Path loss Prediction for TVWS Network for Urban Region of Onitsha, South-East Nigeria

Kebiru Abu[1], Jerome Dada K.[2], Abolaji Stephen O.[3], Usman Abdul-Rasheed O.[4]
[1,2,3,4]*Department of Electronic and Computer Engineering, Nnamdi Azikiwe University Awka, Nigeria*

Abstract: **Cognitive Radio has now become a pragmatic option for the solution of the spectrum scarcity problem in wireless communication. TV channels (primary user) can be protected from secondary user interference by accurate prediction of TV White Spaces (TVWS) by using suitable propagation modeling. To establish any mobile communication system, the fundamental task is to predict the coverage of the proposed system in wide-range, and the accurate determination of the propagation path loss leads to development of efficient design and operation of quality networks. Many such different approaches have been developed, over time, to predict network coverage using what are identified as propagation models. This paper presents a measurement-based path loss model, from experimental data collected in Onitsha urban, South-East Nigeria. Received Signal Strength (RSS) measurements were gathered in Onitsha from Nigerian television Authority (NTA) operating at 583.25MHz. The result of the measurements were used to characterize and develop path loss model for NTA Onitsha Environment and the result depicts that the path loss for the measurement environment increases by 3.10dB per decade.**

Keywords: **TVWS, Propagation models, Spectrum, path loss, South-East Nigeria**

I. INTRODUCTION

In Wireless communication, the propagation path loss and interference level by white space devices (WSDs) to spectrum incumbents (primary users) operations in the television white spaces (TVWSs) could hinder the proliferation of future wireless networks in the TV band, which has greater transmission range and better penetration property as compared to the higher frequency bands [1]. The accurate purpose of path loss and mitigation of interference leads to development of competent design and operation of quality networks. Equipment vendors specify system parameters for deployed Systems [2], and currently, extensive research is going on in various Research centers and institutions to determine or validate the values of Propagation Path Loss in their own environment. Propagation models have been developed as tools in estimating radio wave propagations as accurately as possible. Models have therefore been developed for different environments to predict the path loss between the transmitter and receiver.

Radio propagation is wholly site specific and can vary extensively depending on terrain, frequency of operation, velocity of mobile terminal, antenna heights etc. accurate characterization of radio channel through key parameters and a mathematical model is imperative for predicting signal coverage, achievable data rates, specific performance attributes of alternative signaling and reception schemes [3].

Path loss is the gradual diminution in signal strength (power), of an electromagnetic wave as it propagates through space. It is a chief component in the analysis and design of link budget of a communication system [4]. It depends on frequency, antenna height, receive terminal location relative to obstacles and reflectors, and link distance, amongst many other factors.

When setting up wireless communication systems and scheming wireless networks, the accuracy of the prediction of propagation characteristics of each environment should be taken into consideration. One of the most important parameters, which can be provided by propagation prediction, is large-scale path loss, which affects directly the coverage of a base station residency and its performance. However, by means of field measurements to obtain these parameters without depending on propagation models is time-consuming and expensive [5].

This paper was visualized out of the aspiration to develop an accurate path loss prediction model which could be deployed by TVWS network designers for competent TVWS network planning and verification. This research focused on large scale fading and it is aimed at improving the superiority of wireless services in Onitsha urban environment in the South-Eastern part of Nigeria by carrying out site specific measurements and developing a satisfactory Path loss model for the region.

This paper is structured as follows: Section II presents an overview of some existing propagation models widely in use; Section III describes the method of data collection employed. Data presentation 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 precision for its use within the South-Eastern region of Nigeria is depicted.

II. LITERATURE REVIEW

2.1 Existing Path Loss Models

In wireless communications, when a signal proliferates from transmitter to the receiver, the signal strength is affected by distance, terrain, obstructions (such as trees, buildings etc.), and atmospheric conditions. In this paper, three different propagation models are used to estimate the TVWS: Hata model, Egli model, and Friis Free Space Path Loss (FSPL) model. The next few paragraphs are devoted to giving and explaining the formulae for these models.

2.1.1 Hata for Urban Areas

This is an enhancement of the Okumura model and sometimes called Okumura-Hata model. This model incorporates the effects of diffraction, reflection and scattering caused by city structures [6], [13]. It is suited for both point-to-point and point to multipoint transmissions. Its expression for urban areas is given in Equation 1:

$$PL_{Hata}\,(dB) = 69.55 + 26.16 log_{10} f_{MHz} - 13.82 log_{10} h_t - a(h_r) + (44.9 - 6.55 log_{10} h_t) log_{10} d_{km} \quad (1)$$

Where h_t and h_r are base station and mobile antenna heights in meters respectively,

d_{km} is the link distance

f_{MHz} is the frequency of transmission

The term $a(h_r)$ is an antenna height-gain correction factor that depends upon the environment [7], [13].

It is equal to zero for $h_r = 0$ otherwise it is equal to $3.2(log_{10} 11.75 h_r)^2 - 4.97$ with $f_{MHz} > 300$, which was the case in our situation.

2.1.2 Egli Model

This is a model that assumes smoothly rolling terrain between transmitter and receiver, and does not require the terrain elevation data between them. It is normally used for point-to-point communication. It is valid in scenarios where there is line-of-sight (LOS) transmission between one fixed antenna and one mobile antenna, and where transmission has to go over an irregular terrain. The model is not pertinent to rugged terrain areas and where there is significant hindrance such as vegetation at the central point of the link [8], [13]. Its equations for the propagation loss are given as follows:

$$PL_{Egli} = \begin{cases} 20 log_{10} f_{MHz} + P_0 + 76.3, & h_r < 10 \\ 20 log_{10} f_{MHz} + P_0 + 83.9, & h_r > 10 \end{cases} \quad (2)$$

$$P_0 = 40 log_{10} d_{km} - 20 log_{10} h_t - 10 log_{10} h_r \quad (3)$$

Where f_{MHz} is the frequency of transmission, d_{km} is the link distance, h_t is the base station antenna height in *meters* and h_r is the mobile station antenna height in *meters*.

2.1.3 Free Space Model

Free space model represent the ideal case scenario which is Omni-directional radiation from the radiating source and propagation to an inestimable distance with no degradation. Spreading the power over greater areas causes the attenuation. It is the standard 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 realistic illustration of the transmitter and receiver characteristics [5]. Assuming we have a transmitter with power Pt coupled to an antenna which radiates equally in all directions. At a distance d from the transmitter, the radiated power is dispersed over an area of $4\pi d^2$, so that the power flux density is given by:

$$P_d = \frac{P_t}{4\pi d^2} \quad (4)$$

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 is A_e, the wavelength of the received signal λ, and the power density P_d can be determined [9]. The effective area A_e of the isotopic receiving antenna is given as follows:

$$A_e = \frac{\lambda^2}{4\pi} \quad (5)$$

While power received is

$$P_r = P_d \times A_r = \frac{P_t \times \lambda^2}{(4\pi d)} \quad (6)$$

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

$$L_p = P_t - P_r \quad (7)$$

Substituting (6) in (7) it yields equation (9)

$$L_p(dB) = 20 Log_{10}(4\pi) + 20 Log(d) - 20 Log Log_{10}(\lambda) \quad (8)$$

Then substituting (λ (in km) = 0.3 / f (in MHz)) and rationalizing the equation produces the generic free space path loss formula, which is given as:

$$P_L(dB) = 32.44 + 20 Log F_{MHz} + 20 Log d_i \quad (9)$$

Where *f* = frequency in MHz and *d* = distance in km. Equation 9 is the Harald T. Friss free space path loss.

III. METHODOLOGY

3.1 Measurement Environment and Data Collection

The field measurements were carried out in the urban city of Onitsha. Onitsha is a city situated in Eastern Nigeria in Anambra State. It is a metropolitan city recognized for its river port, and as an Economic hub for trade, industry, and education. The measurements were carried out for a period of three months the measurements span from April 2017 to June 2017 using an existing TV station network (NTA Nigeria) operating at 583.25MHz frequency band. Propagation measurements were carried out using a set of drive test equipment which includes: Spectrum Analyzer (RF explorer 3G combo model), a laptop equipped with touchstone RF spectrum Analyzer software, Mini USB cable, Global positioning system (GPS) Receiver set and a Compass. Readings were taken at intervals of 100m from the base transceiver station at a close proximity constant mobile station height of 1.5meters. Fig. 1 depicts the Google map location of the reference measurement site. Table 1 shows the measurement parameters.

Table 1: Measurement Parameters

Frequency	583.25MHz
Base station Antenna height	114.5m
Transmitted power	35.44dB
Transmitter rating	3.5KW
Channel	35 UHF
Spectrum analyzer antenna height	1.5 meters
Noise threshold	-110dBm
Coordinate	6.172772, 6.809224

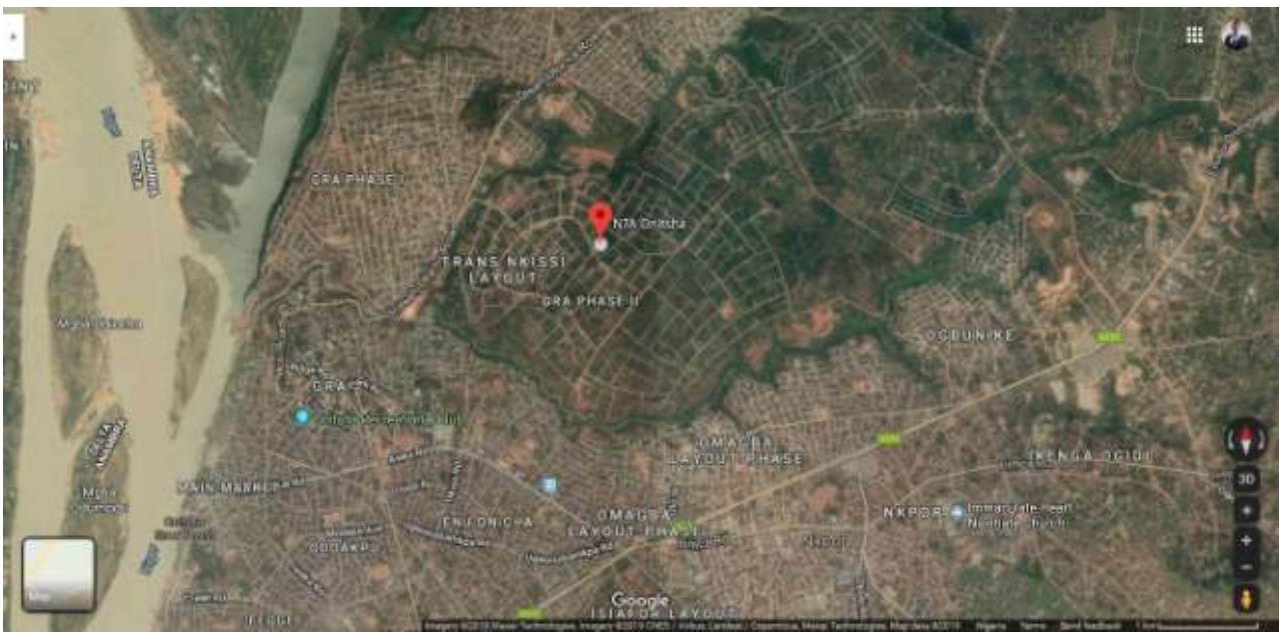

Figure 1: Google Map of Onitsha, Anambra State. (Courtesy: Google Earth)

3.2 NBC Licensed Stations in Anambra State

The Table 2 depicts the licensed TV station signal, their channels and frequency of operation that can be received within the study area.

Table 2: TV Stations Parameters in Anambra State

S/No	Stations	Channel	Frequency
1.	NTA Onitsha	35	583.25MHz
2.	Anambra Broadcasting Service (ASBC)	27	519.25MHz
3.	Silverbird Television	30	543.25MHz
4.	MBI Anambra	41	631.10MHz

IV. DATA PRESENTATION AND ANALYSIS

The measured received signal strength (in dBm) for the site visited and the mean is shown in the Table 3

Due to variations in the measurements of the received signal strength, the mean values are used for the model development.

Table 3: Measured Received Signal Strength Indicator (RSSI) During Experimentation

Distance (m)	RSSI(dBm) (April 2017)	RSSI(dBm) (May 2017)	RSSI(dBm) (June 2017)	RSSI(dBm) Average
0.1	-47	-50	-49	-48.67
0.2	-50	-55	-53	-52.67
0.3	-51	-56	-58	-55.00
0.4	-57	-59	-55	-57.00
0.5	-58	-60	-62	-60.00
0.6	-62	-64	-67	-64.30
0.7	-64	-68	-69	-67.00
0.8	-73	-78	-75	-75.33
0.9	-77	-76	-79	-88.33
1.0	-80	-86	-83	-83.00
1.1	-86	-89	-87	-87.33
1.2	-88	-87	-90	-88.33
1.3	-91	-85	-90	-88.67
1.4	-89	-94	-91	-91.33
1.5	-90	-92	-87	-89.67
1.6	-90	-93	-92	-91.67
1.7	-97	-94	-95	-95.33
1.8	-96	-95	-97	-96.00
1.9	-96	-96	-97	-96.33
2.0	-97	-98	-99	-98.00

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:

$$e(n) = \sum_{i=1}^{m}[P_L(d_i) - P_L(d_o)]^2 \qquad (10)$$

The average large-scale path loss for an arbitrary transmitter to receiver separation is expressed as a function of distance given by [11]:

$$P_L(dB) = P_L(d_0) + 10nLog(\frac{d}{d_0}) \qquad (11)$$

It was shown by [12] 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:

$$P_L(dB) = P_L(d_0) + 10nLog\left(\frac{d}{d_0}\right) + \varsigma \qquad (12)$$

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 is known as the location variability is given as [12]:

$$\sigma = \sqrt{\sum \frac{[P_L(d_i) - P_L(d_0)]^2}{N}} \qquad (13)$$

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 (11) and N is the number of measured data points.

Substitute (11) into (10) gives:

$$e(n) = \sum_{i=1}^{m}[P_L(d_i) - P_L(d_0) - 10nLog(\frac{d}{d_0})\ ]^2 \qquad (14)$$

Differentiating (14) with respect to n and equating $\frac{\delta e(n)}{\delta n}$ to zero gives:

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

Solving for n gives:

$$n = \frac{\sum_{i=1}^{m}[P_L(d_i) - [P_L(d_o)]}{\sum_{i=1}^{m}[10\log_{10}(\frac{d_i}{d_o})]} \quad (15)$$

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 NTA* Onitsha

d_i= [0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0]

P_t = 35.44dB

P_r= [-48.7, -52.7, -55.0, -57.0, -60, -64.3, -67.0, -75.3, -77.3, -83.0, -87.3, -88.3, -88.7, -91.3, -89.7, -91.7, -95.3, -96.0, -96.3, -98.0]

$P_L(d_i) = P_t - P_r = 35.44 -$[-48.7, -52.7, -55.0, -57.0, -60, -64.3, -67.0, -75.3, -77.3, -83.0, -87.3, -88.3, -88.7, -91.3, -89.7, -91.7, -95.3, -96.0, -96.3, -98.0]

$P_L(d_i) =$ [84.14, 88.14, 90.44, 92.44, 95.44, 99.74, 102.44, 150.36, 150.76, 160.76, 163.76, 160.06, 157.06, 160.76, 166.76, 160.06, 165.76, 168.36, 163.36, 157.76]

$P_L(d_i) - P_L(d_o)$ = [84.14, 88.14, 90.44, 92.44, 95.44, 99.74, 102.44, 150.36, 150.76, 160.76, 163.76, 160.06, 157.06, 160.76, 166.76, 160.06, 165.76, 168.36, 163.36, 157.76] – [84.14]

$P_L(d_i) - P_L(d_o)$ = [0, 4, 6.3, 8.3, 11.3, 15.6, 18.3, 26.6, 28.6, 34.3, 38.6, 39.6, 40.0, 42.6, 41.0, 43.0, 46.6, 47.3, 47.6, 49.3]

$$\sum[P_L(d_i) - P_L(d_o)] = 588.9$$

$$d_0 = 0.1km$$

$$\sum_{i=1}^{20}[10\log_{10}(\frac{d_i}{d_o})] = \sum[10\log_{10}[\frac{(0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0)}{0.1}]$$

$$\sum_{i=1}^{20}[10\log_{10}(\frac{d_i}{d_o})] = (0 + 3.01 + 4.77 + 6.02 + 6.99 + 7.78 + 8.45 + 9.03 + 9.54 + 10 + 10.4 + 10.79 + 11.13 + 11.46 + 11.76 + 12.04 + 12.30 + 12.55 + 12.78 + 13.01)$$

$$\sum_{i=1}^{6}[10\log_{10}(\frac{d_i}{d_o})] = 183.8$$

$$\eta = \frac{588.9}{183.8} = 3.20$$

Therefore the path loss exponent for NTA Onitsha is 3.20. Using MATLAB software, the Shadowing factor of base station, NTA Onitsha is 8dB and $PL\ (do)$ which is the path loss at close in reference distance otherwise known as reference path loss is 84.14dB.
Therefore the empirical Path loss for NTA is gotten from (12):

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

Substituting the values above into the equation gives:

$$P_L(dB) = 84.14 + 10(3.20)Log\left(\frac{d}{d_0}\right) + 8$$

The plot of the empirical path loss model for Onitsha urban model in Anambra State is plotted as represented in Fig. 2 using MATLAB.

$$P_L(dB) = 92.14 + 32Log\left(\frac{d}{d_0}\right)$$

The Empirical path loss model for Onitsha urban is then obtained as:

$$P_L(dB) = 92.14 + 32Log\left(\frac{d}{d_0}\right) \quad (16)$$

$$P_L(urban) = 92.14 + 32Log(D)dBm$$

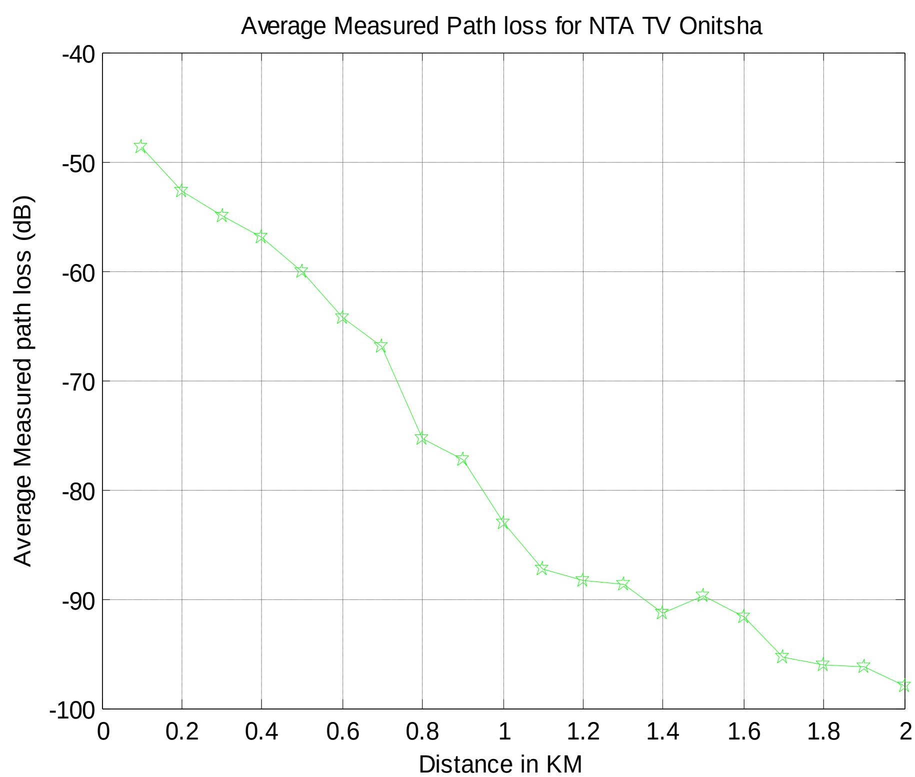

Figure 2: Plot of mean received signal strength for NTA TV Onitsha

4.1 Comparison of Measured Model with Existing Models

Using MATLAB, the values from the various path loss models are computed and tabulated in Table 4, for the Empirically developed model, Hata model and free space path loss model equation with parameters (*f=583.25MHz*, *hm* =1.5m, *hb* = 114.5m).

Table 4: Comparison of Measured Model with Existing Models

Distance	Empirical	Hata	Free Space	Egli
0.1	92.14	82.04	67.76	48.68
0.2	101.77	91.49	73.78	60.72
0.3	107.41	97.03	77.30	67.76
0.4	111.41	100.95	79.80	72.76
0.5	114.51	104.00	81.74	76.64
0.6	117.04	106.48	83.32	79.81
0.7	119.18	108.59	84.66	82.48
0.8	121.04	110.41	85.82	84.80
0.9	122.68	112.02	86.84	86.85
1.0	124.14	113.45	87.76	88.68
1.1	125.46	114.75	88.58	90.34
1.2	126.67	115.94	89.34	91.85
1.3	127.79	117.03	90.04	93.24
1.4	128.82	118.04	90.68	94.53
1.5	129.77	118.98	91.28	95.72
1.6	130.67	119.87	91.84	96.84
1.7	131.51	120.69	92.37	97.90
1.8	132.31	121.47	92.86	98.89
1.9	133.06	122.21	93.33	99.83
2.0	133.77	122.91	93.78	100.72

The plot in Fig. 3 Compares the Empirical Path loss model with other existing models that were considered in the course of this work

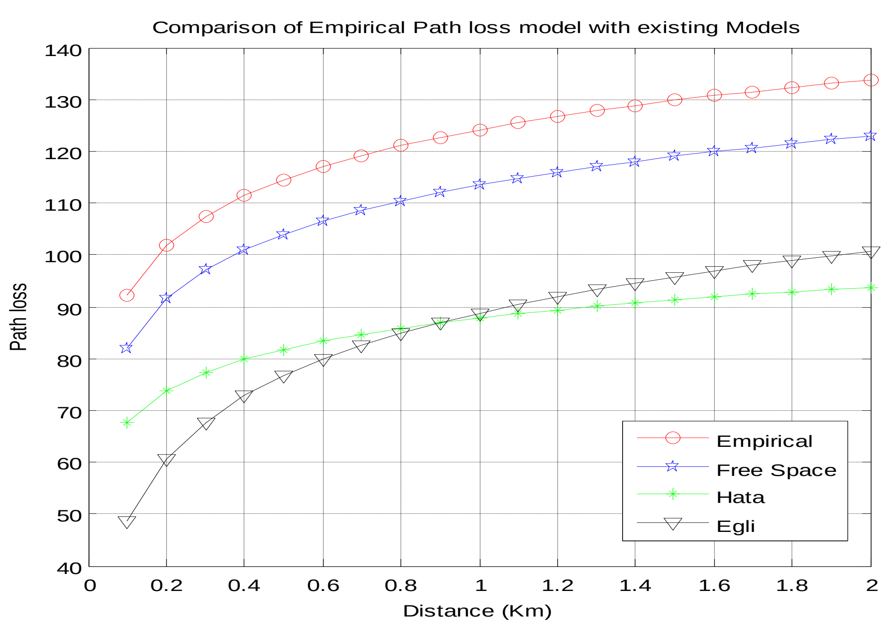

Figure 3: Plot of mean received signal strength for NTA TV Onitsha

V. CONCLUSION

This research work has been able to illustrate 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 was obtained as 3.20 while the standard deviation was computed as 8dB. An efficient and dependable path loss model for study area was eventually developed for the TVWS network and from calculation; it is shown that the efficient path loss model for Onitsha is:

$$P_L(urban) = 92.14 + 32Log(D)dBm$$

Comparisons between the model and that predicted by Hata and other traditional models have shown some variations. These variations show that the Hata model or any existing model cannot fit in successfully into an environment other than that for which it was developed. To make such models suitable for dissimilar 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.

REFERENCES

[1] Yuan Y, Bahl P, Chandra R, Chou P.A., Ferrell J.I., Moscibroda T., Narlanka S., and Wu Y., (2007). "KNOWS: Cognitive radio networks over white spaces." In *New Frontiers in Dynamic Spectrum Access Networks, 2007. DySPAN. 2nd IEEE International Symposium*, pp. 416-427.

[2] Ayyappan, K, et al, (2008). “Propagation Model for Highway in mobile communication system”, indio

[3] Okorogu V.N, Onyishi D.U, Nwalozie G.C, Utebor N.N (May, 2013). “Empirical Characterization of Propagation Path Loss and Performance Evaluation for Co-Site Urban Environment” *International Journal of Computer Applications (0975 – 8887) Volume 70– No.10.*

[4] Nwalozie Gerald .C, Ufoaroh S.U, Ezeagwu C.O, Ejiofor A.C (2014). “ Path loss prediction for GSM Mobile networks for urban Region of Aba, South-East Nigeria”. International Journal of Computer Science and Mobile Computing, Vol.3 Issue.2, February- 2014, pg. 267-281

[5] Electronic Communication Committee (ECC, 2003). The Analysis of the Coexistence of FWA cells in the 3.4-3.8 GHz Band. In the European Conference of Postal and Telecommunications Administration. Tech. Report. ECC Report 33.

[6] Oluwole, F. J., and Olajide, O. Y. (2013). “Radio frequency propagation mechanisms and empirical models for hilly areas.” *International. Journal of Elect. Comput. Eng. (3)*: pp. 372–376.

[7] Wang, H., Noh, G., Kim, D., Kim, S., and Hong, D. (2010). “Advanced sensing techniques of energy detection in cognitive radios.” *Communications and Networks, Journal of* 12, no. 1. pp. 19-29.

[8] Chebil J, Lawas A.K, and Islam M. D, (2013)."Comparison between measured and predicted path loss for mobile communication in Malaysia." *World Applied Sciences Journal* 21: pp. 123-128.

[9] Ubom, E.A., Idigo, V. E., Azubogu, A.C.O., Ohaneme, C.O., and Alumona, T. L. (June, 2015). “Path loss Characterization of Wireless Propagation for South -South Region of Nigeria”. *International Journal of Computer Theory and Engineering, Vol. 3, No. 3,* pp 360-364.

[10] Azubogu, A.C.O., Onoh G.N., Idigo V.E., Ohaneme C.O., (2011), “Empirical-Statistical Propagation Path loss Model for Suburban Environment of Nigeria at 800MHz Band”, *International Union of Papers and Journal of Science and Technology, Hyderabad, India, Vol. 7, No. 2,* pp 56-59.

[11] Smith, M. S. et al., (April, 2000). “A new methodology for deriving path loss models from cellular drive test data, *Proc. AP 2000,Conference, Davos,* Switzerland.

[12] Erceg, V. and Greenstein L J, Tjandra S Y, Parkoff S R, Gupta A, et al. (1999). “An Empirically Based Path Loss Model for Wireless Channels in Suburban Environments” *IEEE journal on selected areas in communications, vol. 17,* pp. 1205-1211.

[13] Hope M, Antoine B, Marco Z., Guy .L. Z (2015). “On the Impact of Propagation Models on TV White Space Measurements in Africa”. *International Conference on Emerging Trends in Networks and Computer Communications (ETNCC) pp. 148–154*. DOI: 10.1109/etncc.2015.7184825