Path loss Characterization of Wireless Propagation for South – South Region of Nigeria

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Abstract—**This paper presents statistical path loss models derived from experimental data collected in Port Harcourt in South-South region of Nigeria from 10 existing microcells operating at 876 MHz. The results of the measurements were used to develop path loss models for the urban (Category A) and the suburban (Category B) areas of Port Harcourt. The measurement results showed that the Pathloss increases by 35.5dB and 25.7dB per decade in the urban (Category A) and suburban (Category B) areas respectively. Variations in path loss between the measured and the predicted values from the Okumura-Hata model were calculated by finding the mean square errors (MSE) to be 10.7dB and 13.4dB for the urban and suburban terrains respectively. These variations (errors) were used to modify the Okumura-Hata models for the two terrain categories. Comparing the modified Hata model with the measured values for the two categories showed a better result. The developed statistical Pathloss models or the modified Hata models can be used in the urban and suburban areas of South-South Nigeria.**

I. Introduction

With the rapid growth in wireless telecommunications services due to increasing desire for next generation services by mobile subscribers, there has been an increasing need for proper network coverage predictions. This planning requires a good understanding of the fundamental limitations caused by environment specific conditions to radio signal propagation.

It has been found that the mechanisms behind electromagnetic wave propagation are diverse and characterised by certain phenomena such as reflection, refraction and diffraction of waves [1]. These phenomena induces signal scattering, fading and shadowing along the signal path and their effects can best be described (in a large scale) by the path loss exponent which defines the rate of change of attenuation that the signals suffers as it propagates from the transmitter to the receiver.

The constant mobility of receivers as in the case of land mobile communications and the way and manner by which the handheld antennas are designed makes them susceptible to the effects caused by obstacles (buildings, hills, foliage etc) and reflecting surfaces that characterize their propagation path. These continuous interactions between the radio signal and the objects and media in which they travel cause them to change direction and sometimes get consumed.

This environmentally induced attenuation can be characterised by the path loss model of such terrain. The average large-scale path loss for an arbitrary transmitter to receiver separation is expressed as a function of distance [1] as:

$$P_L(dB) = P_L(d_0) + 10nLog_{10}\left(\frac{d}{d_0}\right) \quad (1)$$

where n is the pathloss exponent, d the measured distance, d_o the reference distance. Although these pathloss characteristics have been modelled by many technical researchers, research has shown that existing models suffer differences when deployed at areas other than it was designed for [2]. Therefore to determine the actual effect of the South-South Nigerian environment to signal propagation, field measurements have that indisputable advantage of taking into accounts all their effects on the propagated signal. This research aims to improve the quality of wireless services in the South-South region of Nigeria by carrying out site specific measurements and developing an acceptable Path loss model for the region.

In Section II, some existing Pathloss models widely in use are presented. Section III describes the method of data collection deployed. Section IV presents data analysis and results. In Section V we compared the measured results with results from existing models and propose possible adjustments to Hata (urban and suburban) model for improved accuracy of its use within the South-South region of Nigeria.

II. Existing Models

A. Free Space Propagation Model

In free space there are no obstacles. The propagated wave radiates freely to an infinite distance without being absorbed or reflected. This is the ideal case scenario and not very possible in real life situations. Assuming that the radiating source radiates energy at 360o with a fixed power forming an ever increasing sphere, the power flux at the transmitter can be calculated using equation (2).

$$P_d = P_t / 4\pi d^2 \quad (2)$$

where Pt is the transmitted power (W/m^2) and Pd is the power at a distance d from antenna. Knowing the power flux density at any distance from the radiator, it is possible to calculate the power received by the antenna fixed at that point provided

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the antenna aperture A_e, the wavelength of received signal λ, and the power density at receiving antenna P_d can be determined. [3].

Effective area A_e of an isotropic antenna is:

$$A_e = \lambda^2 / 4\pi \quad (3)$$

While power received is:

$$P_r = P_d \times A_e = \frac{p_t \times \lambda^2}{(4\pi d)^2} \quad (4)$$

Any loss can be calculated from the transmitted and received power as:

$$L_p = P_t - P_r \quad (5)$$

Substituting equations (2-4) in equation (5) and re-arranging:

$$L_P(dB) = 20\log_{10}(4\pi) + 20\log_{10}(d) - 20\log_{10}(\lambda) \quad (6)$$

Substituting (λ (in km) = 0.3/f (in MHz)), the generic free space path loss formula is stated in equation (7):

$$Lp\ (dB) = 32.5 + 20\log_{10}(d) + 20\log_{10}(f) \quad (7)$$

B. Hata Propagation Model

This is an empirical based model that formulated the Okumura's observations into a simple mathematical model of type $A + B.LogD$, where A and B are functions of frequency, antenna heights and pathloss exponent and D is the distance. Hata divided the prediction area into three set of terrain categories, namely open, suburban and urban area [4].

The Hata model is a widely used median path loss empirical model and suitable for frequency range of 150-1500 MHz for distance from 1 km to 20km. It specifies the Base Station antenna height to be from 30 m and Mobile Station height from 3m and room for correction factors addition. The equations (8-10) represent the urban, suburban and open area Pathloss equations [5].

For urban clutter:

$$L_p(\text{urban}) = 69.55 + 26.16\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + \{44.9 - 6.55\log_{10}(h_b)\}\log_{10}(d) \quad (8)$$

where:

$$a(h_m) = (1.1log10\,(f) - 0.7)h_m - (1.56log10\,(f) - 0.8)\,. \quad (9)$$

h_m is the mobile antenna height, h_b is the Base station antenna height and f is the frequency

For suburban clutter:

$$L_p\,(suburban) = L_p\,(urban) - 2\{log10\,(f/28)\}^2 - 5.4 \quad (10)$$

For the open area:

$$Lp(open\ area) = Lp(urban) - 4.78\{log_{10}(f)\}^2 + 18.33log_{10}(f) - 40.94 \quad (11)$$

C. COST 231-HATA Model

The COST-HATA model is an extension of the Hata model. It was enhanced by the COST 231 project (European cooperation of scientific and Technical research). The purpose was to extend the limitations of the HATA models and apply appropriate correction factors to improve upon their degree of correctness in Europe [6].

The cost Hata equation is given by

$$L_p(d) = 46.3 + 33.9Logf_c - 13.82Logh_b - a(h_m) + (44.9 - 6.55Log(h_b))Logd + C_m \quad (12)$$

where C_m can be 0 or 3 for suburban and metropolitan cities respectively.

III. Data Collection Method

In order to accommodate the two climatic seasons in Nigeria; Rainy Season and the dry season and to specially accommodate the Harmattan, the test was conducted at three consecutive times of November, December and August at Portharcourt, in Rivers State.

Using the net monitor application of NOKIA 1265 CDMA phone operated in the active mode and MAP76CSX GPS to determine the distance from Base Stations, the received signal strength was measured from 10 existing CDMA microcells at 876MHz. Readings were taken at intervals of 100m from the BTS at a near constant MS height of 1.5meters.

The Base Station Antenna heights range from 30 meters to 50 meters. The BTS were selected to cover the Urban (category 'A') and Suburban (category 'B') terrain conditions in the South-South region of Nigeria.

Terrain category 'A' consisted of sites located near tall, closely built buildings, factories, offices with communication towers and high density of both human and vehicular traffic while category 'B' composed majorly of bungalows and sparsely located storey buildings of about 2 to 3 floors, with low traffic density. The areas tested include, D-line, Nkpor, Ogodona, Winpe, Ozoboko, Amadiama, Abuloma, Iwofe, Aba road, Ikwere road, Elelenwo, Elekahia, Okporo road, Akani, Woji and Trans-amadi.

Table 1 shows the median values of the measured Category 'A' sites. And Table 2 is the median values for category 'B' sites. The respective plot of Pathloss against distance for Category A and Category B are shown in figure 1 and figure 2 respectively.

IV. Data Analysis

Using linear regression analysis [7],

$$e(n) = \sum_{i=1}^{K} \{L_p(d_i) - \hat{L}_p(d_i)\}^2 \quad (13)$$

where $L_p(d_i)$ is the measured path loss at distance d_i and $\hat{L}_p(d_i)$ is the estimated path loss using equation

(1), Substituting equation (1) in equation (13), we have

$$e(n)=\sum_{i=1}^{K}\left\{L_p(d_i)-L_p(d_0)-10nLog\left(\frac{d_i}{d_0}\right)\right\}^2 \qquad (14)$$

Differentiating equation (14) with respect to n, and equating $\frac{\delta E(n)}{\delta n}$ to zero,

$$\sum_{i=1}^{k}\{L_p - L_p(d_o)\}\sum_{i=1}^{k}\{10n\log_{10}(\frac{d}{do})\} = 0$$

$$\sum_{i=1}^{k}\{L_p - L_p(d_o)\} = \sum_{i=1}^{k}\{10n\log_{10}\frac{d}{do}\}$$

Then 'n' is given by:

$$n = \frac{\sum_{i=1}^{K}\{L_p(d_i)-L_p(d_0)\}}{\sum_{i=1}^{K}10Log\left(\frac{d_i}{d_0}\right)} \qquad (15)$$

It is shown in [9] that for any value of d, the path loss $L_p(d)$ is a random variable with a log-normal distribution about the mean value $\bar{L}_p(d)[dB]$ due to shadowing. Therefore to compensate for shadow fading, the path loss beyond the reference distance can be written as

$$L_p(d)=L_p(d)+10nLog\left(\frac{d}{d_0}\right)+S \qquad (16)$$

TABLE 1: MEDIAN PATH LOSS (DB) FOR THE CATEGORY A SITES.

Distance (Km)	Median Rx (dBm)	Median PL (dB)
0.1	-62	106
0.2	-66	110
0.3	-73	117
0.4	-81	125
0.5	-87	131
0.6	-84	128
0.7	-89	133
0.8	-94	138
0.9	-92	136
1	-96	140
1.1	-91	135
1.2	-94	138
1.3	-88	132
1.4	-90	134
1.5	-95	139
1.6	-97	141
1.7	-94	138
1.8	-96	140

where S is the shadow fading variation about the linear relationship and has a rms value that best minimises the error given by equation (17) [8];

$$\sqrt{\sum_{i=1}^{k}\frac{(P_m - P_r)^2}{N}} \qquad (17)$$

TABLE 2: MEDIAN PATH LOSS (DB) FOR THE CATEGORY B

Distance (KM)	Median Rx (dBm)	Median PL (dB)
0.1	-50	95
0.2	-53	98
0.3	-59	104
0.4	-63	108
0.5	-61	106
0.6	-67	112
0.7	-70	115
0.8	-67	112
0.9	-79	124
1	-77	122
1.1	-75	120
1.2	-68	113
1.3	-78	123
1.4	-83	128
1.5	-87	132
1.6	-90	135
1.7	-89	134
1.8	-91	136

where P_m is the measured path loss (dB), P_r is the predicted path loss (dB) from equation (1) and N is the number of measured data points.

Applying equation (15) and equation (17) to table 1 (median pathloss data for the urban category 'A'); using MATLAB program. The Pathloss exponent for category A was found to be 3.55 with a Shadow factor of 8 dB and $L_p(d_o)$ in table1 is 106 dB

Therefore the Pathloss for urban category A is given as

$$L_p(d) = Lp(d_o) + 35.5Log_{10}\left(d/d_0\right) + S \qquad (18)$$

Substituting S and $L_p(d_o)$ and calculating the result; the pathloss at a distance d is given as

$$L_p(dB) = 106 + 35.5Log_{10}\left(d/d_0\right) + S \qquad (19)$$

Similarly, for the suburban category of Table 2, the pathloss exponent of the category was found to be 2.57 with a shadow factor of 5.4dB and from table 2, $L_p(d_o)$ is 95dB.

Substituting these values in equation (16), we have the pathloss for suburban category B as:

$$L_p(dB) = 95 + 25.7Log_{10}\left(\frac{d}{d_0}\right) + S \qquad (20)$$

V. Comparison of Measured Model with Existing Models

Recalling equation (8) for the Urban pathloss determination of the Hata model, equation (12) for the COST231 Model and equation (7) for the free space model and substituting the test parameters (*f=876.87MHz,hm=1.5m and hb=38m*) into the equations, produced plots shown in figure 5.

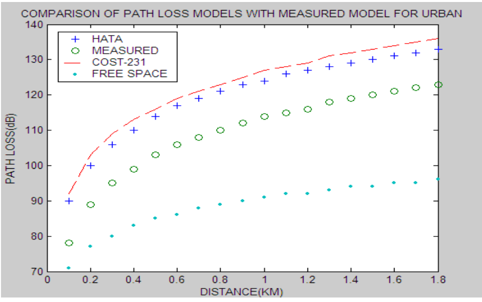

Fig. 5. Comparison of path loss models with measured model for urban.

Similar comparison for the suburban terrains of Port Harcourt is shown in figure 6.

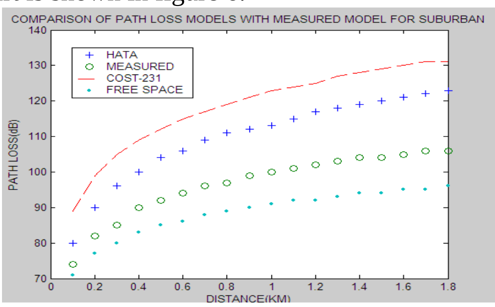

Fig. 6. Comparison of path loss models with measured model for suburban

A. Modified Hata Model

From the comparison result, the Hata and COST-231 model values were higher than the measured values in both the urban and suburban terrains tested. This is certainly due to the differences in the physical development of Tokyo compared to the south-south region of Nigeria. To improve on the accuracy of the Hata model in the region, the mean square error (MSE) between the measured and the Hata models were calculated using equation (21)

$$\sqrt{\sum_{i=1}^{k}\frac{(P_m - P_r)^2}{N}} \qquad (21)$$

where Pr is the Hata predicted values and Pm is the measured values for each instance of distance d. This MSE was found to be 10.7dB and 13.4dB for the urban and suburban terrains respectively. The MSE was used to modify the Hata models and the results were compared to the measured values as shown in figure 7 and 8 for Urban and Suburban terrains. The modified Hata models for urban and suburban south-south Nigerian cities are as follows:

$$L_p(urban) = 58.85 + 26.16Log_{10}(f) - 13.82Log_{10}(h_b) - a(h_m) + \{44.9 - 6.55Log_{10}(h_b)\}Log_{10}d \qquad (22)$$

$$L_p(suburban) = L_p(urban) - 2\left\{Log_{10}\left(\frac{f}{28}\right)\right\}^2 - 18.8 \qquad (23)$$

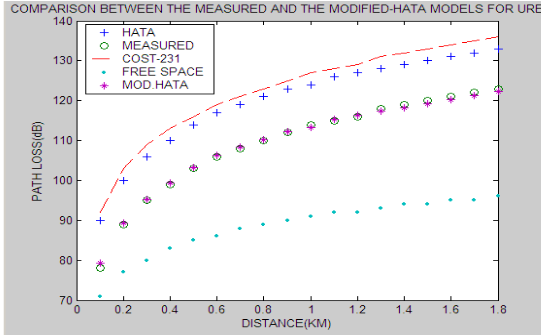

Fig.7. Comparison between the measured and the modified-Hata Models for Urban

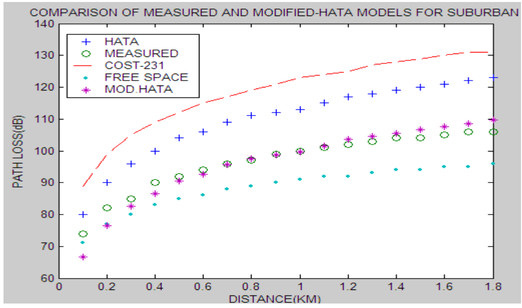

Fig.8. Comparison between the Measured suburban and the Modified-Hata Models

VI. Discussion

Statistical model formulations like this require large scale measurements details and data collections and analysis with minimum level of complexity. This model can therefore be improved upon in many ways.

The rural/open space characteristics were not included in this test as there were no propagation paths among the measured that can best describe the properties of a rural area terrain. Further studies, adequate data collection and analysis from such environment will be needed to characterise the path loss for the rural areas.

The shadow fading as a Gaussian distribution of the standard deviation for both urban and suburban terrain conditions were also determined within the available set of data. More detail study and data collection will be required to further strengthen the determined relationship.

Further research can analyse these changes at other usable mobile frequencies such as 900MHz, 1800MHz and 1900MHz. The relationship between the shadow fading and the pathloss exponent can also be evaluated as one seems to change as the other changes. Analysing the relationship between the base station heights and the path loss exponents will add much value as the experimental data show better pathloss exponent with higher base station heights.

Finally, a repeat of the test and/or a comparison with other urban and suburban cities in the south - south will further confirm the reliability of the stated model.

VII. Conclusion

Presented here are the statistically derived path loss models for microcellular wireless communications systems for both urban and suburban cities of the South-south Nigeria. The comparison between the measured model and the Hata model, showed a difference that was used to modify the Hata model for effective use in South-South region of Nigeria.

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