THE MELTING POT
ISSN 2504 – 8880
THE MELTING POT
Journal of the School of General and Basic Studies
Volume 8 Number 1 March, 2023
themeltingpotj@gmail.com

EMPIRICAL PATH LOSS PROPAGATION MODEL OF URBAN WIRELESS CELLULAR ENVIRONMENT

[1]B. O. Osuesu, [2]C.O. Onyibe, [3]Uche M. Chikezie, [4]Emmanuel Okekenwa

[1,2,3,4]Department of Electrical/Electronic Engineering,

Akanu Ibiam Federal Polytechnic Unwana, Ebonyi State, Nigeria.

[1]boosuesu@akanuibiampoly.edu.ng, [2]chris912111@yahoo.com, [3]uchedimkpagu@gmail.com, [4]emmaokekenwa@gmail.com

Abstract

Radio propagation prediction is one of the fundamentals of radio network planning for future generation communication systems. It is therefore vital that the propagation prediction models are as accurate as possible taking into account the practical limitations that characterized the propagation environment. Propagation path loss models helps to specify key system parameters such as transmission power, frequency, antenna heights, and so on. This work sets out to predict the path loss of a WCDMA cellular network in urban propagation environment of Awka, Anambra State. TEMS software installed in a Laptop computer was used to carry out Received Signal Strength measurements up to 700m from the base station, for a period of ten months, from GLO network. Measured values were used to estimate the path loss exponent used to develop an empirical path loss prediction model suitable for the radio transmission environment under study.

Keywords: Path Loss, Prediction Models, Received signal strength (RSS), Attenuation, Path loss Exponent,

Introduction

The knowledge of the received signal and how it varies at all points in the radio propagation environment plays a very important role in the design of an efficient and reliable wireless cellular transmission network. In every radio communication system, the amplitude of the received signal is usually less than the original transmitted signal. This phenomenon in cellular system is referred to as path loss (path attenuation). Path loss is a commonly used term in wireless communications and signal propagation. Path loss describes the propagation loss due to the distance between the transmitter and the receiver. This simply means that a radio signal (electromagnetic wave) propagating through space experiences reduction in its power density due to the increasing separation of the receiver from the transmitter (Segun & Olasukanmi, 2014). Path loss therefore is a major component in the analysis and design of the link budget of a telecommunication system because of its importance in determining signal strength as a function of distance (Akinwole & Biebuma, 2013). Path loss depends not only on distance but also on many properties of the signal propagation path such as free-space loss, refraction, diffraction, reflection, aperture-medium coupling loss and absorption (Alumona & Nnamani, 2015), among many other factors. The accurate determination of Path Loss and mitigation of interference leads to development of efficient design and operation of quality networks. Calculation of path loss is usually called prediction. Many researchers all over the world have developed different models for path loss prediction. Propagation path loss models prediction plays an important role in the design of cellular systems (Yihuai et al., 2012), to specify key system parameters such as transmission power, frequency, antenna heights etc.

Path Loss Prediction Models

Path loss measurements are conducted with respect to several different parameters. Path loss models are classified as deterministic, empirical, and semi-empirical (Akinwole & Biebuna, 2013). Deterministic models make use of the physical laws governing radio wave propagation mechanisms to predict transmission loss at a particular location. The models involve detailed and accurate description of all the objects in the propagating channel. Empirical model is based on statistical characterisation of the received signal by extensive measurements conducted with respect to several different parameters. It requires less computation effort unlike deterministic model that is site specific. A semi-empirical or semi-deterministic model combines the analytical formulation of physical phenomena with statistical fitting of variables by adjustment using experimental measurements.

Methodology

The research was conducted in Awka radio propagation environment and received signal strength (RSS) measurement was taken for a distance up to 700m from a base station belonging to GLO network. The Awka town is located in the south - east part of Nigeria and it is the capital of Anambra State of Nigeria. The testbed environment is located in Awka along Enugu-Onitsha express way at a location with longitude of 7.0678° E and latitude of 6.2069° N. The Test bed environment where the base station is located is shown in Fig.1. The base station is located at a location between the Judiciary road and secretariat road. The Longitude and latitude of the base station location is 7.0799^{o}N and 6.2352^{o}E respectively.

Figure 1: Map of Test bed environment [google map]

Experimental Set Up

Figure 2: Standard Drive Test Equipment set up

The hardware setup used for the drive test in this work is grouped into the user interface hardware and network interface hardware as shown in fig.2. A complete drive test kit (TEMS Kit) is connected in a special way to represent the user interface design and it is composed of mobile station (UE), two data modem (DC 1 and 2), a GPS antenna, USB dongle (which contain the software license), all connected to a laptop computer. The laptop computer has a TEMS Investigation Drive Test Software installed which has to detect all connected hardware and provides interface to investigate/monitor the radio network during the drive test. The network cell file is loaded on the laptop, this cell file contained information of all the network cells and their identifiers to enable one to identify the cell that is providing the service per time. The laptop computer was connected through an inverter to a DC source of a vehicle. The network interface design is the BTS (Base Transceiver Station) which is the source of the radio network under evaluation

Table 1: Transmission Parameters of the Network

S/N	Transmission parameter	Values
1	Transmitted power	44.4dBm
2	Height of the transmitter	35m
3	User Equipment height	1.5m
4	Gain of transmitter	18dB
5	User Equipment gain	1.7dB
6	Frequency of operation	887.87MHz

Results and Discussion

The received signal strength over several distances of up to 700 meters were recorded for a period of ten months, from September 2019 to June 2020 and average of each month's measurement is as shown in Table 2. The time of measurement range is between 8.00am-6.00pm. The frequency is 887.87MHz, while the transmitted Power is 44.4dBm.

Now, the behavior of RSS against varying distances where calls were initiated were recorded. The average values of RSS for each month is presented in the table 2. The results were plotted using MatLab R2015a to determine the effect of increasing transmitter –receiver separation on received signal strength and path loss.

Table 2: Mean Received Signal Strength between September 2019-June 2020

Dist. (m)	Sept'19 (dBm)	Oct'19 (dBm)	Nov'19 (dBm)	Dec'19 (dBm)	Jan'20 (dBm)	Feb'20 (dBm)	Mar'20 (dBm)	Apr'20 (dBm)	May'20 (dBm)	Jun'20 (dBm)	Ave.
100	-57.70	-57.81	-58.37	-58.10	-56.93	-59.44	-57.58	-57.95	-58.31	-59.94	-58.21
200	-62.16	-62.39	-63.75	-63.68	-60.85	-64.17	-62.54	-62.88	-65.03	-66.26	-63.37
300	-66.92	-67.55	-68.97	-68.40	-65.39	-68.83	-67.51	-68.55	-69.41	-72.15	-68.37
400	-72.74	-73.30	-74.41	-74.12	-71.73	-74.75	-73.25	-73.80	-75.30	-76.72	-74.01
500	-77.56	-77.92	-78.05	-77.91	-76.92	-77.42	-77.78	-78.19	-78.03	-81.68	-78.15
600	-82.68	-82.75	-82.81	-82.83	-81.76	-82.65	-83.09	-83.45	-82.91	-85.03	-83.00
700	-87.98	-88.22	-88.62	-88.83	-87.18	-89.86	-88.23	-88.68	-88.17	-90.94	-88.67

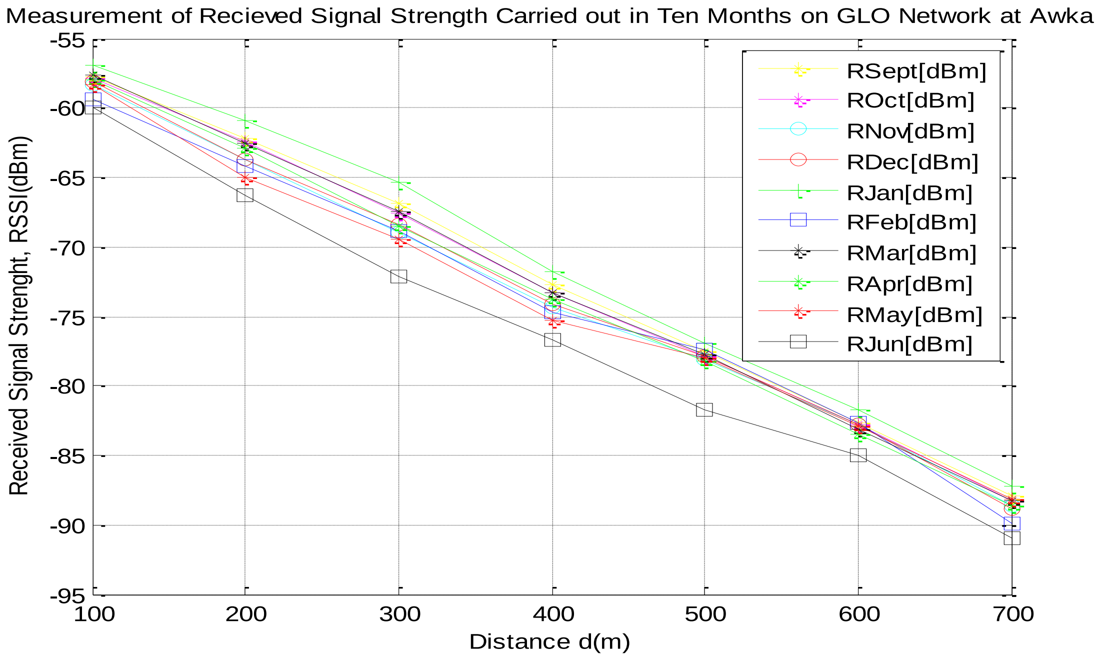
Measurement of Recieved Signal Strength Carried out in Ten Months on GLO Network at Awka

Figure 3: Plot of Ten Months Average RSSI Vs Distance in Awka Propagation environment

The Path Loss Experienced in the Measured Path

Table 3 showcased the signal losses for different months. It was determined using:

$$Pl = P_t - P_r \qquad (1)$$

Where:
Pl = Path loss
Pt = Transmitted power
Pr = Received power

Table 3: Average Measured Propagation Path loss in Awka Radio Environment

Dist. (m)	Sept'19 (dB)	Oct'19 (dB)	Nov'19 (dB)	Dec'19 (dB)	Jan'20 (dB)	Feb'20 (dB)	Mar'20 (dB)	Apr'20 (dB)	May'20 (dB)	Jun'20 (dBm)	Ave. (dB)
100	102.10	102.21	102.77	102.50	101.33	103.84	101.98	102.35	102.71	104.34	102.61
200	106.56	106.79	108.15	108.08	105.25	108.57	106.94	107.28	109.43	110.66	107.77
300	111.32	111.95	113.37	112.80	110.33	113.23	111.91	112.95	113.81	116.55	112.82
400	117.14	117.70	118.81	118.52	116.13	119.15	117.65	118.20	119.70	121.02	118.40
500	121.96	122.32	122.45	122.31	121.31	121.82	122.18	122.59	122.43	126.08	122.55
600	127.08	127.15	127.21	127.23	126.16	127.05	127.49	127.85	127.31	129.43	127.40
700	132.38	132.62	133.02	133.23	131.58	134.26	132.63	133.08	132.57	135.34	133.07

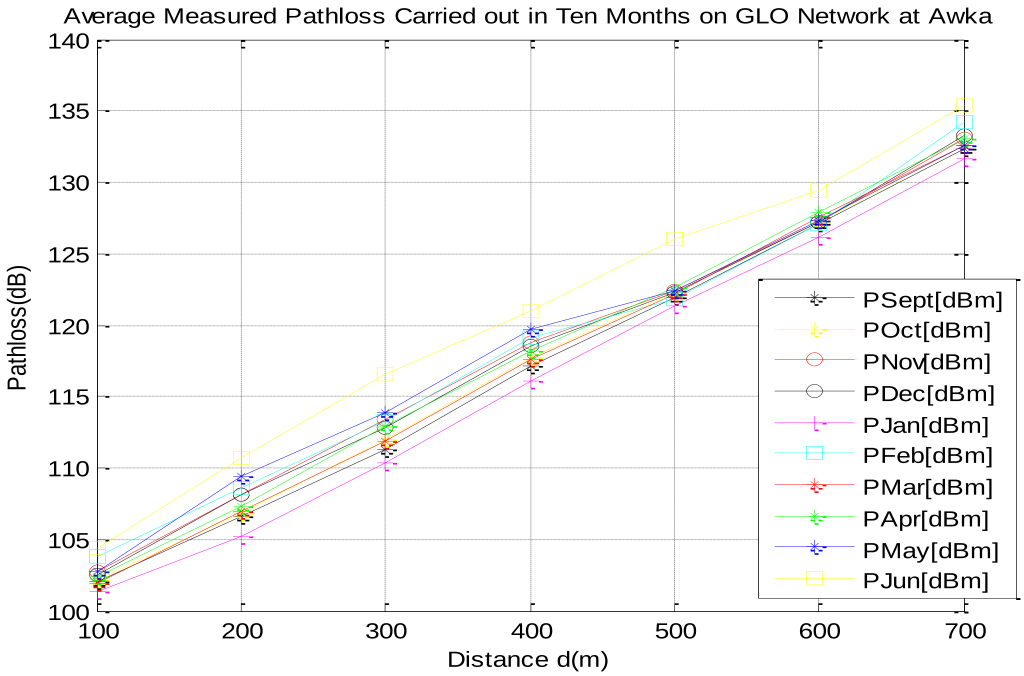

Figure 4: Plot of Average Measured Path loss vs Distance in Awka Radio

From Figs.3 and 4, it is obvious that the signal strength falls and path loss increases as transmitter-receiver distance increases. This implies that users farther from the base station experience severe signal attenuation.

Determination of Testbed Path loss Exponent

In a radio propagation environment depicted in Fig.1, the mean path loss $P_L(d_i)$ [dB] at a transmitter receiver separation d_i is given as (Okumbor and Okonkwo, 2014):

$$\hat{P}_L(d_i)[dB] = \hat{P}_L(d_0)[dB] + 10nlog_{10}(\frac{d_i}{d_0}) \qquad (2)$$

Where *n* is the path loss exponent, which indicates the rate at which the path loss increases with distance. d_0 is the close-in reference distance which is determined from measurement closest to the transmitter, and *di* is the T-R separation distance and $P_L(d_0)$ represents Path loss at a known reference distance. The bars in 2 denote the ensemble average of all possible path loss values for a given value of d*i*.

However, it is accepted on the basis of empirical evidence that it is reasonable to model the path loss $P_L(d_i)$ at any value of *d* at a particular location as a random and log-normally distributed random variable with a distance-dependent mean value (Robert, 2006). That is:

$$PL(di)\ [dB] = PL(d_0)\ [dB] + 10n\ log10(\frac{d_i}{d_0}) + S \qquad (3)$$

Where *S*, the shadowing factor is a Gaussian random variable (with values in dB) and with standard deviation σ [dB]. The path loss exponent, *n*, is an empirical constant which depends on propagation environment. To determine the path loss exponent *n* of the test bed area/environment, (2) can be used to manually compute it as:

$$n = \frac{\{\hat{P}_L(d_i) - \hat{P}_L(d_0)\}}{10log_{10}\left(\frac{d_i}{d_0}\right)} \tag{4}$$

But, using linear regression, the value of *n* which truly characterizes the propagation environment can be determined. In the linear regression analysis, the difference between the measured and the predicted path loss values is usually minimized in mean-square sense. The sum of the squared errors is given (Okorogu et al, 2013) as:

$$e(n) = \sum_{i=1}^{k}\{P_L\,(d_i) - \hat{P}_L(d_i)\}^2 \tag{5}$$

$P_L(d_i)$ is the measured path loss at distance d_i while $\hat{P}_L(d_i)$ is estimated path loss obtained using (2)

Substituting (2) in (5) gives

$$e(n)=\sum_{i=1}^{k}\left[P_L(d_i) - \hat{P}_L(d_0) - 10nlog_{10}\left(\frac{d_i}{d_0}\right)\right]^2 \tag{6}$$

Differentiating (6) with respect to *n*,

$$\frac{\partial R^2(n)}{\partial n} = -20log_{10}(d)\sum_{i=1}^{M}\left[P_L(d_i) - \hat{P}_L(d_0) - 10nlog_{10}\left(\frac{d_i}{d_0}\right)\right] \tag{7}$$

Equating $\frac{\partial R^2(n)}{\partial n}$ to zero,

$$0 = -20log_{10}(d)\sum_{i=1}^{M}\left[P_L(d_i) - \hat{P}_L(d_0) - 10nlog_{10}\left(\frac{d_i}{d_0}\right)\right]$$

Dividing both sides by $-20nlog_{10}\left(\frac{d_i}{d_0}\right)$, gives

$$\sum_{i=1}^{M}\left[P_L(d_i) - \hat{P}_L(d_0)\right] - 10nlog_{10}\left(\frac{d_i}{d_0}\right) = 0$$

$$\sum_{i=1}^{M}\left[P_L(d_i) - \hat{P}_L(d_0)\right] \text{-} \sum_{i=1}^{M}\left[10nlog_{10}\left(\frac{d_i}{d_0}\right)\right] = 0$$

$$\sum_{i=1}^{M}\left[P_L(d_i) - \hat{P}_L(d_0)\right] = \sum_{i=1}^{M}\left[10nlog_{10}\left(\frac{d_i}{d_0}\right)\right]$$

Therefore, $n = \frac{\sum_{i=1}^{M}[P_L(d_i) - \hat{P}_L(d_0)]}{\sum_{i=1}^{M}\left[10log_{10}\left(\frac{d_i}{d_0}\right)\right]}$ (8)

(8) depicts the exact path loss exponent which the proposed model used to characterize the radio propagation environment under study.

Thus for the month of September 2019, n is determined by substituting the values in Table 3 into (8) as follows:

From the Table 3, the reference path loss P_L(do) for the months is Cell 1, at a distance of 100m, for the month of September is 102.10 dB.

$$n = \frac{\sum\{102.10,\ 106.56,\ 111{,}32,\ 117.14,\ 121.96,\ 127.08,\ 132.38\} - 102.10}{\sum 10log_{10}\{(100,\ 200,\ 300,\ 400,\ 500,\ 600,\ 700) \div 100\}}$$

$$n = \frac{\sum 0,\ 4.46,\ 9.22,\ 15.04,\ 19.86,\ 24.98,\ 30.28}{\sum 10log_{10}(1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7)}$$

$$n = \frac{0+4.46+9.22+15.04+19.86+24.98+30.28}{0+3.01+4.77+6.02+6.99+7.78+8.45}$$

$$n = \frac{103.84}{37.02}$$

$$n = 2.80$$

Subsequent values of path loss exponent for October 2019 to June 2020, was evaluated using the same procedure and presented in Table 4 below.

Table 4: Path loss exponent n from September 2019 to June 2020

Months	Exponent(dB)
September	2.80
October	2.84
November	2.87
December	2.89
January	2.76
February	2.73
March	2.89
April	2.91
May	2.94
June	3.06
Average Exponent n	2.87

Having derived the parameter of the propagation loss exponent n, therefore the standard deviation σ (dB) of random shadowing effect is computed using the relationship below:

$$\sigma(dB) = \sqrt{\sum_{i=1}^{k} [P_L(di) - \hat{P}_L(di)]^2 / K} \tag{9}$$

Where

$P_L(di)$ is the measured path loss at any distance di and $\hat{P}_L(di)$ is the predicted path loss using (2). K is the number of measurement points.

At a reference distance of 100m, the value of average path loss is 102.61dB

To get the values of predicted path loss at all measurement points:

Recall: $\hat{P}_L(d_i)[dB] = \hat{P}_L(d_0)[dB] + 10nlog_{10}(\frac{d_i}{d_0})$

At 200m, $\hat{P}_L(d_i)[dB] = 102.61 + 10nlog\frac{200}{100}$

Recall: $n = 2.87$

Therefore, substituting the value of n gives $\hat{P}_L(d_i)[dB]$=111.25dB.

Subsequent values of predicted path loss for distances between 300m to 700m were evaluated using the same procedure and presented in Table 5 below:

Table 5: Mean Square Error

Distance(m)	$P_L(di)(dB)$	$\hat{P}_L(di)(dB)$	$P_L(di) - \hat{P}_L(di)$	$[P_L(di) - \hat{P}_L(di)]^2$
100	102.61	102.61	0	0
200	107.77	111.25	-3.48	12.11
300	112.82	116.30	-3.48	12.11
400	118.40	119.89	-1.49	2.22
500	122.55	122.67	-0.12	0.01
600	127.40	124.94	2.46	6.05
700	133.07	126.86	6.21	38.56
				Total =71.06

Evaluating the value of the mean square error from the Table 5 gives:

$$\sum_{i=1}^{k} [P_L(di) - \hat{P}_L(di)]^2 /_{K} = 71.06/_{7} = 10.15$$

$$\sigma(dB) = \sqrt{\sum_{i=1}^{k} [P_L(di) - \hat{P}_L(di)]^2 /_{K}} = \sqrt{1\ 0.15} = 3.19$$

Substituting the above calculated propagation path loss exponent n and the standard deviation into the log-normal shadowing model in (3) gives the model that describes the design parameters of the mobile link in Awka propagation environment as:

$$PL\ [dB] = 102.61 + 10(2.87)\ logd + 3.91$$

Therefore the empirical path loss model for Awka is:

$$PL[dB] = 105.80 + 28.7\ logd \qquad (10)$$

This is the propagation path loss model developed empirically for the experiment, where d is a variable depending on the distance travelled in the environment under study.

To validate the developed path loss model for the experimental testbed, the model is compared with the statistically predicted result of path loss and that of other existing (traditional) models, with the measured results. The path loss is therefore, calculated under the same set of transmission conditions (see Table 6), using same simulation parameters from the experimental testbed as shown in Table 1.

Table 6: Computed Path loss for various Models.

S/N	Distance (m)	Measured Path Loss (dB)	Developed (dB)	Free Space (dB)	COST 231 (dB)	Hata (dB)
1	100	102.61	113.95	67.54	81.07	64.21
2	200	107.77	121.90	73.56	90.89	74.03
3	300	112.82	126.55	77.09	96.63	79.78
4	400	118.40	129.84	79.58	100.71	83.85
5	500	122.55	132.40	81.52	103.87	87.01
6	600	127.40	134.49	83.11	106.64	89.50
7	700	133.07	136.26	84.45	108.64	91.78

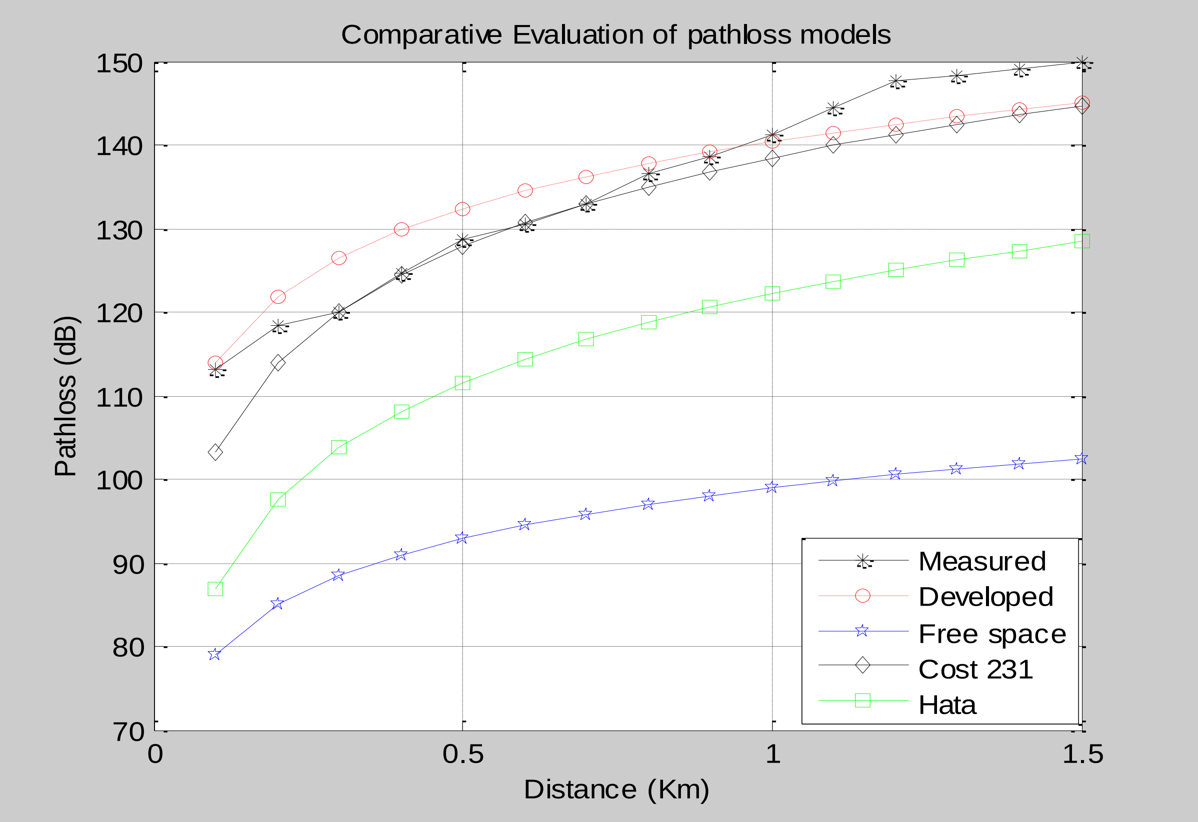

Figure 5: Comparison of Different Path loss Models.

Figure 5 showed that the Comparison between the model and that predicted by Hata and other traditional models has shown some variations. These variations showed the effects of some environmental factors (Tall trees, mountain, topology etc) on the transmitted signal and equally the variations show that the Hata 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.

Conclusion

This work has presented an empirical path loss propagation model for cellular wireless systems in Awka urban environment. This was aimed to serve as a preliminary work on how to predict the mean signal strength using common available equipment. The RSS measurements enabled this work to determine the Path Loss and characterize Awka Urban environment. The study revealed that signal strength decreases with increasing transmitter-receiver separation. From the measured received power in this environment, the path loss exponent was manually predicted and the results obtained shows that the month of February had better signal reception while June had more signal losses. The result is a general statistical framework for describing path loss that can be upgraded with further measurements.

We recommend that the knowledge and estimates of path loss exponent will enable the network engineer determine the signal strength, model and examine the percentage of how the signal received were affected due to attenuation, thus this will assist the network designer in carrying out effective planning for improve services.

References

Akinwole, B. & Biebuma, J. (2013). Comparative Analysis of Empirical Path Loss Model for Cellular Transmission in Rivers State. *American Journal of Engineering Research (AJER)*, 28,.24 – 31. Available at: www.ajer.org

Alumona, T. & Nnamani, K. (2015). Path Loss Prediction of Wireless Mobile Communication for Urban Areas of Imo State, South-East Region of Nigeria at 910 MHz. *Journal of Academia and Industrial Research (JAIR)*, volume 3 (9). Available at: www.jairjp.com

Gallager, R. (2006). Wireless Digital Communication "Course materials for 6.450 Principles of digital communications I", Fall 2006. MIT OpenCourseWare (http://ocw.mit.edu/), Massachusetts Institute of Technology. Downloaded on [17/06/2016] pp.305-365

Okorogu, V., Onyishi D., Nwalozie G. & Utebor, N. (2013). Empirical Characterization of Propagation Path Loss and Performance Evaluation for Co-Site Urban Environment. *International Journal of Computer Applications,* 70 (10)

Okumbor, N. & Okonkwo, O. (2014). Characterization of Signal Attenuation using Path loss Exponent in South-South Nigeria. *International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)*, 3(3). Available at: www.ijettcs.org

Segun, I. & Olasunkanmi, F. (2014). Empirical Path Loss Models for GSM Network Deployment in Makurdi, Nigeria. *International Refereed Journal of Engineering and Science (IRJES)*, 3(6), 85 – 94. Available at: www.irjes.com.

Yihuai, Y., Dongya, S., Yonggang, X., & Xiangde, L. (2012). MATLAB Simulink of COST 231 – WI Model. *International Journal of Wireless and Microwave Technologies*, 3, 1 – 8.