourt, River State. Field measurements were carried out in some selected areas namely GRA phase II and Aggrey Road categorized as urban and Sub urban areas respectively using Sony Ericsson (W995) Test Phone and GPS receiver (BU353). The analyses were based on linear regression (mean square error) approach. The computed path loss exponents and standard deviation based on the empirical analyses conducted for urban and suburban environments are 3.57dB, 2.98dB and 19.6, 13.2, respectively. The results obtained were used to compare the performance of the various existing path loss prediction models such as Okumura-Hata, Cost 231 and ECC-33. Okumura-Hata model showed better performance in urban environment while Cost 231 performed better in rural environment. They study therefore recommends the deployment of Okumura-Hata model in urban, while Cost 231for suburban study areas.***

Key Words: *Path loss, linear regression analysis, Okumura-Hata, Cost 231, Propagation Environment*

1. INTRODUCTION

One factor that determines wireless signal characteristics is the propagation environment. The propagation environment constitutes channel impairments such as shadowing, path loss and interferences that affect signal propagation through scattering, reflection and refraction. Thus, the environment is a key factor that must be considered in the design and deployment of base stations.

A number of path loss propagation models have been developed in the past and are presently deployed for coverage prediction. These models cannot be seen as generalized models owing to the fact that the environment from which they were developed differs from where they are being applied [1]. This entails that the physical structure, topology and weather in the area of deployment differs. Environmentally induced attenuation can be characterized by path loss model of such terrain. The average path loss for an arbitrary transmitter to receiver separation expressed as a function of distance is given by [2];

$$\mathrm{L_p(dB)} = \mathrm{L_p(d_o)} + 10\mathrm{nLog_{10}}\left(\frac{d_i}{\mathrm{d_o}}\right) \qquad (1)$$

Where n is the path loss exponent, d_i is the measured distance and $\mathrm{d_o}$ represents reference distance, $\mathrm{L_p(d_o)}$ represents path loss at reference distance.

This study is aimed at examining how the environment (building, vegetation and topology) affects the propagation of radio wave signal transmitted from GSM network operator (Airtel) base stations at 900MHz in GRA Phase II, and Aggrey Road in Port Harcourt, River State. By using the measured signal strength from the study area and path loss, Path loss exponent and empirical path loss model were determined.

2. Existing Propagation Models

2.1Free Space Model

In this model, the received power is dependent on transmitted power, antenna gains and distance between the transmitter and receiver. The received power is inversely proportional to square of the distance between the transmitter and the receiver [3];

$$\mathrm{P_r(I)} = \frac{P_t G_t G_r \lambda^2}{4\pi^2 I^2 L} \qquad (2)$$

Where;
P_t = Transmitted Power
G_t =Transmitted power gain
G_r =Received power gain
L = Distance between transmitter and receiver

This model applies only when there is a single path, one without an obstruction between transmitter and receiver. It does not consider the effects of wave propagation over ground.

2.2 Okumura-Hata Model

This model is commonly employed for macro-cell coverage planning in urban and sub-urban areas. It was developed from a work by Okumura and Hata. Okumura carried out test measurements in Japan, these measurements had a range of clutter type, transmitter height, transmitter power and frequency. He found out that the signal strength decreased at a much greater rate with distance than the predicted free space loss.
Hata's model was based on Okumura's free test results and predicted various equations for path loss with different types of clutter. It does not consider the effect of reflection and shadowing. This model is effective at carrier frequency 150MHz – 1500MHz and at distance range of 1km -20km, while mobile height of 1m to 10m [4];

$$L_p(\mathrm{Urban})(\mathrm{dB}) = A + B\mathrm{Log}_{10}(d) \qquad (3)$$

Where

d = distance in kilometre.

A = is a fixed loss that depends on the frequency of the signal. A is given by

$$A = 69.55 + 26.16log_{10}(f) - 13.82log_{10}(h_B) - a(h_m) \qquad (4)$$

$$B = 44.9 - 6.55log_{10}(h_b) \qquad (5)$$

f = frequency measured in MHz;

h_b= height of the base station antenna in metres;

h_m= height of mobile antenna in metres;

a (h_m) = correction factor in dB.

Therefore,

$$L_p(\mathrm{Urban}) = 69.55 + 26.16\mathrm{Log}_{10}(f) - 13.82\mathrm{Log}_{10}(h_b) - a(h_m) + [44.9 - 6.55\mathrm{Log}_{10}(h_b)]\mathrm{Log}_{10}(d) \qquad (6)$$

Where

$$a(h_m) = (1.1Log_{10}(f) - 0.7)h_m - (1.56log_{10}(f) - 0.8) \qquad (7)$$

2.3Cost -231 Model

This model is applied widely for calculating path loss prediction in mobile wireless communication system. The Cost 231 Hata model was designed for use in the frequency band of 1500MHz to 2000MHz, base station height range from (30 – 200metres) and receiver antenna height (1- 10m) with distance between two antennas from 1- 2km. It also contains correction factors for urban, suburban and rural (flat) environments, which has seen its wide application in path loss prediction at the above stated frequency band [5].

$$L_p = 46.3 + 33.9\mathrm{Log}_{10}(f) - 13.82\mathrm{Log}_{10}(h_b) - a(h_m) + [44.9 - 6.55\mathrm{Log}_{10}(h_b)]\mathrm{Log}_{10}(d) + C_m \qquad (8)$$

Where,

f = frequency in MHz

h_b= Base station height in meters

h_m= Mobile station height in meters

a(h_m) = Mobile antenna height correction factor

d = link distance in km

c_m= 0dB for medium cities or suburban centre with medium tree density

c_m = 3dB for urban environment

For urban environments,

$ah_m = 3.20[\log_{10}(11.75h_m)]2 - 4.97$,
for f >400 MHz (9)

and for suburban or rural (flat) environments,

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

2.4ECC-33 Model

The ECC 33 path loss model was developed by the Electronic Communication Committee (ECC). It was developed from an extrapolation of original measurements made by Okumura and its assumptions modified. This path loss model is defined as [6];

$$L_p(\mathrm{dB}) = A_{fs} + A_{bm} - G_t - G_r \qquad (11)$$

A_{fs} = free space attenuation

A_{bm}= basic Median path loss

G_t = Base station height gain

G_r = Received antenna height gain factor

These are separately defined as

$$A_{fs} = 92.4 + 20\log(d) + 20\log(f) \qquad (12)$$

$$A_{bm} = 20.41 + 9.83\log(d) + 7.894\log(f) + 9.56(\log(f))^2 \qquad (13)$$

$$G_t = \log\left(\frac{h_b}{200}\right)[13.98 + 5.8(\log(d))^2 \qquad (14)$$

For medium city environments,

$$G_r = [42.57 + 13.7\log(f)][\log(h_m) - 0.585 \qquad (15)$$

Where, f is the frequency in GHz.

2.5LOG NORMAL SHADOWING MODEL

Shadowing refers to the gradual variation of Received Signal Strength around an average value. This model describes the random shadowing effect which occurs over a large number of measurement locations, it has the same T-R distance separation, but with different levels of yields [7];

$$L_P(d_i) = L_P(d_o) + 10n\log\left(\frac{d_i}{d_o}\right) + X\sigma \qquad (16)$$

Where $X\sigma$, describes a Zero-Mean Gaussian distributed random variable (in dB) with standard deviation σ in (dB). Using linear regression analysis, the path loss exponent n, can be determined by minimizing (in a mean square error, sense) the difference between measured and predicted values of (16) to yield:

$$n = \frac{\sum_{i=1}^{N}[L_P(d_i) - L_P(d_o)]}{\sum_{i=1}^{N} 10\log\left(\frac{d_i}{d_o}\right)} \qquad (17)$$

Where $L_P(d_i)$ represents measured path loss and $L_p(d_o)$ predicted path loss at any reference distance. N is the number of measured data or sample points. The standard deviation is minimized as:

$$\sigma = \sqrt{\frac{1}{N}\sum\left(L_p(d_i) - L_p(d_o)\right)^2} \qquad (18)$$

3. RELATED WORK

According to [8], an extensive study of the behavior of propagating electromagnetic waves through office building with vegetation along possible line of sight was done. The study presented propagation loss measurements of Global systems at 951, 952, 954, and 955 MHz along line of sight. The study was carried out at Ladoke Akintola University of Technology in Oyo State, Nigeria. The environment comprised of buildings and vegetation with average thickness of 0.1m to 0.5m and 0.7m to 15m respectively. The spacing between them ranges between 2m to 7.5m, building height ranging from 3m to 5m. A GSP- 180 model spectrum analyzer was used to measure the GSM signal power at a distance of 20m to 500m along a possible line of sight (LOS). With the data obtained, a comparison was done between measured and existing propagation loss models. The determined values were 56.58 and 71.42 respectively. A new model for RF planning was formulated which could be used for buildings with vegetation environment.

In [9], various propagation models were compared with field measurements. The study compared the Log distance path loss model, Stanford University Interim (SUI) Model, Hata model, Okumura model, Cost 231 and ECC 33 and measured data. Measurements were made from environments in Narnual city, India which were categorized into 3 namely urban (high density region), suburban (medium density region) and rural (low density region).The obtained path losses were graphically plotted for better conclusion using MATLAB software. They opined that ECC-33 and SUI models gave best results in urban area. ECC-33, SUI and COST -231 models showed better results in suburban area. Hata and Log distance path loss models gave better results in urban and suburban environments.

Nadir et al in [10], determined the path loss using Okumura-Hata model. The study was carried out in the urban area of Oman using measurements from Oman mobile. In their work, the effect of terrain situation was analyzed. It was observed that the Okumura-Hata model did not adapt to the environment. The Mean square error (MSE) was calculated between measured path loss values and predicted values based on Okumura – Hata model for an open area. The mean square error was recorded as 6dB and minimized by subtracting the calculated MSE of 15.31dB from the original equation of an open area for Okumura – Hata model. Further analysis was done using theoretical simulation by Okumura-Hata model comparing the experimental data and analyzed using a piece- wise cubic spline to interpolate on the set of experimental data and found the missing experimental data points.

4. MEASUREMENT ENVIRONMENT AND CONFIGURATION

The measurement campaign was carried out in Aggrey Road with co-ordinate (04° 45′ .06″N, 07° 02′ .24″E) and GRA Phase II with co-ordinate (04° 45′ .06″N, 07° 02′ .24″E) and are situated in the capital city of Rivers State, (South South, Nigeria). The environment consists of high rise buildings, trees and tarred roads.

Measurement data was collected with Test Mobile System (TEMS) Investigation software which was installed on a Laptop and placed in a vehicle which served as the mobile unit. The Radio Propagation Simulator (TEMS), recorded the base station details and corresponding details of each test point coordinate (Latitude and Longitude), together with their Received Signal Strength (RSS) and Path loss. The test vehicle drove in the direction of one antenna sector, with the aid of a cell reference which gives a road map of all Airtel installations within the area under study. The test phone was configured automatically to make continuous calls to a fixed destination number. The received signal strength was measured using Ericsson (W995) handset as shown in fig 1 and transferred to the TEMS log file in the laptop. The GPS receiver (Bu353) gave the location and distance from the base station synchronously with the received power level reading. The experimental data were collected at distances ranging from 0.1km to 1.2 km. The log files were post processed using actix analyser software which converts the log to an excel file format which is readable and easier to manipulate from. Fig. 1 illustrated block representation of the equipment setup.

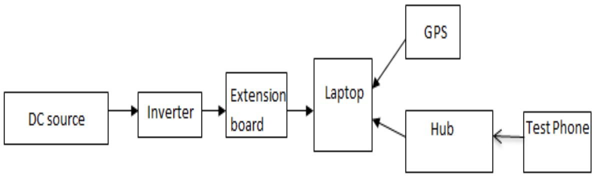

Fig-1: Equipment setup

5. Result and Analysis

In deriving the empirical model suitable for the area under investigation, measured data consisting of Received Signal Strength (RSS) and path loss were recorded. Table 1 and 2 showed the path loss values predicted from existing models in (3), (8), and (11) with corresponding values of the measured Path loss.

Table-1: Existing Path loss values for urban environment

Distance (Km)	Ecc-33(dB)	Cost-231 (dB)	Okumura-Hata (dB)	Measured (dB)
0.1	262.65	93.00	90.27	100
0.2	269.55	103.30	100.63	106
0.3	273.93	109.30	106.67	104
0.4	277.19	113.61	110.97	120
0.5	279.81	116.90	114.31	158
0.6	282.00	119.67	117.03	158
0.7	283.90	121.97	119.34	158
0.8	285.57	123.96	121.33	113
0.9	287.07	125.72	123.09	112
1.0	288.42	127.30	124.67	128
1.1	289.66	128.72	126.08	135
1.2	290.81	130.02	127.39	136

Table-2: Existing Path loss values for sub-urban environment

Distance(km)	ECC-33 (dB)	COST 231 (dB)	OKUMURA-HATA (dB)	MEASURED (dB)
0.1	296.60	89.88	90.27	111
0.2	303.51	100.25	100.63	113
0.3	307.89	106.31	106.69	114
0.4	311.15	110.61	110.99	131
0.5	313.77	113.95	114.32	116
0.6	315.96	116.67	117.04	158
0.7	317.86	118.97	119.35	140
0.8	319.53	120.97	121.34	158
0.9	321.02	122.73	123.10	152
1.0	322.38	124.30	124.68	128
1.1	323.62	125.71	126.10	141
1.2	324.77	127.03	127.40	124

Path loss exponent n, was derived statistically through the application of linear regression analysis by minimizing the difference between the measured and predicted path loss in a mean square error sense, as shown in table 3. Where, $L_p(d_o)$ is the reference path loss measured at the reference distance d_o. In this work, d_o= 0.1km was chosen as a reference distance. The expression $L_p(d_i) - L_p(d_o)$represents an error term with respect to n as shown in table 3, and the sum of the mean squared error, e(n) is therefore shown as:

$$e(n) = \sum_{i=1}^{N} \left(L_p(d_i) - L_p(d_o) \right)^2 \qquad (20)$$

The value of n, which minimizes the Mean Square Error (MSE), is obtained by equating the derivative of (19) to zero, and solving for n:

$$\frac{\partial e(n)}{\partial n} = 0 \qquad (21)$$

From table 3 (see Appendix), the Mean square error was determined as [1].

$$e(n) = \sum_{i=i}^{N} [L_p(d_i) - L_p(d_o)]^2 = 14162 - 5338n + 746.30n^2$$

$$\frac{\partial e(n)}{\partial x} = 2[746.303n] - 5338n = \frac{5338}{1492.606} = 3.57$$

Therefore, standard deviation $\sigma\ (dB)$, about a mean value could be determined from equation (18):

$$\sigma = \sqrt{\frac{1}{N} \sum \left(L_e(d_i) - L_e(d_o) \right)^2}$$

$$\sigma = \sqrt{\frac{1}{12}(746.30(3.57)^2 - 5338(3.57) + 14162)^2}$$

$$\sigma = 19.61\text{dB}$$

Substituting for $L_p(d_o)$,n and adding σ to compensate for the error into (19), will lead to the development of a modified Log-normal shadowing empirical model for the investigated area given by;

$$L_p(d_i) = 100 + 3.57(10)\log\left(\frac{d_i}{d_o}\right) + 19.61dB$$

The resultant path loss model for the urban environment is represented as

$$L_p(d_i) = 119.61 + 35.7\log\left(\frac{d_i}{d_o}\right)(dB)$$

$$L_p(d_i) = 119.61 + 35.7\log(D)\ (dB)$$

The analyses deployed in the determination of $L_p(d_i)$, n and σ for the urban environment was repeated for the sub-urban case under the same operating conditions. The values are presented in table 4.

Table-4: Showing Path loss exponent, standard deviation and Reference path loss

Parameter	Urban	Sub-urban
N	3.57	2.9
σ(dB)	19.61	13.25
$L_p(d_o)$	100	111

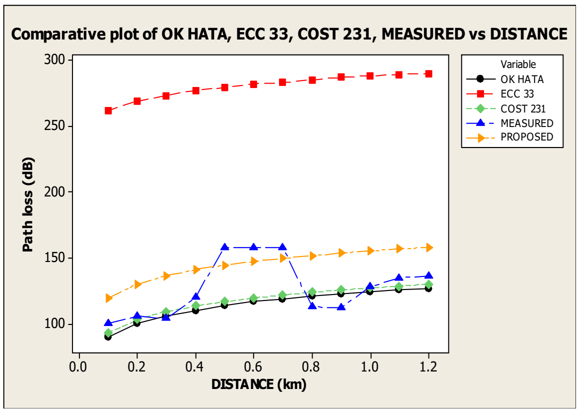

Fig-2: Comparison of existing, measured and proposed models for Urban environment

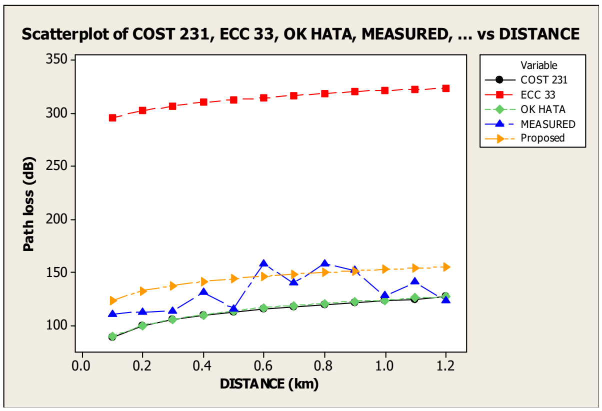

Fig-3: Comparison of existing, measured and proposed models for sub-urban environment

Fig. 2 presents a comparative plot of proposed model, existing and measured path loss values for urban environment. The existing Path loss models are namely; Cost 231, ECC 33, and Okumura-Hata. There is a general trend of Path loss increasing with distance for all predicted models. The ECC-33 model incurred the highest Path loss with Okumura-Hata and Cost 231 in descending order. The average predicted path loss values were 290.81, 130.02 and 127.39 for ECC-33, Cost 231 and Okumura-Hata model respectively. The measured path loss showed some deviation which is attributed to obstacles on the signal path. Path loss was recorded to increase at 35.7dB as the signal travelled with a deviation of 19.61dB. It is worthy to note that the Okumura–Hata model showed better performance when compared against the proposed model in the urban environment and is recommended for tuning on deployment in the study area.

A comparative plot of existing models ECC-33, Cost 231, Okumura-Hata, Measured values and the proposed model for sub urban environment is shown in fig 3. Prediction from ECC-33 model is highest as compared to Okumura-Hata and Cost 231 models. There is minimal variation between

Okumura-Hata and Cost 231 models for the suburban environment. The measured path loss showed some fluctuations which are attributed to obstructions in the form of buildings and tress within the environment. From the measured path loss values, Path loss increased at a rate of 29dB with deviation of 13.25db. The Cost 231 model showed better performance. For better performance, it is recommended for tuning and deployment in the sub-urban environment.

6. CONCLUSION

Field data obtained from Port Harcourt were analyzed and compared with the existing models. The investigation shows that Path loss exponents determined are 3.57dB and 2.9dB for urban and sub-urban environment respectively which describes the environments as shadowed urban area and the sub-urban area. Comparing the developed model against existing models, it was observed that Okumura-Hata predicted better in the urban environment and Cost 31 for the sub-urban environment. Okumura and Cost 231 models are the most suitable models for radio propagation for the area under study. For these models to be deployed, model tuning using environment specific parameters are recommended for better performance.

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APPENDIX

Table 3 Measured and predicted path loss values for urban environment

Distance(km)	Predicted $L_s(d_o)$(dB)	$L_s(d_i) - L_s(d_o)$	$(L_s(d_i) - L_s(d_o))^2$
0.1	100	0	0
0.2	100+3.010n	6-3.010n	36 - 36.12n + 9.061n^2
0.3	100+4.771n	4-4.77n	16 - 38.16n + 22.75n^2
0.4	100+6.020n	20-6.020n	400 - 240.8n + 36.24n^2
0.5	100+6.989n	58-6.9989n	3364 - 810.72n + 48.846n^2
0.6	100+7.781n	58-7.7781n	3364 - 902.595 + 60.543n^2
0.7	100+8.450n	58-8.450n	3364 - 980.2n + 71.4025n^2
0.8	100+9.030n	13-9.030n	169 - 234.78n + 81.5409n^2
0.9	100+9.542n	12-9.542n	144 - 229.008n + 91.0497n^2
1.0	100+10.0n	28-10.0n	784 - 560n + 100n^2
1.1	100+10.413n	35-10.413n	1225 - 728.9n + 108.430n^2
1.2	100+10.791n	36-10.791n	1296-776.952n+116.445n^2