CORPUS PUBLISHERS

Current Trends in Engineering Science (CTES)

ISSN: 2833-356X

Volume 3 Issue 1, 2023

Article Information

Received date : January 25, 2023

Published date: February 09, 2023

*Corresponding author

Yussuff Abayomi IO, Department of Electronic and Computer Engineering, Lagos State University, Nigeria

DOI: 10.54026/CTES/1021

Keywords

TV White Space; Path loss; Hata Okumura model; COST 231 model; Egli model; Plain Earth model

Distributed under Creative Commons CC-BY 4.0

Research Article

Empirical Pathloss Model Analysis of Television White Space in Lagos, Western Nigeria

Yussuff Abayomi IO*, Oreoluwa Oluwakemi E and Ayeni Michael O

Department of Electronic and Computer Engineering, Lagos State University, Nigeria

Abstract

To conduct feasible unlicensed communications in the television band, radio equipment must first identify transmission possibilities, or the proportion of the permitted spectrum for broadcasting services that is vacant at a given time in a particular location, which is referred to as Television White Space (TVWS). A drive test was conducted to determine the signal strength of three cell towers in three distinct areas of Lagos state (rural, suburban, and urban). The signal power parameters were measured in rural, urban, and suburban parts of Lagos in order to provide empirical values for the parameters that unlicensed radio devices can utilize to distinguish between vacant and occupied television channels in a real-world scenario. This research presents the results of field measurements in the UHF television band (470-860 MHz) conducted in Lagos. This work investigated and compared several propagation models (COST 231 model, Egli model, Okumura-Hata model, and Plain Earth model). The Standard Deviation Error (SDE), Root Mean Square Error (RMSE), and Mean Error (ME) analysis showed that the COST-231 Hata model is the optimal model for calculating path loss based on path loss exponents. This discovery led to the development of an improved model, the Oressuff TV model, which uses COST-231 Hata parameters to predict path loss in the 470–870 MHz spectrum for rural, urban, and suburban locations. From the result of Root Mean Square Error analysis, the proposed model predicted path loss in rural, urban, and suburban stations with low RMSE of 3.06dB, 3.08dB, and 1.19dB respectively. These figures indicate that the model optimization was successful, and that the Oressuff TV proposed model can estimate the path loss incurred by television signals with greater precision. Telecommunications firms may improve their service by utilizing the proposed model.

Introduction

In today's world, propagation models are widely used for coverage planning and optimization, signal prediction, and interference analysis. In cellular environments, fixed wireless access networks, and television broadcast systems, path loss models are used. The channel's propagation parameters determine the performance and peaceful coexistence of primary and secondary users (white space devices). The FCC's rule permits the use of received signal prediction models to assist with coverage optimization and to estimate secondary users' safe service locations. There are two types of path-loss models in use today: theoretical and empirical. Theoretical methods estimate transmission losses by analyzing the topographical path geometry between the transmitter and receiver, as well as the troposphere's refractivity [1]. Empirical models calculate net path loss by combining free-space loss with environmental-dependent loss variables. As these models require measurements, they are thought to be more accurate in terms of compatibility with the environment. Pathloss models can be used to develop transmission strategy parameters such as transmit power and frequency. Due to the various topographical conditions, these models may have different qualities depending on where they are used [2].

The vast majority of modern TVWS studies use propagation curves to estimate TV coverage, such as the Egli, ITU Radio Communications Sector (ITU-R) P.1546-2, Hata, and Okumura models. These models' applicability may differ depending on the environment and terrain profile because they are based on measurements conducted outside of Nigeria. Furthermore, when used outside of their intended context, these models exhibit significant prediction errors. As a result of these failures, secondary operations may be jeopardized. This raises the question of whether current prediction models should be implemented or updated, or if a new model that minimizes errors while protecting primary users from interference should be developed. The error may have a significant impact on white space recovery and the implementation of secondary networks. For instance, a wireless mesh network established with a defined path loss model may significantly over- or under-provision due to minor changes in model parameters, according to the author in [3]. This is a significant problem since over-provisioning would increase costs during the rollout process, while under-provisioning would negatively impact network QoS.

The focus of this work is a systematic analysis of TV white space availability in Lagos, Nigeria which has not been done to the best of my knowledge.

Methodology

The field measurements were taken in three different locations within Lagos state. These locations are Ajah, Ikorodu and Epe for the realistic evaluation of Urban, Suburban and Rural areas.

The coordinates of these area of study is shown on Table 1. Figure 1 describes the satellite imagery of the measurement route of the urban location while figures 2 & 3 show the measurement route of the suburban and rural location respectively.

Copyright © Abayomi YIO

Table 1: Coordinates of Area of Study.

Region	Location	Coordinates
Urban	Ajah	6.4646° N, 3.5725° E
Suburban	Ikorodu	6.6194° N, 3.5105° E
Rural	Epe	6.6055° N, 3.9470° E

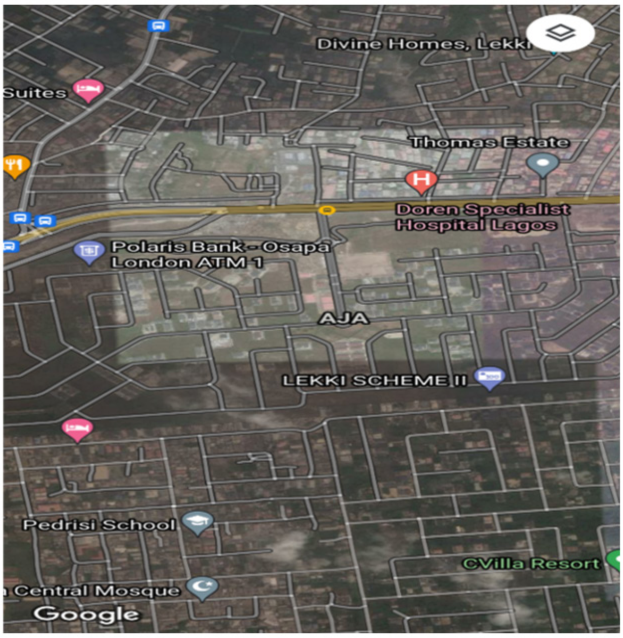

Figure 1: Measurement route in Ajah (Urban) (Courtesy Google Map).

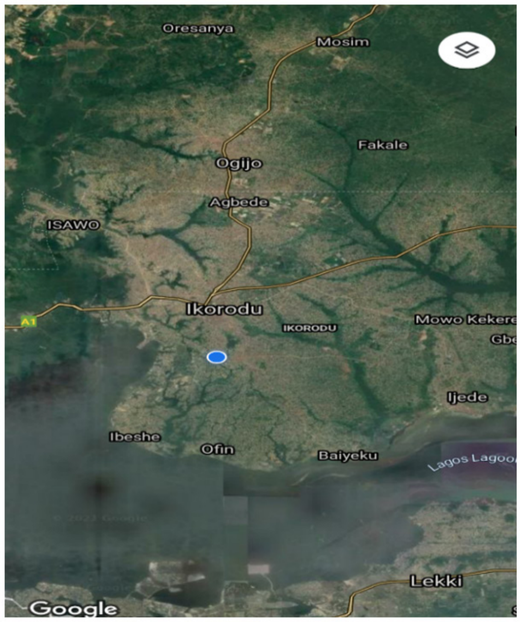

Figure 2: Measurement route in Ikorodu (Suburban) (Courtesy Google Map).

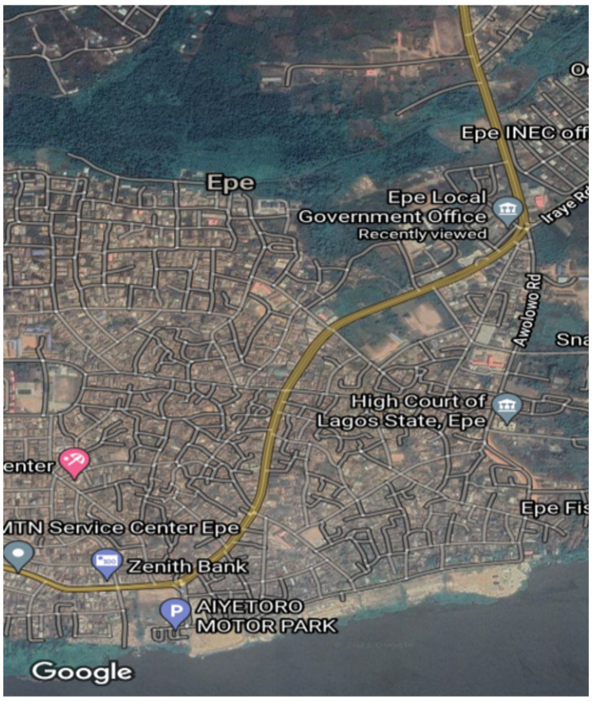

Figure 3: Measurement route in Epe (Rural) (Courtesy Google Map).

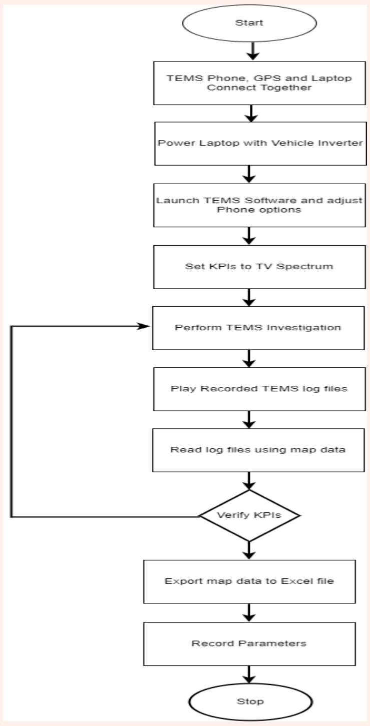

Figure 4: Drive test flow chart.

Citation: Yussuff A.I.O., Oreoluwa O.E., Ayeni M.O. (2023) Empirical Pathloss Model Analysis of Television White Space in Lagos, Western Nigeria. Current Trends in Eng Sci. 3: 1021

A drive test was carried out in these regions in Lagos state in which Test Mobile System (TEMS) tools were used. The experimental data was obtained during the day in Lagos, Nigeria, in an urban, suburban and rural setting. The measurement lasted about four weeks and was carried out in virtually ideal weather conditions that had no effect on the results. During the drive test for the measuring campaign, the base transmitter station was fixed. The base station antenna was mounted to the mast in the test scenario. The experiment was carried out on a TV band frequency of 615.25MHz. The information gathered included the location's name, latitude and longitude, measurements of the signal intensity, DTT operators, operational frequencies/channels, antenna height, and transmission power. For later use, the dBV/m signal intensity values were converted to dBm. The power of transmission was set at 35.44 decibels. Table 2 describes these measurement parameters while figure 4 shows the flow chart of the process.

Table 2: Measurement Parameters.

Frequency	615.25MHz
Base Station Antenna Height	114.5m
Transmitted Power	35.44dB
Transmitting Rating	3.5KW
Channels TV	UHF 39
Mobile Antenna Height	1.5m
Noise Threshold	-110dBm

The received signal intensity and path loss were measured, and MATLAB was used to analyse the received signal strength into theoretical and empirical path loss. Graphs of Egli model, Plain Earth model, Hata-Okumura model and COST 231 model against mobile station – base station distance were plotted, and comparison with measured path loss were also plotted using MATLAB R2020a.

Plane earth propagation model

Path loss equation for plain earth propagation model is given as

$$\beta_p = 40Log_{10}(d) - 20Log_{10}(h_1) - 20Log_{10}(h_2) \qquad (1)$$

Given that d is the path length measured in meters while h_1 and h_2 are respectively the heights of the antenna for the base station and mobile [4].

Empirical path loss model

The Empirical Path loss model is based on a mathematical formalism that is based on extensive field measurements and algebraic expressions [5].

Hata – Okumura Model

Hata equations, on the other hand, are divided into three types [6]:

$$\beta(dB) = \alpha + \delta\log_{10}(d) \qquad (2)$$

$$\beta(dB) = \alpha + \delta\log_{10}(d) + \rho \qquad (3)$$

$$\beta(dB) = \alpha + \delta\log_{10}(d) + \gamma \qquad (4)$$

The terms, α, δ, ρ, and γ are expressed as follows:

$$\alpha = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_1) - \alpha(h_2) \qquad (5)$$

$$\delta = 44.9 - 6.55\log_{10}(h_1) \qquad (6)$$

$$\rho = 5.4 + \left[\log_{10}\frac{f_c}{28}\right]^2 \qquad (7)$$

$$\gamma = 18.33 - 4.78\left[\log_{10}(f_c)\right]^2 \qquad (8)$$

While,

$$\alpha(h_2) = [1.1\log_{10}(f_c) - 0.7]h_2 - \Gamma \qquad (9)$$

For suburban and rural areas

$$\alpha(h_2) = 3.2\left[\log_{10}(11.75\times h_2)\right]^2 - 4.97 \qquad (10)$$

And,

$$\Gamma = 1.56 \log_{10}(f_c) - 0.8 \qquad (11)$$

Therefore,

Path loss (in dB) for Hata model in Urban area is defined as:

$$L(dB) = L(dB) = 69.55 + 26.16 \log fc - 13.82 \log h_1 + (44.9 - 6.55 \log h_1) \log d - 3.2[\log(11.7554 h_2)]^2 - 4.97 \qquad (12)$$

Path loss (in dB) for Hata model in Suburban area is defined as:

$$L(dB) = 69.55 + 26.16 \log fc - 13.82 \log h_1 + (44.9 - 6.55 \log h_1) \log d - 2 \log(\frac{f_c}{28}))^2 + 5.4 \qquad (13)$$

Path loss (in dB) for Hata model in rural area is defined as:

$$L(dB) = 69.55 + 26.16 \log fc - 13.82 \log h_1 + (44.9 - 6.55 \log h_1) \log d - 4.78(\log fc)^2 + 18.33 \log fc + 40.94 \qquad (14)$$

COST 231 Hata

The Path loss, β_c (dB) is given by the equation below:

$$\beta_c = \alpha_c + \delta \log_{10}(d) + \rho_c \qquad (15)$$

Where,

$$\alpha_c = 46.3 + 33.9 \log_{10}(f_c) - 13.82 \log_{10}(h_1) - \alpha(h_2) \qquad (16)$$

for urban areas and medium cities) (for metropolitan areas)

$$\rho_c = \begin{cases} 0 \\ 3 \end{cases} \qquad (17)$$

where δ, a (h_2), are in equations (6), (9) respectively [6].

Egli model

Path loss equation for Egli are as follows:

$$P_{egli} = \begin{cases} 20 \log_{10} f + q_o + 76.3, & h_2 < 10 \\ 20 \log_{10} f + q_o + 76.3, & h_2 > 10 \end{cases} \qquad (18)$$

$$q_o = 40 \log_{10} d - 20 \log_{10} h_1 10 \log_{10} h_2) \qquad (19)$$

Where, f is frequency of transmission, h2 and h1 are heights of the mobile station antenna and base station antenna respectively in metres [7].

Statistical analysis

Furthermore, mean prediction error, standard deviation error, and root mean square error, are used to assess the models' effectiveness. As calculated using equations (20), (21) and (22).

$$Mean\ error = \frac{1}{n} \sum_{i=1}^{n} (P_m - P_r) \qquad (20)$$

According to [8], it is possible to calculate the standard deviation of error (SDE) between measured and anticipated path losses by using (21)

$$SDE = |\varepsilon_m - \varepsilon_c| \qquad (21)$$

ε_m = Standard deviation of measured path loss
and ε_c = Standard deviation of anticipated path loss.
The Root Mean Square Error (RMSE) of the path loss for each of these four kinds of models was calculated and compared to the measurement data in order to identify the optimal path loss model [9].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (P_m - P_c)^2}{n}} \qquad (22)$$

Where n is the number of measured path loss samples, P_m is the measured path loss in dBm, P_c is the calculated path loss in dBm [9].

Results and Discussion

Predicting the coverage of a potential mobile network system is a step in the design process. Over the years, a number of techniques for predicting coverage area using propagation models have been created, some of which were already mentioned earlier in this paper. Transmission in a communication system frequently occurs over uneven terrain. When calculating path loss, the topography profile of a certain location must be taken into consideration. To anticipate path loss over irregular terrain, a variety of propagation models are available. While all of these models aim to predict the signal strength at a particular receiving site or location, the methods, complexity, and precision differ

Copyright © Abayomi YIO

significantly. The aim of this research is to determine path loss of transmission within the TV band for the specified areas using a combination of elicited data and other models previously discussed. The model is completely empirical and is based on several measurements. The predicted territory is classified using this technique into a variety of clutter and terrain types, such as urban, suburban, and rural. To achieve this, a single-direction drive test was conducted with a decreasing distance from the BTS.

It is believed that the information acquired during the field measurement is complete and sufficient for model development. The measured path loss numerical values were thoroughly reviewed and compared to Hata-model, Okumura's COST 231's model, Egli's model, and Plain Earth's model. The COST 231 model closely matches the results obtained in the three environments (urban, suburban and rural). Table 3's signal intensity is converted into path loss for each of the locations measured at a distance of d (km) (dB) on table 4. The governing equations of the model are then used to calculate the path loss values in decibels.

Table 3: Measured received signal strength.

Distance (km)	Ajah	Ikorodu	Epe
0.1	-43	-48	-47
0.2	-45	-51	-49
0.3	-49	-54	-53
0.4	-51	-56	-58
0.5	-55	-59	-55
0.6	-56	-64	-57
0.7	-58	-68	-62
0.8	-63	-74	-67
0.9	-66	-78	-69
1.0	-73	-88	-75
1.1	-77	-87	-79
1.2	-79	-85	-87
1.3	-80	-93	-90
1.4	-82	-92	-89
1.5	-84	-94	-91
1.6	-90	-95	-95
1.7	-89	-96	-97
1.8	-91	-98	-96
1.9	-97	-98	-97
2.0	-96	-99	-99

Table 4: Measured Path loss.

Distance (km)	Ajah	Ikorodu	Epe
0.1	91.14	92.41	93.20
0.2	101.62	100.07	101.26
0.3	106.42	104.24	107.14
0.4	110.41	109.62	110.41
0.5	113.41	111.74	113.79
0.6	116.04	115.24	117.04
0.7	118.18	117.25	119.81
0.8	120.04	119.15	120.40
0.9	121.14	120.70	121.64
1.0	124.46	123.40	122.86
1.1	125.64	126.20	124.41
1.2	127.97	127.10	125.64
1.3	127.28	128.15	126.76
1.4	128.82	129.40	127.97
1.5	129.11	128.15	128.28
1.6	130.76	129.30	129.33
1.7	131.15	130.25	130.76
1.8	132.13	131.40	131.15
1.9	133.60	132.50	132.13
2.0	134.77	133.66	133.60

After estimating the path loss of the actual measurements for each distance, MATLAB R2020a was used to compare the experimental and theoretical values. The results for path loss at 615.25MHz for 1.5m height antennas in urban, suburban and rural areas are displayed in figures 2-4. As a function of the separation between the transmitter (base station) and mobile station antennas, the computational results of predicted and measured field path loss data are graphically plotted. This clearly illustrates the outcomes of path loss prediction from the Hata-Okumura model, COST 231 model, Egli model, Plain earth model, and measured path loss.

Copyright © Abayomi YIO

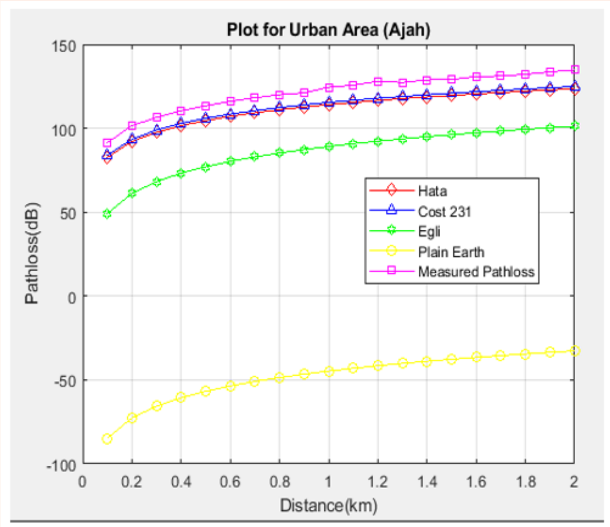

Figure 2: Graph of path loss against distance for Urban area.

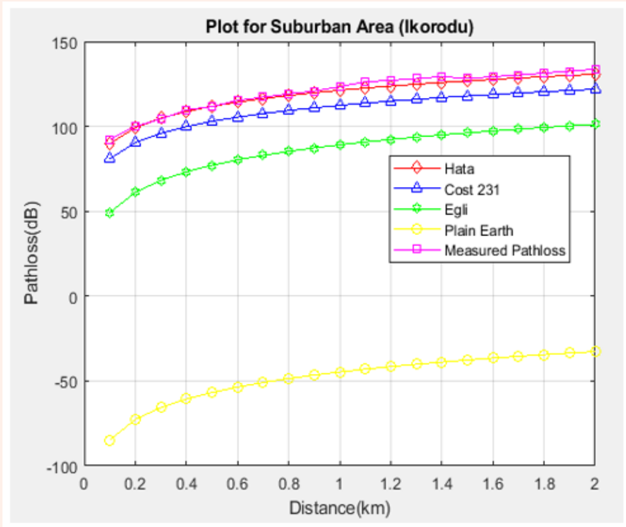

Figure 3: Graph of path loss against distance for Suburban area.

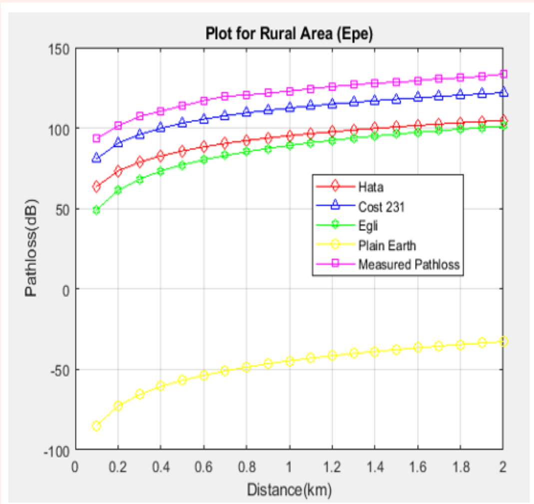

Figure 4: Graph of plot of path loss against distance for Rural area.

The COST 231 model's forecast fared the best of all the models tested in all three routes, according to the findings, because it closely matched the measured data. Despite the fact that system parameters such as the operating frequency, transmitter height, and measurement route distance fit within the validity of the model, the Plain Earth model performed poorly.

For further analysis, the Root Mean Square Error (RMSE), Standard Deviation Error and Mean Error are calculated while the results are given on table 5.

Table 5: Standard Error Values for the Path loss models.

Model	Environment	RMSE (dB)	Standard deviation error(dB)	Mean error (dB)
Egli	Urban	16.65	2.41	16.4685
	Suburban	15.98	2.43	15.8
	Rural	16.45	3.21	16.1035
Plain earth	Urban	169.15	2.42	169.13
	Suburban	168.44	2.43	168.4615
	Rural	168.83	3.22	168.8045
Hata	Urban	9.73	0.59	9.6925
	Suburban	2.14	0.60	1.7745
	Rural	28.22	0.19	28.2105
Cost 231	Urban	8.38	0.61	8.34
	Suburban	10.7	0.59	10.6325
	Rural	11.02	0.19	11.015

From the RMSE of the theoretical models, it is discovered that COST 231 has the lowest values of 8dB, 10dB and 11dB for Urban, Suburban and Rural areas respectively. Therefore, modified equations (equations 23, 24, 25) were derived for COST 231 model called ORESSUFFTV MODEL to cater for the parameters of transmission in a TV white space.

$$ORESSUFFTV_{urban} = 54.68 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_1) - 3.2\left[\log_{10}(11.75 * h_m\right]^2 - 4.97 + (44.9 - 6.55\log_{10}(h_1))(\log_{10}(d)) + 3 \quad (23)$$

$$ORESSUFFTV_{urban} = 57 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_1) - (1.1\log_{10} f_c - 0.7)h_r - (1.56\log_{10} f_c - 0.8) + (44.9 - 6.55\log_{10}(h_1))(\log_{10}(d)) \quad (24)$$

$$ORESSUFFTV_{urban} = 57.328 + 33.9\log_{10}(f_c) - 13.82\log_{10}(h_1) - (1.1\log_{10} f_c - 0.7)h_r - (1.56\log_{10} f_c - 0.8) + 44.9 - 6.55\log_{10} h_1))(\log_{10}(d)) \quad (25)$$

In the areas investigated, the RMSE for OressuffTV proposed model in urban, suburban and rural are 3.082, 1.19 and 3.061 respectively. These RMSE are less than 6dB, as displayed on table 6 and are acceptable [9].

Table 6: Standard Error Values for the Derived Path loss model.

Model	Environment	RMSE (dB)	Standard Deviation Error(dB)	Mean Error (dB)
Oressuff TV	Urban	3.082	0.62	2.96
	Suburban	1.19	0.60	-0.0525
	Rural	3.061412	0.18	-3.0165

Figures 5-7 displays the comparison between the optimized model with Measured, Hata-Okumura, Cost 231, Egli, and Plain earth models.

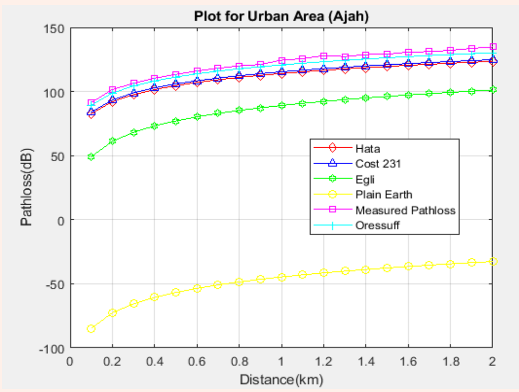

Figure 5: Graph of derived model with the other models in urban area.

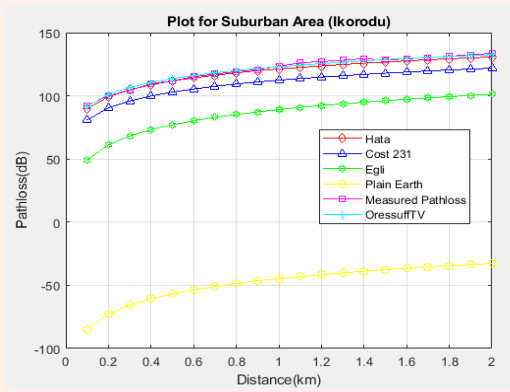

Figure 6: Graph of derived model with the other models in suburban area.

Copyright © Abayomi YIO

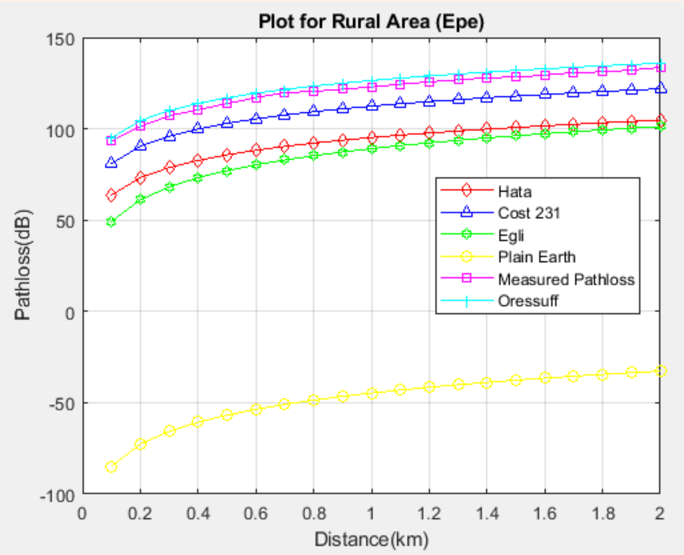

Figure 7: Graph of derived model with the other models in rural area.

The COST-231 model is selected as the basis for optimization to create a new model for estimating path loss for TV spectrum in the 470-870MHz band based on the best agreement with measured path loss exponents. The performance of the COST-231 model is compared with the observed path loss and the calculated path loss after the model was modified to match the measured path loss in figures 5-7.

Conclusion

This paper investigated the characteristics of the TVWS spectrum that make it ideal for long-range, low-power, and large-area uses like detection and monitoring, agricultural Internet of Things, fixed wireless access, smart utility applications, location-based services, transportation, and logistics. Increased availability, a broader bandwidth, and good propagation characteristics. Once the switch from analogue to digital television is achieved, the majority of the spectrum in the broadcast bands will continue to be unused and open for usage by the internet. More so, technological improvements are making it possible to plan terrestrial broadcasting with a better degree of precision, leading to the creation of new white spaces. Signals transmitted over the TVWS spectrum have the ability to travel enormous distances and break through buildings and other obstructions, demonstrating that the broadcast spectrum possesses exceptional propagation properties. Consequently, TVWS technology is very well suited for the provision of Internet connectivity in underserved metropolitan regions, as well as rural and suburban locations.

The utilization of white space spectrum to provide the much-required dual communication channels in urban, suburban, and rural areas has a lot of potential, mainly in developing countries where white space is available but where the infrastructure for telecommunications is lacking. This is especially true in rural areas. Indoor white spaces in cities like Lagos can be better utilized for wireless sensor applications such as electrical power metres and indoor web streaming services, thereby reducing congestion in the 2.4 and 5 GHz unlicensed bands. The power level threshold for measuring spectrum occupancy should be investigated further.

Reference

1. Ayeni A, Faruk N, Lukman O, Muhammad MY, Gumel MI (2012) Comparative assessments of some selected existing radio propagation models: A study of Kano City, Nigeria. Eur J Sci Res 70(1): 120-127.
2. Faruk N, Ayeni AA, Adediran YA (2013) On the Study of Empirical Path Loss Models. 49: 55-176.
3. Camp J, Robinson J, Steger C, Knightly E (2014) Measurement Driven Deployment of a Two-Tier Urban Mesh Access Network.
4. Nadir Z, Ahmad MI (2014) Pathloss determination using Okumura-Hata model and cubic regression for missing data for Oman. Proc Int MultiConference Eng. Comput Sci pp. 804-807.
5. Obot A, Simeon O, Afolayan J (2011) Comparative Analysis of Path Loss Prediction Models for Urban Macrocellular Environments 30(3).
6. Shoewu OO, Oborkhale LI, Udo EU, Akinyemi LA (2019) Approaching the Evolution of Path loss Prediction Models for Dryland and Wetland Environments in Lagos, Nigeria. Eng Technol Res J 4(1): 8-16.
7. Mauwa H, Bagula B, Zennaro M, Lusilao G On the Impact of Propagation Models on TV ces Measurements in Africa.
8. Rama Rao T, Vijaya Bhaskara Rao S, Prasad MVSN, Sain M, et al. (2000) Mobile radio propagation path loss studies at vhp/uhf bands in southern India. IEEE Trans. Broadcast 46(2): 158-164.
9. Wu J, Yuan D (1998) Propagation measurements and modeling in Jinan City. IEEE Int Symp Pers. Indoor Mob Radio Commun PIMRC 3: 1157-1159.