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Path Loss Prediction of Wireless Mobile Communication for Urban Areas of Imo State, South-East Region of Nigeria at 910 MHz

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Abstract

This paper provides an extension of path loss prediction in urban city of Imo State of Nigeria with a measured set of propagation at 910 MHz band. This paper work discusses and implements Okumura, Hata, cost-231, walfisch-Ikegami model, Sagami-Kuboi Model even though Hata and cost-231 Hata Models are extensively used in path loss analysis for GSM and CDMA systems comparison with the set results developed. It is of utmost importance that this paper work guides network designers in mobile cellular propagation and inculcates an accurate method of designing, deploying and managing of their network for proper attenuation.

Keywords: Path loss; Propagation models; Hata model; Urban area; PCHIP (Piecewise cubic Hermite Interpolating polynomial); WCDMA (Wireless code division multiple access systems); GSM (Global System for mobile communications); WIMAX (Worldwide interoperability for microware access)

Introduction

Path loss is the degradation in received power of an electromagnetic signal when it propagates through space. Path loss is due to several effects such as free space path loss, refraction, diffraction, reflection, coupling and cable loss, and absorption. Path loss depends on several factors such as type of propagations, environments, distance between the transmitter and receiver, height and location of antennas. Also, the signal from the transmitting antenna may take multiple paths (multipath) to reach the receiving side, which results in either increase or decrease of received signal level depending on the constructive or destructive interference of the multipath waves [1].

Path loss is highly inevitable in evaluating networks quality and capacity as regards efficient and reliable coverage areas in the growth of mobile communication [2]. This article centres its results on the experimental and statistical analysis at GSM frequency of 910 MHz using Okumara model which is most widely used propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial deployment. They are also very useful for performing interference studies as the deployment proceeds numerous experiments have been carried out in urban city of Imo State, for checking the applicability of suitable path loss models in mobile communications. This research aims at enhancing the quality of wireless service in Imo State of Nigeria by carrying out site specific measurements and developing an acceptance path loss model for the state.

Existing Models

Free space propagation model

The wave is not reflected or absorbed in free space propagation model. The ideal propagation radiates in all directions from transmitting source and propagating to an infinite distance with no degradation. Attenuation occurs due to spreading of power over greater areas. Power flux at the transmitter can be calculated using equation [3].

$$P_d = P_t/4\pi d^2 \quad (1)$$

Where P_d is the power density at a distance, d from an isotropic source, in watts/square meter.

P_t is the transmitted power, in watts

d is the distance in meters, from the source.

The power is spread over an ever-expanding sphere if radiating elements generates a fixed power. As the sphere expands, the energy will be spread more thinly. The power received can be calculated from the antenna if a receiver antenna is placed in power flux density at a point of a given distance from the radiation. To calculate the effective antenna aperture and received power, the formulas are shown in equations below.

The amount of power captured by the antenna at the required distance, d, depends on the effective aperture of the antenna and the power flux density at the receiving element. These are mainly three factors by which the actual power received depends upon by the antenna:

(a) The aperture of receiving antenna (b) The power flux density (c) and the wavelength of received signal.

For isotropic antenna, effective area is given by

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

Power received is gien by.

$$P_r = P_d \text{ X } A_e = \frac{P_t \text{ X } \lambda^2}{(4\pi d)^2} . \quad (3)$$

Pathloss is,

$$L_p = \text{power transmitted } (P_t) - \text{ power received } (P_r) . \quad (4)$$

Therefore, $L_p = P_t - P_r$

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Substituting equation 3 and 4, we get

$$L_p\ (dB) = 20\log_{10}(4p) + 20\log_{10}(d) - 20\log_{10}(\lambda) \quad (5)$$

Then substituting (λ (in Km) = 0.3/f (in MHz), and rationalizing the equation produces the generic free space pathless formular,

$$L_p\ (dB) = 32.5 + 20\log_{10}(d) + 20\log_{10}(f). \quad (6)$$

Plane earth propagation model

The effects of propagation model on ground are not considered for the free space propagation mode. Some of the power will be reflected due to the presence of ground and then received by the receiver when a radio wave propagates over ground. The free space propagation model is modified and referred to as the "plane earth" propagation model by determining the effects of the reflected power. Thus, these model suites better for the true characteristics of radio wave propagation over ground. This model computes the received signal to be the sum of a direct signal which reflected from a smooth, flat earth. The relevant input parameters include; the length of the path, the antenna heights, the operating frequency and the reflection coefficient of the earth. The coefficient will vary according to the type of terrain either water, wet ground, desert etc. [4].

For this, path loss equation is given by

$$L_{pe} = 40\log_{10}(d) - 20\log_{10}(h1) - 20\log_{10}(h2). \quad (7)$$

Here 'd' is the path length in meter, h, and h2 are the antenna heights at the base station and the mobile, respectively.

Furthermore, if the mobile height changes (as it will in practice) then the predicted pathloss will also be changed.

Empirical Propagation Models

Empirical propagation models will be discussed in this section, amongst them are Okumara and Hata models.

Okumura and Hata are among the two empirical propagation models. The two basic propagation models are free space loss and plane earth loss would be requiring detailed knowledge of the location and constitutive parameters of building, terrain features, every tree and terrain feature in the area to be covered. It is too complex to be practical and would be providing an unnecessary amount of detail therefore appropriate way of accounting for these complex effects is by an empirical model. There are many empirical prediction models like, cost 231, Hata model, Okumura-Hata model, sakagami-kuboi model, cost 231, walfisch-Ikegami model [5-7].

Okumura propagation mode

In mobile communications, the terrain between the transmitter and the receiver plays a very important role in determining the signal strength at the receiver. Okumura model is one of the popular models, especially used for urban areas. It is generally applied for frequencies in the range of 150 MHz-1920 MHz, for a distance separation ranging from I km to 100 km, and for antenna heights from 30 m to 1000 m.

The pathloss is given as:

$$L_p\ (dB) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G(AREA) \quad (8)$$

Where L_p is the median value of the propagation Path loss.

L_F is the free space propagation loss

A_{mu} is the median attenuation relative to the free space.

$G(h_{te})$ is the base station antenna height gain factor

$G(h_{re})$ is the mobile antenna height gain factor

G (AREA) is the gain due to the type of the environment.

Hata's propagation model

The Hata model is used for frequency range of 150 MHz to 1500 MHz. The median pathloss from the Hata is given as:

$$L_p\ (urban)\ (dB) = 69.55 + 26.16\log_{10}f_c - 13.82\log_{10}h_{te} - \propto(h_{re}) + (44.9 - 6.55\log_{10}h_{te})\log_{10}d \quad (9)$$

where, f_c is frequency from 150 MHz to 1500 MHz

h_{te} is effective transmitter antenna height of the base station ranging from 30 m to 200 m.

h_{re} is effective receiver antenna height (mobile) ranging from 1 m to 10 m.

d is distance between the transmitter and the receiver in km.

$\propto(h_{re})$ is correction factor for effective mobile antenna.

The mobile antenna correction factor for a small to medium city is obtained as:

$$\propto(h_{re}) = (1.1\log_{10}f_c - 0.7)\, h_{re} - (1.56\log_{10}f_c - 0.8) \quad (10)$$

The mobile antenna correction factor for a large city is given as

$$\propto(h_{re}) = 8.29\ (\log_{10}1.5\, h_{re})^2 - 1.1\ dB \text{ for } f_c \le 300\ MHz. \quad (11)$$

$$\propto(h_{re}) = 3.2\ (\log_{10}11.75h_{re})^2 - 4.97dB \text{ for } f_c \ge 300MHz. \quad (12)$$

The pathloss for a suburban area from the Hata model is given by the following equation

$$L_p(dB) = L_p(urban) - 2\left\{\log_{10}\left(\frac{f_c}{28}\right)\right\}^2 - 5.4. \quad (13)$$

The pathloss for the open rural areas is obtained from the following equation:

$$L_p\ (dB) = L_p\ (urban) - 4.78\ (\log_{10}f_c)^2 + 18.33\log_{10}f_c - 40.94. \quad (14)$$

The Hata model predicts the mean signal pathloss for transmitter receiver separation of more than 1km. Therefore, it is very much suited for large cell mobile communications, but not for personal communication systems (PCS, radius < I km)

Data Collection Procedures

The event of this research was taken on a hot Sunny day about three times on August, 2014 with average temperature of 27°C in urban city Imo State of Nigeria.

The test was carried out in urban areas of Imo State such as Okigwe Road, Tetlow Road, Ikenegbu layout, wetheral road and government house roundabout with necessary analysis taken at frequency range of 910 MHz using a net monitor application of NOKIA 3310 CDMA. The net monitor is software compatible with some Nokia phones, with the capability of giving information on a BTS over the air interface. Thus, the signal strength information sent over the air interface between the BTS and the mobile station were read. The base station antenna lengths of 42 m operated by GSM base station over a transmitted power of 25 W mounted on a tower.

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The measured data of pathloss (in dB) against their corresponding receive-transmit separation distance median values over the period of the investigation are presented as in Tables 1 and 2 grouped as sites A and B respectively.

The BTS were selected to cover the urban (group A) and sub urban (group B) terrain in Imo State, South-East region of Nigeria. The terrain group A consisted of sites located near dense vegetation, highly populated areas with nucleated settlements such as linear and nodal settlements as seen in Edinburgh, shopping complex along wetheral road, cherubim junction and Imo State government house round about while group B composed mainly of down stairs fitted with communication gadgets such as Imo State library, Nicon insurance, mobis mall along ikenegbu layout.

Results and Analysis

Applying linear regression formulae,

$$e(n)=\sum_{i=1}^{K}\{L_p(di)\acute{L}_p(\text{do})\}^2 \tag{15}$$

Where L_p (di) is the measured path loss at distance di and $\acute{L}_p$ (di) is the estimated path loss using equations below [8]:

P_L (dB) = P_L (do) + $10\, n \log_{10}\left(\frac{di}{do}\right)$ and replacing it in equation above, yields

$$e(n)=\sum_{i=1}^{K}\left\{L_p(di)-L_p(do)-10n\log_{10}\left(\frac{di}{do}\right)\right\}^2. \tag{16}$$

Appling differentiation in equation (16) with respect to n, and equating $\frac{\delta E(n)}{\delta n}$ to zero,

$$\sum_{i=1}^{K}\left\{\{L_p-L_p(do)\}\sum_{i=1}^{K}10n\log_{10}\left(\frac{di}{do}\right)\right\}=0$$

$$\sum_{i=1}^{K}\{L_p-L_p(do)\}=\sum_{i=1}^{K}\left\{10n\log_{10}\left(\frac{di}{do}\right)\right\}$$

Then, 'n' given by

$$n=\frac{\sum_{i=1}^{K}\{L_p(di)-L_p(do)\}}{\sum_{i=1}^{K}10\log\left(\frac{di}{do}\right)}. \tag{17}$$

The combined path loss model for shadowed Imo urban environment is expressed as

$$L_p(d)=L_p(d)+10n\log_{10}\left(\frac{d}{d_o}\right)+S. \tag{18}$$

Where S is the shadow fading variation about the linear relationship and has a r.m.s value that reduces the Error as seen below in the given equation.

$$\sqrt{\sum_{i=1}^{K}\frac{(Pm-pr)^2}{N}} \tag{19}$$

In Figure 1 below, ORIGINLAB program was used to plot the regression analysis of path loss against distance. The significance of this using least square method, shows that the intercept or maximum path loss is about 80dB with acceptable range of 10dB. In the analysis, the linear plot of the path loss yields a correlation coefficient of 0.898 which is less than unity and this shows strong positive relationship between median path loss (dB) and its equivalent distance. The coefficient of determination, r^2=0.80717. This value of 0.80717 can be expressed in percentage as 80.8% and it can interpreted to mean that 80.8% of the variation in the path loss is propagated over distance. The slope of the graph is 26.37255 with error of 3.19874. The intercept is 78.91176 with error of 3.27774.

In Figure 2, a linear regression model way fitted using a scatter plot of the experimental data on path loss against distance. This reveals a first order polynomial trend. The method of least squares method was employed to estimate the correction coefficient of 0.9881 which is close to Unity and thus shows a strong positive path loss propagation over a distance. Also, the coefficient of determination of this regression suggested that about 98% variation in path loss over a propagated distance is attained. Also, the maximum number of measured data points was about 129dB with range of 10dB which is the acceptable range i.e. 4 to 20dB.

Distance (km)	Median Rx (dBm)	Median PL (dB)
0.10	-54	88
0.20	-58	90
0.30	-61	94
0.40	-65	96
0.50	-70	84
0.60	-74	86
0.70	-71	82
0.80	-76	98
0.90	-80	100
1.00	-82	106
1.10	-86	110
1.20	-83	107
1.30	-90	113
1.40	-92	118
1.50	-94	120
1.60	-91	123
1.70	-93	130

Table 1: Measured median path loss for group a sites.

Distance (km)	Median Rx (dBm)	Median PL (dB)
0.10	-48	81
0.20	-51	85
0.30	-56	87
0.40	-57	83
0.50	-53	88
0.60	-58	95
0.70	-63	98
0.80	-67	102
0.90	-72	107
1.00	-75	109
1.10	-77	113
1.20	-80	110
1.30	-76	117
1.40	-84	120
1.50	-88	122
1.60	-90	126
1.70	-93	129

Table 2: Measure median path loss for group B sites.

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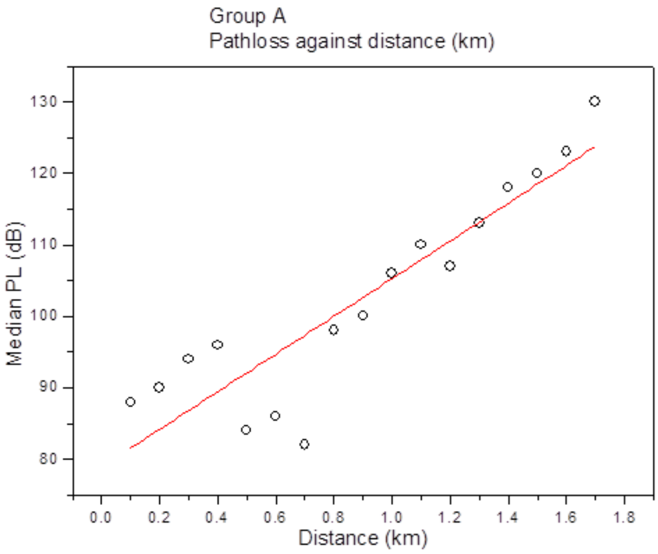

Figure 1: Regression plot for Pathloss against distance of urban model.

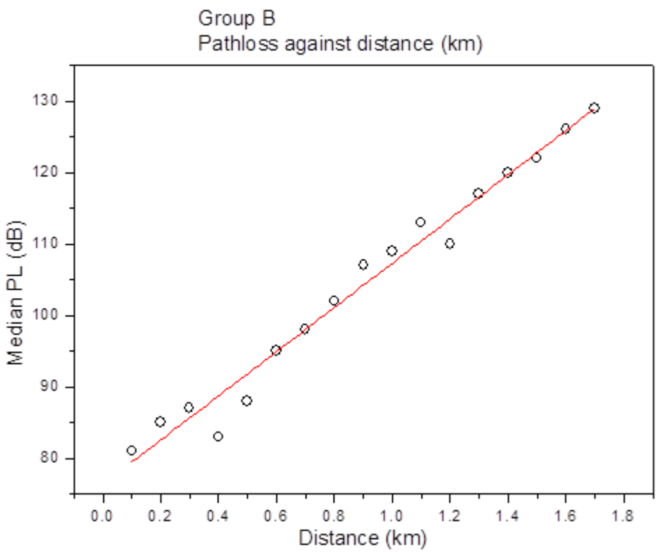

Figure 2: Regression plot for pathloss against distance of sub-urban model.

Conclusion

This work was aimed at predicting the mean signal strength of Owerri. However, most propagation models aim to predict the median path loss. Today's predictions models differ in their applicability over different environmental and terrain conditions. There are many predictions methods based on deterministic processes through the availability of improved data values, but still the Okumura- Hata models is most commonly used empirical propagation model. That is because of the ITU-R recommendation for its proven reliability and its simplicity.

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