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Development of an Empirical Propagation Path loss Model for an LTE Network in Onitsha, South-Eastern Nigeria

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Abstract
In any Long Term Evolution (LTE) network, the propagation path between the transmitter and the receiver may vary from eNB to eNB. This also varies from a simple line-of-sight (LOS) to very complex one due to factors such as diffraction, reflecting and scattering (which could either be natural or man-made). Such propagation environments suffer from multipath propagation and large scale pathloss. Several research have been done to predict the pathloss of different environments using propagation models which were developed for different locations other than the region in question. In most cases, such acts lead to power wastages as the propagation environment differs. In this work, the propagation path loss for south-east Nigeria is determined using empirical measurements from specific sites in the region. The results of the measurements show that the pathloss exponent for the reference measurement environment is 3.79 and the shadowing factor is 9.22.

Keywords: Path Loss, Propagation model, LTE, Path loss exponent, Fading,.

1.0 Introduction

In wireless communications, fading describes the rapid variation of the amplitude of a radio signal over a travel distance. It is usually caused by the interference between two or more versions of the transmitted signal which arrive at the receiver at slightly different times. Attenuation of a signal with various (Rappaport 2006). Fading is often modeled as a random process. In wireless systems, fading may either be due to multipath propagation, which can be induced either by weather (particularly rain), or obstacles in the path of the signal. Fading is described as the fluctuation of the amplitude of the mobile signal in a short period of time. The effect of multipath fading on the amplitude and the phase of the received signal depend on the propagation time, intensity, speed and the bandwidth of the signal. The signals arriving at the base station are therefore a combination of signal paths with different amplitudes and time delays (phases). The superposition of these paths may be constructive or destructive, depending on the phase differences between all the arriving paths. 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 (Ufoaroh 2017).

There are two (2) types of fading, namely large-scale fading and small-scale fading. Large scale-fading represents the average signal-power attenuation or path loss due to motion over large areas (usually distances ranging from several hundreds to thousands of meters) and it is impacted by terrain configuration between the transmitter and receiver (Adit 2003; Ufoaroh and Inyiam (2017)). On the contrary, small-scale fading refers to the rapid changes of the amplitude and phase of a radio signal over a short period of time (in the order of seconds) or distance (a few wavelengths).This classification is important because power control scheme to overcome the large-scale propagation loss is different from that for the small-scale propagation loss. Prediction of path loss is an important element of system design in any communication system. The prediction methods are divided into empirical and deterministic/physical models. The choice of the coverage prediction model depends on the propagation environment and the coverage area Rama and Vijaya (2000). In communications, propagation takes place through multiple diffraction, reflection and scattering among others from an extremely large number of objects. Since it is very difficult to locate scatterers deterministically, characterisation of the signal within the coverage zone is done statistically. For this reason, prediction models have been developed using either empirical or statistical methods. The accuracy of a particular model in a given environment depends on the fit between the parameters required by the model and those available for the area concerned Rama and Vijaya (2000). This paper investigates the propagation path loss in an LTE network for Onitsha in south-east Nigeria using empirical measurements from specific sites in the region.

Several works have been done by diverse researchers in this research area. The need to improve services, service providers, radio engineers and mobile network planners have proposed and reported several propagation models. Among these models include the Okumura-Hata model (Hata 1980), free space model (Rappaport 2006), Lee model (Seybold 2005), COST 231-Hata model (Seybold 2005), Ericsson model (Milanovic 2007), Weissberger model (Weissberger 1982), Erceg model (Erceg 1999), and ECC-33 model (Abhayawardhana 2005). The work by (Wang 2015) investigated the scattering phenomena of the propagation channel on the Baltic Sea, at an operating frequency of 5.2 GHz. The Karasawa model was used to study the scattering effect, and it was concluded that the model showed validity for the propagation of radio waves at the carrier frequency of 5.2 GHz. Parmar and Nimavat (2015) gave a brief introduction to several path loss models. From their findings, they concluded that each model is suitable for a specific environment. Roslee and Kwan (2010) used the least-square method to optimize the Hata empirical path loss model for accurate prediction suited to a suburban area in Malaysia. Different propagation models were presented by Ekpenyong and Isabona (2010) for LTE Advanced Networks. The work carried out by Imoize and Ibhaze (2019) involved extensive measurements taken in Lagos state, Nigeria at a frequency of 3.4GHz. They made a comparison with 6 standard propagation models. From their findings, it was concluded that the COST 231-Hata and Ericson models showed the best performance in urban and suburban areas. Sharma and Singh, (2010) presented a comparative analysis of path loss models with field-measured data. The models include Stanford University Interim (SUI) model, Hata model, COST231 Extension to Hata model, Walfisch - Bertoni model, and the ECC-33 model. The work by Khan and Kamboh (2012) showed that propagation models in urban areas experience higher losses compared with suburban areas. Ufoaroh and Inyamah (2017) developed an empirical propagation path loss medel for a Wide Band Code Division Multiple-Access (WCDMA) cellular system in a sub-urban environment. From this extensive review, it is clear that for all environments, no single model could be used for all environments, hence there is a need to develop path loss models that are site or area specific.

2.0 Material and methods

2.1 Mobile Radio Propagation Pathloss Models

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 phenomenas, 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 (Rappaport 2006). Traditionally, propagation models are focused on predicting the average received signal strength at a given distance from the transmitter, as well as the variability of the signal strength in close spatial proximity to a particular location. Such models that predict the mean signal strength for an arbitrary transmitter-receiver (T-R) separation distance (ranging from several hundreds to thousand meters) are called large scale propagation models.

Though there exist various path loss models, there are some empirical pathloss models which can be used to predict both large-scale and medium-scale coverage for mobile communication system design. These pathloss models include:

i. Free space model
ii. The log-distance path loss model.
iii. The log-normal shadowing model.

The following section describes some of the commonly used propagation models.

2.1.1 Free Space Propagation Model

The simplest and fundamental propagation model is the free space propagation model, which explains the behavior of signal attenuation for the LOS radio path with no obstacles in between. The free space propagation loss depends on the distance from the transmitter and the frequency in use. Satellite communication systems and microwave line-of-sight radio links typically undergo free space propagation (Rappaport 2006).

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 (Rappaport 2006):

$$S = \frac{P_t}{4\pi d^2} \tag{1}$$

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 (Rappaport 2006):

$$P_r = SA_r \tag{2}$$

The effective area of the isotopic receiving antenna is:

$$A_r = \frac{\lambda^2}{4\pi} \tag{3}$$

Substituting equation (1) and equation (3) into equation (2):

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

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

Thus: $$\frac{P_t}{P_r} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \tag{5}$$

Expressing equation (5) in decibels:

$$L_p(dB) = 10\log_{10}\left(\frac{P_t}{P_r}\right)$$

$$L_p(dB) = 10\log_{10}\left(\left(\frac{4\pi df}{c}\right)^2\right)$$

$$L_p(dB) = 20\log_{10}\left(\frac{4\pi df}{c}\right)$$

$$L_p(dB) = 20\log(d) + 20\log(f) + 20\log(\frac{4\pi}{c}) \tag{6}$$

Rationalizing equation (6) gives the generic free space path loss formula which is given as:

$$L_p(dB) = 32.4 + 20\log(d) + 20\log(f) \tag{7}$$

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

2.1.2 The log-distance path loss model.

The average large-scale path loss for an arbitrary transmitter to receiver separation is expressed as a function of distance as (Jari Rasinen 2010):

$$P_L(dB) = P_L(d_0) + 10\eta Log(\frac{d}{d_0}) \tag{8}$$

Where: $P_L(d_o)$ is the estimated path loss at reference distance d_0, η is the path loss exponent and d is the distance between User Equipment (UE) and Evolved NodeB (eNB). It is important to select a close in reference distance that is appropriate for the propagation environment. In large coverage cellular systems, 1km reference distance is commonly used, whereas in microcellular systems smaller distance such as 100m is commonly used.

2.1.3 The log-normal shadowing model

It was shown by Erceg and Greenstein (1999) that for any value of distance d, the path loss $P_L(dB)$ is a random variable with a log-normal distribution about the mean value due to shadowing effect. To compensate for shadow fading, the path loss beyond the reference distance can be written as:

$$P_L(dB) = P_L(d_0) + 10\eta Log\left(\frac{d}{d_0}\right) + \varsigma \quad (9)$$

Where ς is the shadowing factor and also a Gaussian random variable (with values in dB) and modelled as log normal with zero mean and standard deviation σ (also in dB). The standard deviation of the shadowing factor is known as the location variability. The standard deviation is given as Erceg and Greenstei (1999):

$$\sigma = \sqrt{\sum \frac{(P_L(d_i) - P_L(d_0))^2}{N}} \quad (10)$$

Where $P_L(d_i)$ is the measured path loss at distanced_i, $P_L(d_o)$is the estimated path loss using (8) and N is the number of measured data points. The path loss exponent η, is obtained from measured data by applying the method of linear regression analysis (Azubogu 2011) such that the sum of squared errors gives:

$$e(\eta) = \sum_{i=1}^{m}(P_L(d_i) - P_L(d_o))^2 \quad (11)$$

Making $P_L(d_o)\ in$ (8) the subject of formular and substituting into equation (11) gives:

$$e(\eta) = \sum_{i=1}^{m}(P_L(d_i) - P_L(d_0) - 10\eta Log(\frac{d}{d_0}))^2 \quad (12)$$

The value of η which minimizes mean square error can be obtained by equating the derivative of $e(\eta)$ to zero. Differentiating equation (12) with respect to η and equating to zero gives:

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

$$\sum_{i=1}^{m}(P_L(d_i) - P_L(d_0) - 10\eta Log\left(\frac{d}{d_0}\right)) = 0$$

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

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

Making η subject of formular gives:

$$\eta = \frac{\sum_{i=1}^{m}(P_L(d_i) - P_L(d_o))}{\sum_{i=1}^{m}(10\log_{10}(\frac{d_i}{d_o}))} \quad (13)$$

Where:
$P_L(d_i)$ is the average path loss which 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 eNB to UE.

3.0 Result and Discussions

3.1 Measurement Environment and Data Collection

The field measurements were carried out in the suburban city of Onitsha using MTN Base stations. Onitsha is a metropolitan city known for its river port, and as an economic hub for commerce, industry, and education. The Onitsha environs predominantly comprise of densely situated two to four storey buildings, a few trees and random settlers. The Onitsha environment covered are Akuora base Station (T0219), CIDS Base Station (T4089), Minaj Base station (AN0693). The Google map of Onitsha is shown in figure 1. For the purpose of this experiment, drive test was conducted in a car, and the network data (short and long) collected with the aid of TEMS DT kit as shown in figure 2. The data collected includes data for serving cell as well as the neighbours. This collected data is then analyzed and deductions made using the simulator software. Network optimization triggers whenever the analyzed data indicates faulty network condition. Note that to distinguish the LTE signals received from the eNB from other signals, the UE is set to only 4G mode.

The equipment used for the drive Test includes:

i. Vehicle
ii. Test Mobile System (TEMS) software
iii. Drive test mobile phone (UE)
iv. Dongle (network inspection USB)
v. External vehicle mounted GPS
vi. Laptop with drive test software and GPS connection capability and data cables, multi-connector port etc.

The system was queried to output readings of the Reference Signal Received Power (RSRP) from a distance of 100m (as the starting or reference point) and then readings were taken at 100m intervals up to a distance of 1500m. The RSRP measurement provides cell-specific signal strength metric. RSRP is defined for a specific cell as the linear average received power (in Watts) of the signals that carry cell-specific Reference Signals (RS) within the considered measurement frequency bandwidth. Three different base stations were visited on three different days as shown in table 1.
The plots of the readings is shown from figure 3 to figure 5.

Figure 1: Google map view of Onitsha

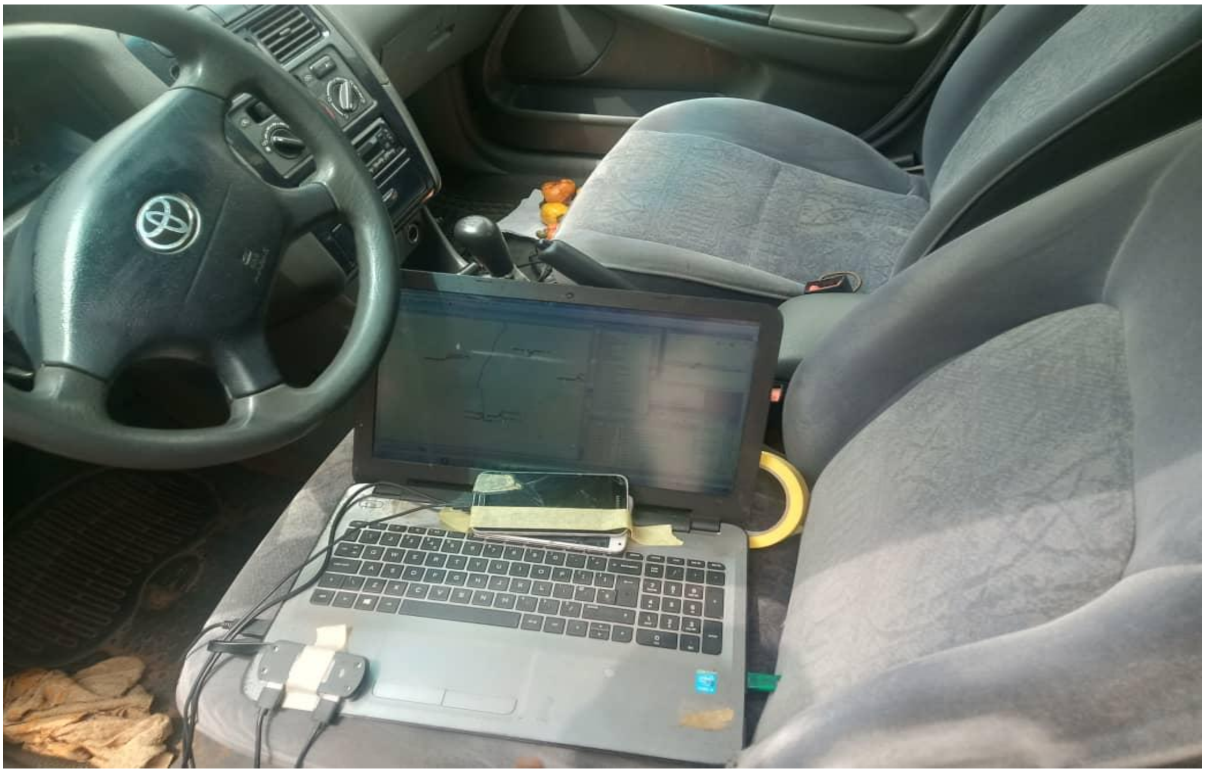

Figure 2: Drive Testing Equipment Setup

Table 1: Readings obtained from the eNB's in Onitsha for 3 different day

D (km)	RSRP (dBm) of eNB T0219 on 22/6/21	RSRP (dBm) of eNB T4089 on 22/6/21	RSRP (dBm) of eNB AN0923 on 22/6/21	RSRP (dBm) of eNB T0219 on 26/6/21	RSRP (dBm) of eNB T4089 on 26/6/21	RSRP (dBm) of eNB AN0923 on 26/6/21	RSRP (dBm) of eNB T0219 on 30/6/21	RSRP (dBm) of eNB T4089 on 30/6/21	RSRP (dBm) of eNB AN0923 on 30/6/21
0.1	-56.80	-42.30	-49.10	-61.20	-55.50	-53.10	-62.12	-49.14	-51.20
0.2	-55.00	-42.30	-53.60	-63.48	-58.30	-57.20	-55.66	-48.45	-60.43
0.3	-59.30	-46.30	-65.50	-67.60	-61.10	-63.10	-68.89	-54.20	-64.12
0.4	-63.40	-53.10	-64.50	-83.65	-71.60	-65.20	-69.45	-58.56	-67.10
0.5	-66.60	-57.20	-69.70	-87.26	-74.10	-74.10	-70.12	-65.90	-76.20
0.6	-68.70	-63.10	-72.60	-89.28	-72.10	-78.50	-71.23	-69.87	-75.31
0.7	-72.10	-71.20	-75.40	-88.78	-73.40	-80.10	-72.25	-70.65	-73.36
0.8	-72.10	-74.10	-78.10	-92.52	-74.90	-85.20	-75.80	-78.45	-87.40
0.9	-78.30	-78.50	-82.40	-98.21	-79.90	-89.30	-79.89	-89.34	-90.50
1.0	-80.10	-80.10	-81.30	-99.83	-83.10	-91.10	-80.34	-90.67	-91.60
1.1	-86.50	-85.20	-87.20	-97.10	-88.30	-90.20	-80.67	-90.10	-97.51
1.2	-90.10	-90.30	-90.40	-96.33	-92.10	-89.10	-98.12	-102.23	-95.30
1.3	-97.23	-92.88	-96.33	-99.83	-95.50	-93.40	-97.14	-98.46	-96.20
1.4	-99.10	-90.10	-94.44	-107.10	-98.30	-97.30	-108.80	-92.10	-94.10
1.5	-106.30	-96.45	-97.10	-119.33	-115.10	-100.20	-111.99	-96.11	-100.25

From the plots shown from figure 3 to figure 5, the effect of large scale fading can be observed as the amplitude of the RSRP varies. It can also be noticed that as the UE moves away from the eNB, the RSRP drops significantly. Applying (11) and (10) to Tables 1, using MATLAB program, the average Path loss exponent and shadowing factor for each site is obtained as shown in Table 2.

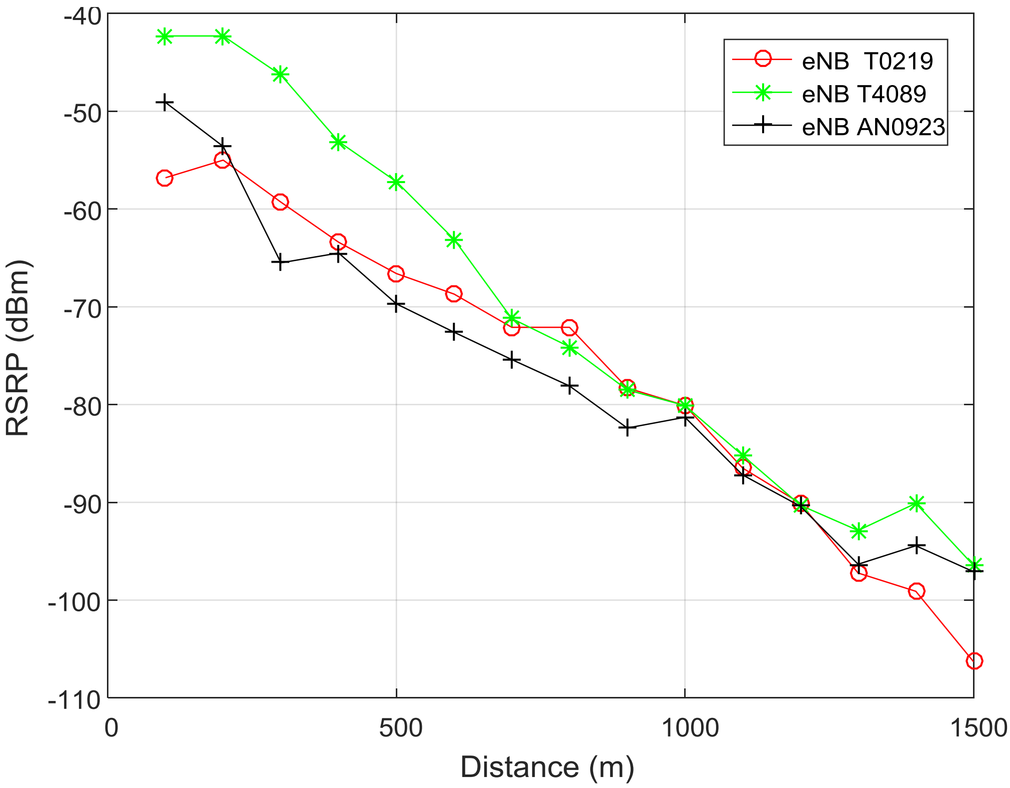

Figure 3 Plot of Readings measured from eNB's in Onitsha on 22/6/21

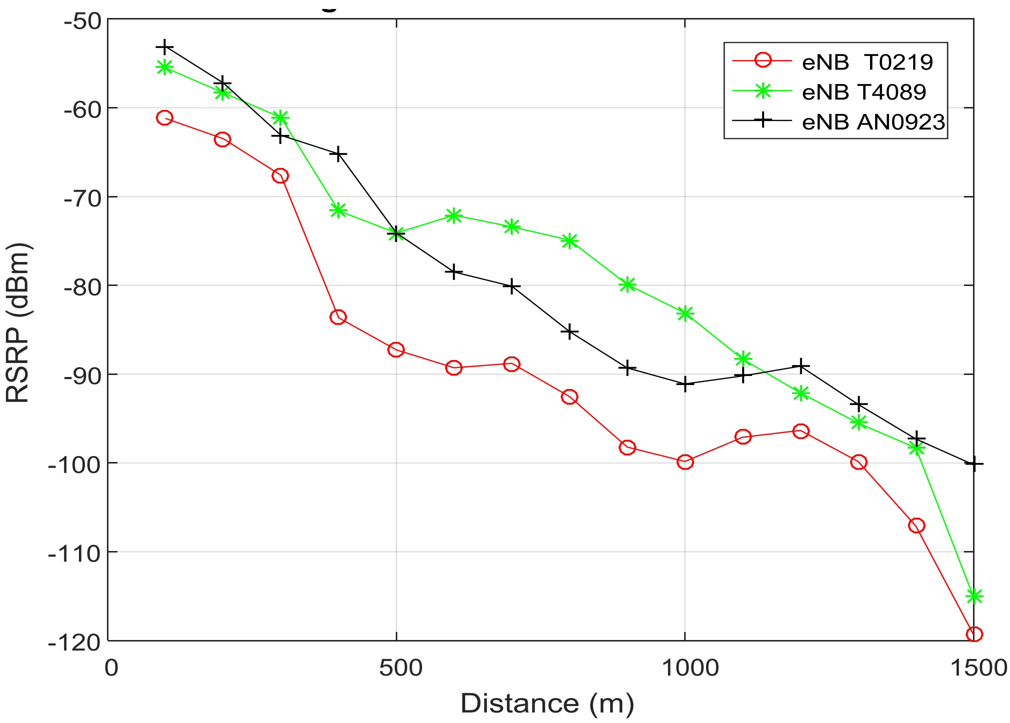

Figure 4 Plot of Readings measured from eNB's in Onitsha on 26/6/21

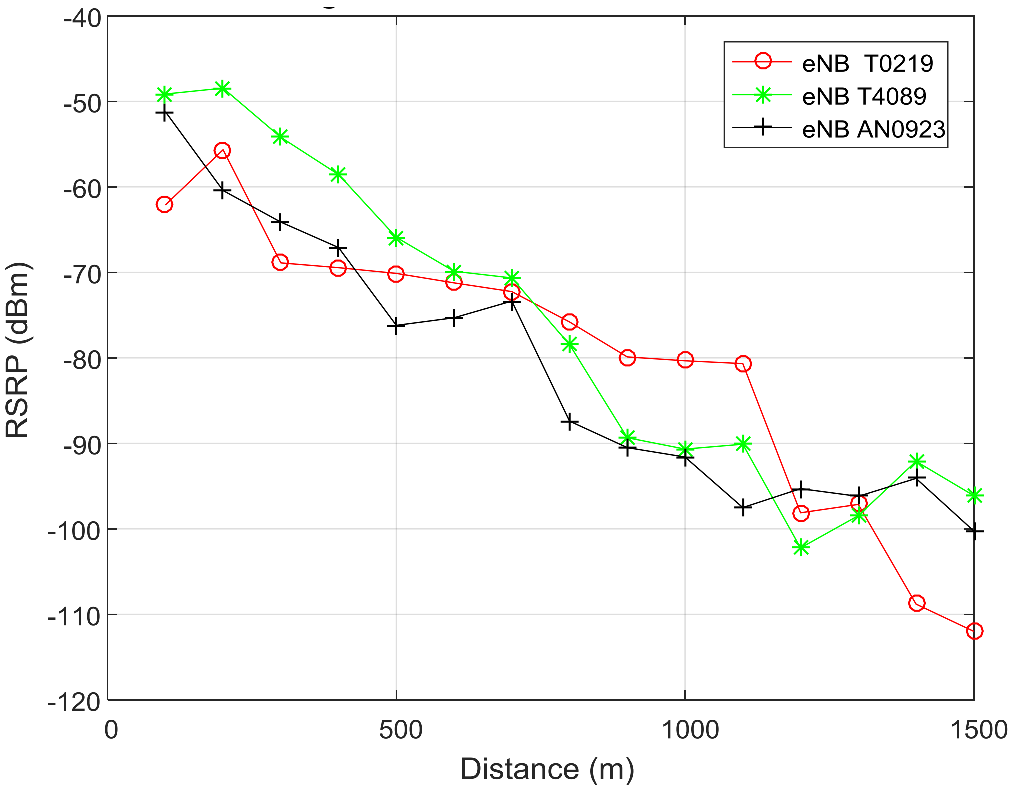

Figure 5 Plot of Readings measured from eNB's in Onitsha on 30/6/21

Table 2 Path loss exponent and shadowing factor for each site

Base Station	Rainy Season (June)	
	Path loss Exponent	**Shadowing Factor**
T0219	3.79	9.22
T4089	3.65	9.13
AN0693	3.28	9.45

Using eNB T0219 as reference, the path loss model for Onitsha was determined using the information provided in Table 2. The measured path loss is obtained as follows:

Using the information provided by Table 2, the empirical path loss model for Onitsha suburban can be obtained using the data of any of the base stations as reference. The eNB T0219 was used as reference. From Table 2, the average Path loss exponent for T0219 was found to be 3.79 with an average Shadow factor of 9.22 dB and $P_L(d_o)$which is the path loss at close-in reference distance otherwise known as reference path loss is 105.02dB. This is obtained by summing the average measured pathloss (at 100m) and the eNB transmit power.

Substituting the values above into equation (9) gives:

$$P_L(dB) = 105.02 + 10(3.79)Log\left(\frac{d}{d_0}\right) + 9.22$$

$$P_L(dB) = 114.24 + 37.9Log\left(\frac{d}{d_0}\right)$$

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

$$P_L(dB) = 114.24 + 37.9Log\left(\frac{d}{d_0}\right) \quad (14)$$

This is the efficient path loss model determined for Onitsha Sub-urban in this work. The model obtained was also compared with other existing models so as to see the variation and acceptability. In this work, our comparison will be limited to only free space model. The free space path loss equation is:

$$P_L(dB) = 32.4 + 20Logf + 20Logd_i$$

Where,
f = frequency in MHz
d_i = distance in km

This equation shows the relationship between the path loss, the frequency and distance of the transmission medium.

Using the following test parameters: $f = 2600MHz$

$$P_L(dB) = 32.4 + 20Log2600 + 20Logd_i$$

$$P_L(dB) = 32.4 + 68.29 + 20Logd_i$$

The free space path loss model for Onitsha suburban is given as:

$$P_L(dB) = 100.69 + 20Logd_i \quad (15)$$

Using Matlab, the values from the developed path loss model and free space model was computed and tabulated in table 3. The plot of table 3 is also shown in figure 6.

Table 3: Comparison of Path loss models

Distance (Km)	Free Space Model (dB)	Developed model For Onitsha(dB)
0.1	78.89	102.22
0.2	84.91	111.37
0.3	88.43	116.72
0.4	90.93	120.52
0.5	92.87	123.47
0.6	94.45	125.88
0.7	95.79	127.91
0.8	96.95	129.67
0.9	97.98	131.23
1.0	98.89	132.62
1.1	99.72	133.88
1.2	100.47	135.03
1.3	100.98	135.23
1.4	101.89	136.62
1.5	104.22	137.88

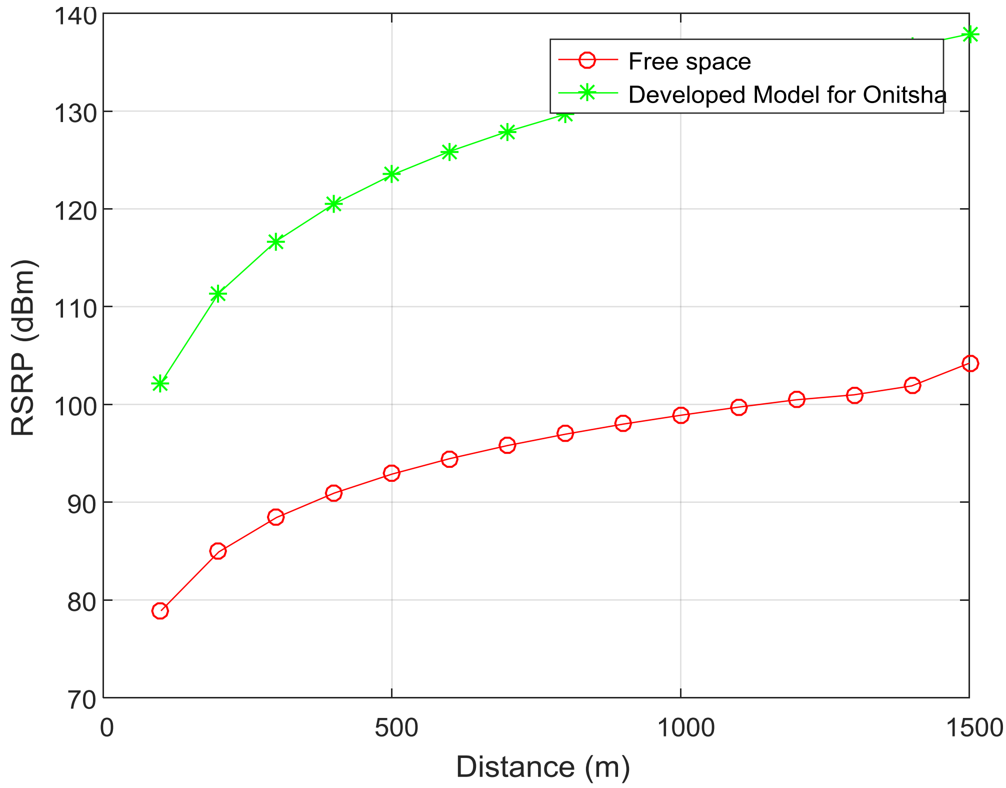

Figure 6 Graph showing the comparison of various Path Loss Models

This work presents the path loss model for Onitsha Urban, which would help base station engineers and network planners during the network planning phase which is usually carried out before the installation of new base stations in such areas. From the results obtained in this work, it would be discovered that the research goes further to establish the fact that no single model can be used for all environments, hence showing the need to develop path loss models that are site or area specific.

4.0 Conclusion

It was shown from experiments carried out in this work that the efficient path loss model determined for Onitsha Sub-urban is:

$$P_L(dB) = 114.24 + 37.9Log\left(\frac{d}{d_0}\right)$$

Comparisons between the model and that of free space showed some variations. These variations show that the free space 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.

5.0 Recommendation

We recommend that further models be developed for this region using results obtained from eNB's of other mobile service providers, so as to help present a broader view of the effect of large scale fading in that environment.

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