An Empirical Propagation Path loss Model for a WCDMA Cellular System in a Suburban Environment

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Abstract: **This study investigates the propagation path loss for south-east Nigeria using empirical measurements from specific sites in the region. Usually it is common to find predictions done using propagation models which were developed for different locations other than the region in question. Such practices most times results to power wastage and co-channel interference as the propagation environment differs. In this paper, real time field data were collected from a WCDMA network located in Onitsha suburban town. The measured data were used in determining an empirically based pathloss model for the test-bed environment. The results of the measurements show that the pathloss for the measurement environment increases by 3.04dB per decade.**

Keywords: Path Loss, Propagation model, WCDMA, Path loss exponent.

1.0 Introduction

In cellular communication systems, the radio propagation environment is defined as the surroundings of the path travelled by the radio signal between the transmitter and the receiver. Propagation environments differ based on terrain types i.e. if there is LOS (line of sight) path or an obstructed radio path due to natural or created obstacles [1]. The presence of these obstacles results to multipath propagation. For Such environments, the propagation path may be modelled as a randomly varying propagation path and in many instances there exists more than one propagation path leading to multipath propagation. Such environments are characterised by such effects as: shadowing, multipath fading and pathloss. Multipath propagation occurs when the same transmitted signal arrives at the receiver in different time instances while fading is described as the fluctuation of the amplitude of the mobile signal in a short period of time. In addition to the rapid signal fluctuation, the received signal also decays dramatically with increasing transmitter-receiver separation distance because of severe path loss. This path loss also may vary from area to area due to the shadowing effect. Therefore, a signal propagating through a mobile channel will experience a large attenuation, shadowing variation, and multipath fading, which will result in an overall path loss. Expressed in decibel (dB), this total path loss is calculated using the propagation equation:

$$L(t) = L_p(d) + m(t) + \beta(t) \qquad (1)$$

Here $L_p(d)$ is the mean path loss as a function of the transmitter-receiver separation distance d, m(t) represents the shadowing variation, and β(t) represents the fading fluctuation [2].

This work was borne out of the desire to develop an accurate path loss prediction model which could be deployed by cellular network designers for efficient cellular network planning and verification. This research focused on large scale fading and it is aimed at improving the quality of wireless services in the South-Eastern Nigeria by carrying out site specific measurements and developing an acceptable Pathloss model for the region.

Section 2.0 of this work presents an overview of various Path loss models widely used for WCDMA. Section III describes the method of data collection employed. Data analysis and results are presented in Section IV. In Section V measured results are compared with results from existing models and the proposed model for improved accuracy of its use within the South-Eastern region of Nigeria is shown.

2.0 Literature Review

2.1 Existing Path Loss Models For WCDMA

A propagation model is needed to estimate the path loss between the mobile station and base station. This need occurs for example in the network dimensioning phase. Propagation models are divided into empirical, semi-empirical and deterministic models. Empirical models are based on measurement campaigns: the measurement statistics are turned into mathematical models. Semi-empirical models rely on physical phenomena's, such as diffraction, refraction and reflection, and combine these with field measurements. Deterministic models, such as ray tracing and ray launching, have a basis on the

electromagnetic theory, therefore providing more accuracy in path loss calculations in cost of computational power requirement [3].Though there exist various path loss models, the most commonly used ones for WCDMA due its high range of frequency include: Free space model, COST-231 Hata model and ECC-33 model [4]

a. Free Space Model

Free space model represents the ideal case scenario which we hope to approach in our real world radio link. It is the benchmark by which a loss in transmission is measured. In free space, the wave is not reflected or absorbed since it is assumed that there are no obstacles. Calculating free space transmission loss requires a faithful representation of the transmitter and receiver characteristics [5].Assuming we have a transmitter with power $P_t$coupled to an antenna which radiates equally in all directions. At a distance *d* from the transmitter, the radiated power is distributed over an area of$4\pi d^2$, so that the power flux density is

$$S = \frac{P_t}{4\pi d^2} \qquad (2)$$

Transmission loss for such a system depends on how much of this power is captured by the receiving antenna. If the effective aperture of the antenna isA_r, then the power which can be delivered to the receiver (assuming no mismatch or feeding losses) is simply:

$$P_r = SA_r \qquad (3)$$

The effective area of the isotopic receiving antenna is:

$$A_r = \frac{\lambda^2}{4\pi} \qquad (4)$$

Substituting (2) and (4) into (3):

$$P_r = \frac{P_t}{4\pi d^2}\left(\frac{\lambda^2}{4\pi}\right) = P_t\left(\frac{\lambda}{4\pi d}\right)^2 \qquad (5)$$

The free space path loss between isotropic antennas is $\frac{P_t}{P_r}$ and $\lambda = \frac{C}{f} = \frac{0.3}{f}$,

Thus:

$$\frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 \qquad (6)$$

Rationalizing (5) gives the generic free space path loss formula which is given as:

$$L_p = 32.5 + 20\log(d) + 20\log(f) \quad (7)$$

Where *f* = frequency in MHz and *d* = distance in km.

b. COST- 231 Hata model

The Hata model took into consideration frequencies at 1.5GHz and below which could not be used for most WCDMA frequencies, this limitation as well as the interest in personal communications systems operating near 1.9GHz made the European Cooperation in the field of Scientist and Technical research (COST) organization to perform propagation measurements to extend the Hata model to 2GHz. This extended Hata model is applicable for frequencies from 1.5 to 2GHz. The COST-231 Hata model apart from being designed for frequency band covering 1.5 to 2GHz also contains corrections for urban, suburban and rural (flat) environments [6].

The basic equation for the path loss in dB [7] is

$$P_L = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10}(d) + C_m \quad (8)$$

Where f is the frequency in MHz, d is the distance between AP and Customer-Premises Equipment (CPE) antennas in km, *hb* is the AP antenna height above ground level in meters (m). The perimeter *Cm* is defined as *0 dB* for suburban or open environments and *3 dB* for urban environment. The perimeter $ah_m$is defined for urban environments as:

$$ah_m = 3.20(\log_{10}11.75h_r))^2 - 4.97, \quad when\ f > 400MHz \qquad (9)$$

While for suburban or rural (flat) environments:

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

Where $h_r$is the CPE antenna height above ground level.

From (9) and (10) the path loss exponent of the prediction made by COST-231 is given by

$$n_{cost} = (44.9 - 6.55\log(h_b))/10 \qquad (11)$$

To evaluate the applicability of the COST-231 model for the 3.5GHz band, the model predictions are compared against measurement for three different environment namely, rural (flat), suburban and urban.

c. ECC – 33 Path Loss Model

Although the Hata Okumura model is widely used for UHF bands, its accuracy is questionable for higher frequencies [8]. The COST-231 model extended its use up to 2GHz but it was proposed for mobile systems having Omni-directional CPE antennas sited less than *3m* above ground level. A different approach was taken by the Electronic communication Committee (ECC) which extrapolated the original measurements by Okumura and modified its assumptions. The path loss equation for ECC-33 model [9] is defined as:

$$P_L = A_{fs} + A_{bm} - G_b - G_r \qquad (12)$$

Where, $A_{fs}, A_{bm}, G_b, G_r$are the free space attenuation, the basic median path loss, the *BS* height gain factor and the terminal (CPE) height gain factor. They are individually defined as

$$A_{fs} = 92.4 + 20LogF + 20Logd_i \quad (13)$$

$$A_{bm} = 20.41 + 7.894Logf + 9.83Logd_i + 9.56[Logf]^2 \quad (14)$$

$$G_b = \log\left(\frac{h_b}{200}\right)[13.958 + 5.8Log(d_i)]^2 \quad (15)$$

And for medium city environments [4],

$$G_r = [42.57 + 13.7LogF][Log(h_m) - 0.585] \quad (16)$$

And for large city:

$$G_r = 0.759h_m - 1.862 \quad (17)$$

Where f is the frequency in GHz, d is the distance between base station and mobile station in km, h_b is the BS antenna height in meters, h_m is the mobile antenna height in meters.

3.0 Methodology

3.1 Measurement Environment and Data Collection

The field measurements were carried out in the suburban city of Onitsha. Onitsha is a city located in eastern Nigeria in Anambra State. It is a metropolitan city known for its river port, and as an economic hub for commerce, industry, and education. The measurements were carried out for a period of eight (8) months, the measurements span fromJune 2016 to January 2017 using an existing WCDMA cellular mobile network (GLOBACOM Nigeria) operating at 2112 MHz band. Propagation measurements were carried out using a set of drive test equipment such as USB Global Positioning System (GPS), Software Activator/Processing Unit (USB License Dongle), the Operation/Monitoring Unit (Laptop computer), Samsung galaxy S5 phone, Transmission Evaluation and Monitoring System (TEMS), Geographical Information System software (Map Info), Google Earth, Power Inverter and a car driven round the cell coverage areas employing both single and cluster site verification.

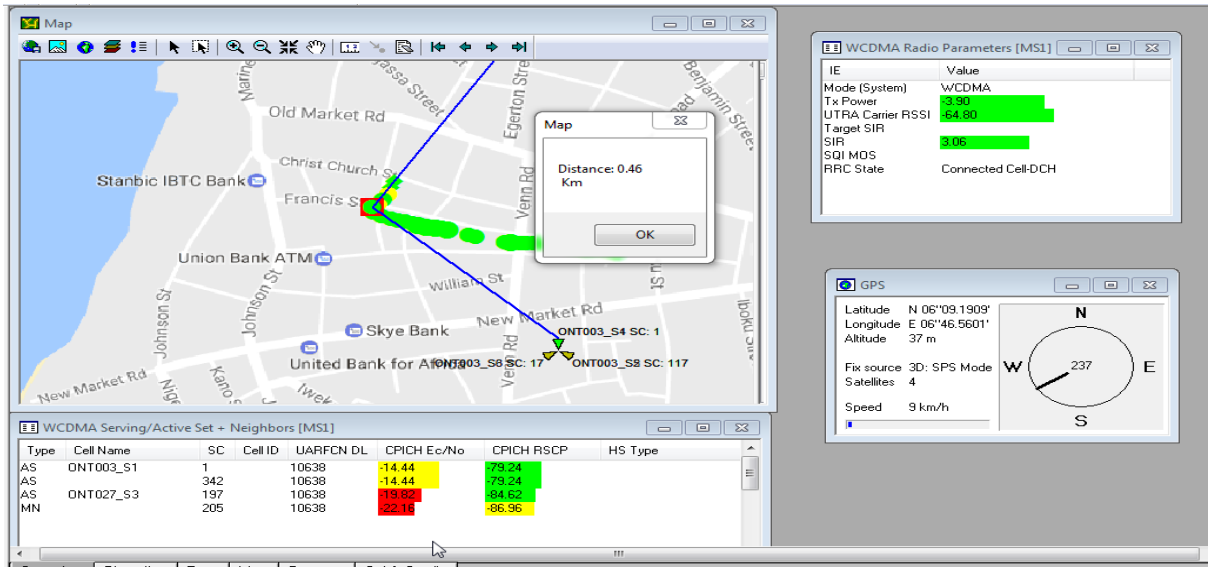

Figure 1: Map info image of Onitsha

The data obtained from the base stations were based on automated logs outputted from the investigation/monitoring software (TEMS). The system was queried to output readings of the received signal strength from a distance of 100m (as the starting or reference point) and then readings were taken at 100m intervals up to a distance of 1200m. Due to the presence of several micro cells in the area, quick handovers to neighbouring cells deterred any effort to carry out purely single cell verification beyond this distance; rather a combination of both single cell and cluster cell verification would be employed (i.e. a situation where more than one cell is monitored on a drive test).

4.0 Data Presentation And Analysis

The measured received signal levels (in dBm) for the site visited and the mean is shown in the Table 1. Due to variations in the measurements of the received signal strength, the mean values are used for the model development.

Table1.: Measured Received Signal Strength Indicator (RSSI) during experimentation

Distance (m)	RSSI (dBm)	RSSI (dBm)	RSSI (dBm)	RSSI (dBm)

	Rainy Season (June 2016)	**Harmattan Season (December 2017)**	**Dry Season (January 2017)**	**Average**
100	-51.00	-50.60	-49.10	-50.23
200	-59.40	-51.00	-53.60	-54.66
300	-50.80	-64.10	-65.50	-60.13
400	-62.70	-66.50	-64.50	-64.56
500	-65.50	-71.10	-69.70	-68.76
600	-68.50	-71.20	-72.60	-70.76
700	-75.10	-74.50	-75.40	-75.00
800	-77.80	-79.10	-78.10	-78.33
900	-84.40	-83.10	-82.40	-83.30
1000	-82.10	-82.50	-81.30	-81.96
1100	-90.40	-89.60	-87.20	-89.06
1200	-88.10	-90.10	-90.40	-89.53

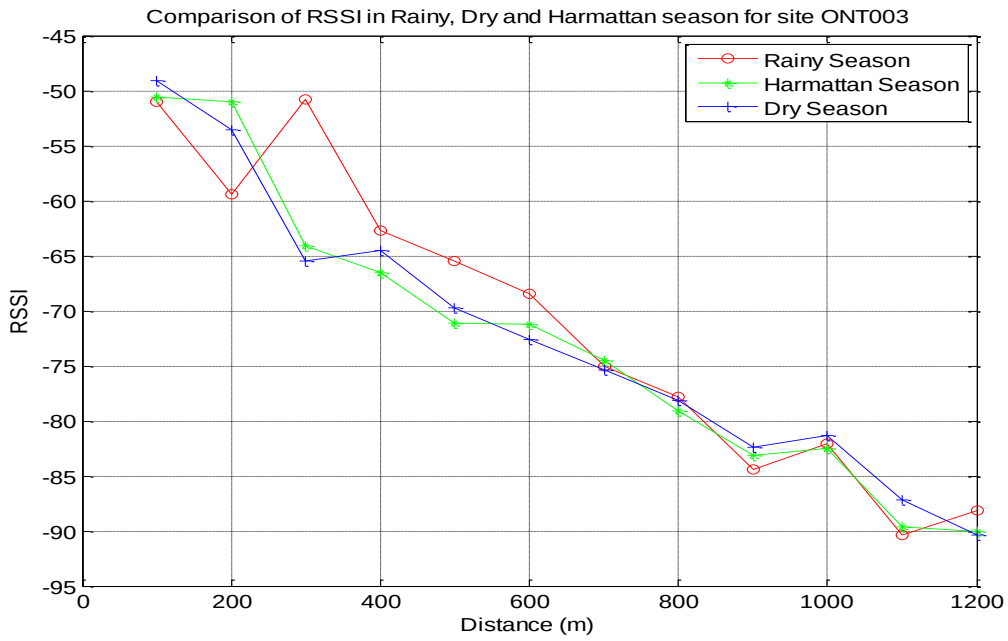

Figure 2: Plot of Measured RSSI for different seasons

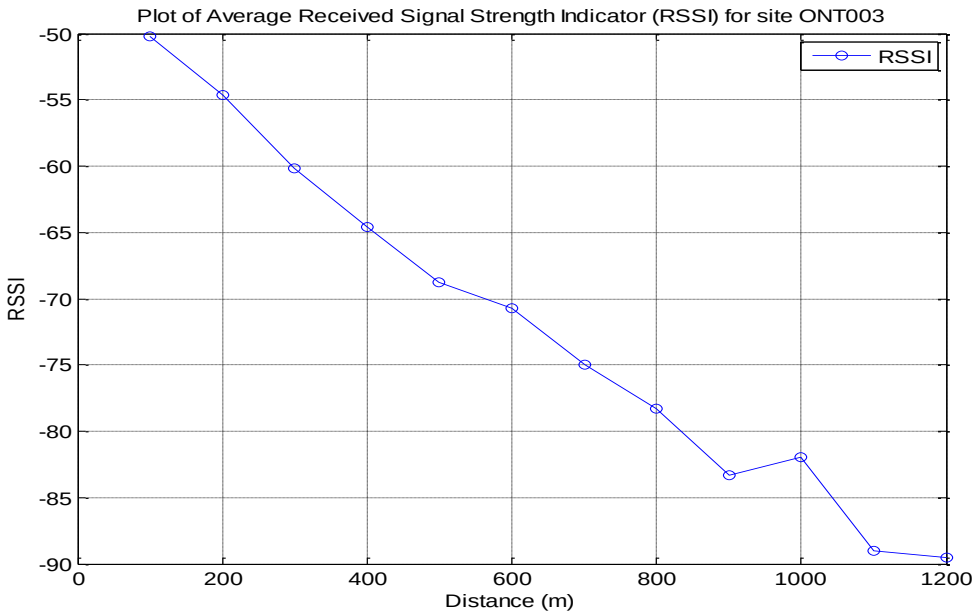

Figure 3: Plot of mean RSSI for the base station visited

The path loss exponent η, is obtained from measured data by applying the method of linear regression analysis [10] (or method of least squares) such that from:

$$e(\eta) = \sum_{i=1}^{m}[P_L(d_i) - P_L(d_o)]^2 \qquad (18)$$

The average large-scale path loss for an arbitrary transmitter to receiver separation is expressed as a function of distance as:

$$P_L(dB) = P_L(d_0) + 10\eta Log\left(\frac{d}{d_0}\right) \qquad (19)$$

It was shown in [11] that for any value of *d*, the path loss $P_L(dB)$ is a random variable with a log-normal distribution about the mean value due to shadowing. To compensate for shadow fading, the path loss beyond the reference distance can be written as:

$$P_L(dB) = P_L(d_0) + 10\eta Log\left(\frac{d}{d_0}\right) + \varsigma \qquad (20)$$

Where ς is the shadowing factor and is a Gaussian random variable (with values in dB) and standard deviation σ (also in dB). The standard deviation of the shadowing factor which is known as the location variability is given as:

$$\sigma = \sqrt{\sum \frac{[P_L(d_i) - P_L(d_0)]^2}{N}} \qquad (21)$$

Where $P_L(d_i)$ is the measured path loss at distance, d_i, $P_L(d_o)$ is the estimated path loss using equation (19) and N is the number of measured data points.

Substitute (19) into (18)

$$e(\eta) = \sum_{i=1}^{m}[P_L(d_i) - P_L(d_0) - 10\eta Log(\frac{d}{d_0})]^2$$

Differentiating equation (18) with respect to n and equating to zero

$$\frac{\delta e(\eta)}{\delta n} = -20\log\left(\frac{d}{d_0}\right)\sum_{i=1}^{m}\left[P_L(d_i) - P_L(d_0) - 10\eta Log\left(\frac{d}{d_0}\right)\right] = 0$$

Solving for η *gives*:

$$\eta = \frac{\sum_{i=1}^{m}[P_L(d_i) - P_L(d_o)]}{\sum_{i=1}^{m}[10\log_{10}(\frac{d_i}{d_o})]} \qquad (22)$$

Where, $P_L(d_i)$is the average path loss and it is the difference between the transmitting power (P_t) in dB and received power (P_r) in dBm,$P_L(d_o)$= the path loss at close in reference distance otherwise known as reference path loss, $d_o$is close in reference distance,$d_i$is distance at intervals from the BS to MS.

- *Path Loss exponent calculation for BS ONT003*

d_i=(100,200,300,400,500,600,700,800,900,1000,1100,1200)

P_t= 44.7dBm

P_r= (-50.23 -54.66 -60.13 -64.56 -68.76 -70.76 -75.00 -78.33 -83.30 -81.96 -89.06 -89.53)

$P_L(d_i) = P_t - P_r$ = 44.7 −(-50.23 -54.66 -60.13 -64.56 -68.76 -70.76 -75.00 -78.33 -83.30 -81.96 -89.06 -89.53)

$P_L(d_i)$ = (94.93 99.36 104.83 109.26 113.46 115.46 119.70 123.03 128.00 126.66 133.76 134.23)

$P_L(d_o)$ = 94.93

$P_L(d_i) - P_L(d_o)$ = (94.93 99.36 104.83 109.26 113.46 115.46 119.70 123.03 128.00 126.66 133.76 134.23) – (94.93)

$P_L(d_i) - P_L(d_o)$ = (0 4.43 9.90 14.33 18.53 20.53 24.77 28.10 33.07 31.73 38.83 39.30)

$$\sum [P_L(d_i) - P_L(d_o)] = 263.52$$

$$d_0 = 100$$

$$\sum_{i=1}^{12} (10 \log_{10}(\frac{d_i}{d_o}))$$

$$= \sum (10 \log_{10}(\frac{(100,200,300,400,500,600,700,800,900,1000,100,1200)}{100})$$

$$\sum_{i=1}^{12} (10 \log_{10}(\frac{d_i}{d_o})) = 86.80$$

$$\eta = \frac{263.52}{86.80} = 3.04$$

Therefore the pathloss exponent for ONT003 is 3.04.

Using MATLAB software, the Shadowing factor of base station ONT003 is 7.29 dB and $P_L(d_o)$which is the path loss at close in reference distance otherwise known as reference path loss is 94.93dB.

Therefore the empirical Path loss for ONT 003 is gotten from (20):

$$P_L(dB) = P_L(d_0) + 10\eta Log\left(\frac{d}{d_0}\right) + \varsigma$$

Substituting the values above into the equation gives:

$$P_L(dB) = 94.93 + 10(3.04)Log\left(\frac{d}{d_0}\right) + 7.29$$

$$P_L(dB) = 102.22 + 30.4 \log \frac{d}{d_0}$$

The empirical path loss model for Onitsha suburban is then obtained as:

$$P_L(dB) = 102.22 + 30.4Log\left(\frac{d}{d_0}\right) \qquad (23)$$

5.0 Comparison Of Measured Model With Existing Models

Using Matlab, the values from the various path loss models are computed and tabulated in Table 2.0 for the free space model, Empirically developed Model and ECC-33 path loss model equation with parameters (*f=2112MHz*,h_m =1.5m, h_b = 36m).

Table 2: Comparison of Path loss models

Distance (Km)	Free Space Model (dB)	Developed model (dB)	ECC-33 Path loss Model (dB)
0.1	78.89	102.22	370.19
0.2	84.91	111.37	372.24
0.3	88.43	116.72	383.46
0.4	90.93	120.52	397.78
0.5	92.87	123.47	413.56
0.6	94.45	125.88	430.16
0.7	95.79	127.91	447.26
0.8	96.95	129.67	464.68
0.9	97.98	131.23	482.34
1.0	98.89	132.62	500.15
1.1	99.72	133.88	518.08
1.2	100.47	135.03	536.10

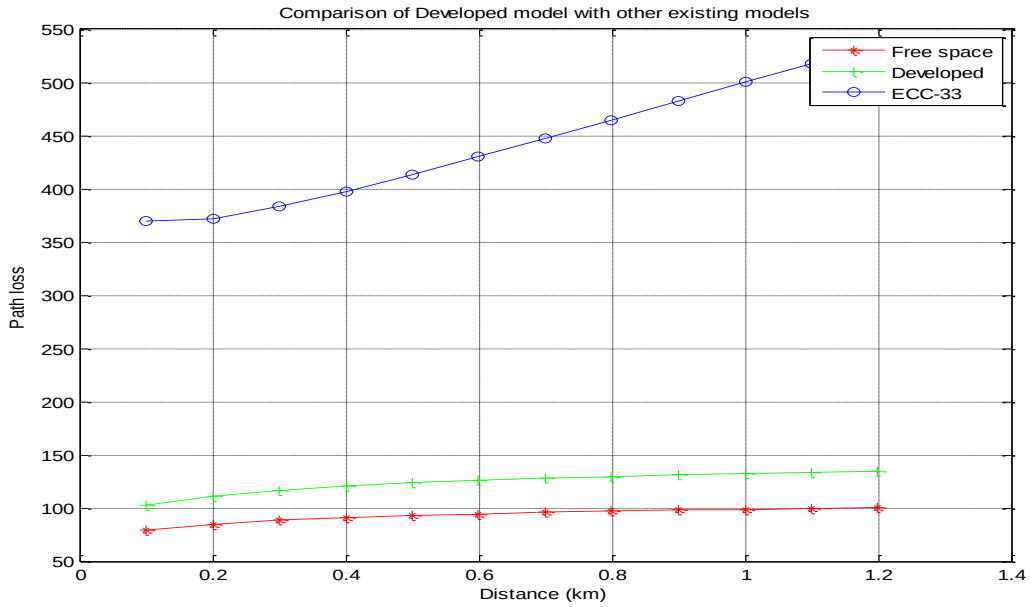

Figure 4: Image showing the comparison of various Path Loss Models

Comparisons between the empirical model developed in this work and that predicted by ECC-33 and other traditional models have shown some variations. These variations show that the ECC-33 model or any existing model cannot fit in effectively into an environment other than that for which it was developed. To make such models appropriate for different environments, they must be corrected. This can only be done by carrying out field measurements in the environment. The measured data is then used to correct an existing model or to develop a new model for the environment.

6.0 Conclusion

This research work has been able to show the outdoor path loss model for Onitsha, obtained using the log-normal shadowing model. The result from the computation of measured data showed that the path loss exponent is 3.04 and from calculation, it is shown that the efficient path loss model for Onitsha is:

$$P_L(dB) = 102.22 + 30.4Log\left(\frac{d}{d_0}\right)$$

A repetition of the test and/or a comparison with other cities in the south - east will further confirm the reliability of the stated model above. The developed pathloss model can be used for accurate path loss prediction of the received signal strength of WCDMA networks in the region. Consequently, for accurate pathloss prediction in these environments, the developed pathloss model can be used as a correction factor otherwise, field measurement must be carried out to ensure accuracy.

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