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EMPIRICAL PATH LOSS MODELS OF UHF BAND IN SOUTH–WEST NIGERIA: A CASE STUDY OF OSOGBO TELEVISION STATION

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Abstract: Before implementing any wireless system, the path loss analyses play an important role in designing wireless communication systems. The performance of most empirical models varies from place to place. The suitable models for a particular location with correct predicted signal path loss needed to be determined for proper communication budget planning. This paper examined the signal path loss of a UHF television station using different empirical path loss models. Okumura model, SUI model for type A, Wilfisch–Ikegami model for urban, Hata model for urban, Hata–Okumira model for urban, Cost 231 Hata model for urban, Egli's model and free space model were used to analysed the signal path loss characteristics of NTA Osogbo, Ile Ife, Osun state network Centre in different routes within Ile–ife metropolis. The propagation measurements of signal strength and path loss were conducted in Ilorin using Agilent N9342C 100Hz–7GHz spectrum analyser. From the data collected, the signal powers received at each of the locations were estimated. The measured UHF signal strength and path loss of Agilent Spectrum Analyser was compared with the predicted signal path loss from eight different models and the models with best performance was determined by estimating errors between measured and predicted values of each models. The results showed that the path loss increased with the distance from the transmitter while the received power signal decreases with the distance from transmitter antenna. Wilfisch–Ikeami model and Hata model are best suitable for the path loss prediction although Hata model has better performance with least mean error and standard error of precision and their mean bias error less than –13dB and –10dB respectively.
Keywords: UHF channel, Egli model, Okumura, Cost 231, Hata–Okumura, Wilfisch–Ikegami, path loss models

1. INTRODUCTION

In wireless communication, electromagnetic waves spread uniformly along different path using isotropic antenna but they are sometime channel through a particular direction using aerial antenna, (Stutzma & Thiele, 1998), (Roger, 1988). Along their path, they encounter attenuation or degradation in their signal strength depends on the characteristic of the channel medium. The degradation of signal strength may be one or combination of multi-path, reflection, scattering and diffraction which hinder effective and efficient communication (Zia, Elfahil & Touati, 2008; Stutzma & Thiete, 1998). Hence, the performance of any wireless communication depends greatly on the channel characteristics, (Wu & Yuan, 1998). This causes losses in power of the transmitted signal and can sometime leads to total loss of the signal. This effect is called signal path loss.

Radio signal path loss is a particularly important element in the design of any radio communications system or wireless system. The radio signal path loss will determine many elements of the radio communications system in particular the transmitter power, and the antennas, especially their gain, height and general location. The radio path loss will also affect other elements such as the required receiver sensitivity, the form of transmission used and several other factors. As a result, it is necessary to understand the reasons for radio path loss, and to be able to determine the levels of the signal loss for a give radio path along the traveling distance. The signal path loss can often be determined mathematically and these calculations are often undertaken when planning and doing budgeting for any base station. Hence, it is therefore necessary to carried out proper study of the area and channel characteristic of the environment before any transmission of communication signal.

Accordingly, path loss models are used in many radio and wireless survey tools for determining signal strength at various locations. Propagation models are very useful in network planning and performing interference studies as the deployment proceeds. These models can be broadly classified into three types; Empirical, Deterministic and Stochastic, (Jhon S. Seybold, 2005). An empirical model is based on observed and measurements alone. These models are mainly used to predict the path loss. It can be further classified into two sub part- non time dispersive and time dispersive. For example, the Stanford University Interim (SUI) model is one of the perfect examples of time dispersive models while Hata model, COST-231 Hata model, ITU – R model are the best example of non-time dispersive models.

For deterministic models, they are deployed laws of governing electromagnetic wave propagation for determination of received signal power at a particular location. These kinds of models often require a complete 3-D map of the propagation environment. Ray-tracing models are the best example of the deterministic models. The third type of models is stochastic. These models are used in terms of random variables. Stochastic models are the least accurate but require the least information about the environment and use much less processing power to generate predications. These are mostly used for predication at above 1.8GHz.

One of the key reasons for understanding the various elements affecting radio signal path loss is to be able to predict the loss for a given path, or to predict the coverage that may be achieved for a particular base station, broadcast station, etc. this study focused many on empirical models. Many empirical models have been developed to predict the path loss of a given channel and their performance and accuracy varies from place to place depending on the nature of the environment. The effects of channels on the propagation of radio waves have been studied by a number of researchers.

Greg., Theodore and Hao, (1998) worked on measurements and models for radio path loss and penetration loss in and around Homes and Trees at 5.85 GHz. Olaniyi, (2010) who carried out research on propagation model for determining the coverage area of a television broadcasting station, taking the Nigeria television authority, Ibadan as a case study. Adebayo, T.L and Edeko, F.O (2006) worked on characterization of propagation path loss at 1.8 GHz: A case study of Benin City, Nigeria.

There are report of poor transmission and noises as a result of poor signal reception due to losses along the transmission line. This leads to poor quality of service (QoS). In order to overcome the challenges, there is a need to study the caused of poor signal reception and possibly proving a lasting solution to the problems. This best approach is to study the channel characteristics for the proper planning of the signal before being transmitted. This work is to comparative analysis of predicted path losses of different empirical path loss models with the measured UHF signal path losses as key determinants in system design and proper RF planning. Therefore, the results obtained will provide useful information on the best empirical model suitable for the better radio planning and good quality of service (QoS) for users by provide a good output at the receiving end. A good quality of service (QoS) in TV broadcasting stations will attract the interest of the viewers/consumers and also provide larger coverage areas when properly planned. This work was carried out to assess the extent of signal degradation using different path loss models for NTA Oshogbo metropolis, South-West, Nigeria. And also to determine the effects of path losses on communication signals of their based stations.

2. METHODOLOGY

Description of Data Measurement and studied Station

The NTA Oshogbo is located at the Ile-Ife Jewel of the West, Oke Oloyinbo, Mokuro Road, frequency of transmission is 692.25MHz. NTA, Oshogbo is on channel 45 in, New State Secretariat, P.M.B 4315 deals in media communication, TV Station .With the promulgation of Decree 24 by the then Federal Military Government in May 1977, the Nigerian Television Authority was born. The decree which took effect retrospectively from April 1976 brought all the ten existing television stations under the control of the Federal Government of Nigeria. Television stations were later established in the remaining State Capitals where none existed, which NTA Oshogbo was among. NTA Oshogbo located at the Ile-Ife Jewel of the West, frequency of transmission is 692.25MHz and its address is NTA, Oke Oloyinbo, Mokuro Road, PMB 5510, Ile-Ife, Osun State.

Table 1.0: Propagation Characteristics of the Two Stations

Parameters	NTA TV, Osogbo
Longitude $(°E)$	4.520623
Latitude $(°N)$	7.733698
Transmitter height $h_r(m)$	136.0
Receiver height $R_x(m)$	1.5
Frequency $F_m(MHz)$	695.25
Transmitter power $P_T(m)$	10
Transmitter gain $G_T(dBi)$	5.5

Propagation measurement was conducted in Ile ife (Long.; 4.520623°E, Lat.; 7.733698°N), Osun state. The measurement setup is mainly made up of an Agilent N9342C 100Hz -7 GHz spectrum analyzer. The Agilent N9342C 100Hz -7 GHz spectrum analyzer was placed inside a vehicle while the GPS device was attached to the roof on the vehicle. An average speed of 40 km/h was maintained for measurement along the selected routes while the field strength for all the transmitters were measured simultaneously and continuously stored in an external memory stick of 2GB for subsequent analysis.

Empirical Path Loss Models

— Free Space Path Loss

The free space loss occurs as the signal travels through space without any other effects attenuating the signal it will still diminish as it spreads out. This can be thought of as the radio communications signal spreading out as an ever increasing sphere.

For free space model path loss, it can be seen that the mean path loss, L, increases as the square of the antenna separation distance, d, increases in the logarithmic domain. The same relationship is also present for variations in the carrier frequency, fc. Hence, every time the antenna separation distance or the carrier frequency is doubled, the free space path loss is increased by 6dB. This is the fundamental reason why smaller cell sizes are deployed for higher carrier frequencies and therefore why it is of such great importance to be able to design these complex cell structures as accurately as possible (Balanis, 1982), (Herndon & Grob, 1999). The path loss (P_L) equation for free space model is written as follows:

$$P_L = 10n\log10(d) + 10n\log10(f) + 32.44 \quad (1)$$

where, n is the path loss exponent. The value of path loss exponent for free space model is always given by equation (7)

$$P_L = 20\log10(d) + 20\log10(f) + 32.44 \quad (2)$$

where, f [MHz] is the frequency of operation. d [m] is the distance between transmitter & receiver.

— Egli's Models

The model has been developed based on the real data collected for UHF transmission around the word. It can be seen from the path loss equation (3) that there is a negative relationship between the signal field strength and distance, i.e. the field strength decreases with increase with distance. The Egli's propagation loss prediction is applicable when the receiving antenna height $h_R \leq 10\mathrm{m}$ (Kennedy& Davis, 1999) (Dashpande & Rangole 2001). The loss can be expressed mathematically as:

$$P_L(\mathrm{dB}) = 20\log_{10} f + 40\log_{10} d - 20\log_{10} ht + 76.3 - 10\log_{10} hr \quad (3)$$

From the previous works, it was confirmed that in macro-cellular links over smooth, plane terrain, the received signal power (expressed in dB) decreases with "40 log d". Also a "6 dB/octave" height gain is experienced: that is doubling the height increases the received power by a factor 4.

In contrast to the theoretical plane earth loss, Egli measured a significant increase in the path loss with the carrier frequency f_c. He proposed the semi-empirical model.

$$P_R = [\frac{40\mathrm{MHz}}{f}]^2[\frac{[hrhR]^2}{d^4}]P_r G_r G_R \quad (4)$$

A frequency-dependent empirical correction was introduced for ranges 1< d < 50 km, and carrier frequencies 30 MHz < f_c < 1 GHz (or from 40MHz to 900MHz) (Kennedy& Davis, 1999) (Dashpande & Rangole 2001). Thus, in a nut shell, path loss can also be computed mathematically as follows;

$$\mathrm{Loss} = \mathrm{EIRP} - P_R \quad (5)$$

— Stanford University Interim (SUI) models

The SUI models were proposed for frequency below 11GHz by a working group of IEEE 108.16. It is derived as an extension to Hata model with 1900MHz band and above. The SUI Models are divided into three different based on the terrain of the area. They are Type A, Type B and Type C. The type A is applicable where there is hilly terrain with moderate to heavy foliage densities. The Type B is applicable where there is flat terrains with moderate to heavy tree densities or hilly terrain with light tree densities. This has a minimum path loss. The Type C is applicable where there is flat terrains with light tree densities. This has a minimum path loss. The empirical models for the path loss of SUI model along with correction factor is expressed as (Magdy and Zhengquing Yun, 2012)

$$P_L = A + 10\gamma\log_{10}\left({}^{d}/_{d_0}\right) + X_f + X_h + e \quad (6)$$

Where d= distance between transmitter and receiver antennas (m), d_0= 100m and d >d_0, X_f=correction factor for frequency> 2GHz, X_h= correction factor for receiving antenna height, γ= Path loss exponential, A(dB) =correction factor for shadowing effect (value between 8.2dB-10dB).

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— **Okumura Model**

The Okumura Model is classical empirical model to measure the radio signal strength in an urban or semi-urban areas with tall buildings. Work more accurate in an environment classified as city with highly dense tall structures. It was developed from data collected in Tokyo city of Japan (Jhon S. Seybold, 2005) and it is applicable from frequency less than 3000MHz. the median path loss model is expressed as (Abhaywardhana, Wassell, Crosby, Sellars and Brown, 2005)

$$P_L = L_f + A_{mn}(f, d) - G(h_t) - G(h_r) - G_{area} \quad (7)$$

where, L_f= free space path loss, $A_{mn}(f, d)$= median attenuation relative to free space, $G(h_t)$= transmitter antenna height, $G(h_r)$= mobile station antenna height gain factor, G_{area}= gain due to type of environment, f= operation frequency (MHz), d= distance between receiver and transmitter antennas (Km), h_t =transmitter antenna height, h_r =receiver antenna height.

— **Cost 231 Hata Model**

The Cost 231 Hata Model is mostly applicable for predicting path loss in mobile wireless system. It is an extension of Hata model used for predicting the path loss in an urban, sub-urban and rural areas. The frequency range from 500MHz to 2000MHz. the path loss equation is given by:

$$P_L = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - a(h_m) + n\begin{bmatrix}44.9 \\ -6.55\log_{10}(h_b)\end{bmatrix}\log_{10}(d) + c_m \quad (8)$$

where, f =frequency (MHz), d=distance between the transmitter and receiver antennas (Km), h_b=height of the transmitter antenna. The parameter ah_m is given by

$$a(h_m) = [1.1\log_{10}(f) - 0.7]h_r - [1.56\log_{10}(f) - 0.8] \quad (9)$$

where h_r=receiver antenna (m)

— **Hata Model for Urban Areas**

The Hata model is simply the empirical path loss model of the graphical path loss data developed by Okumura. It is also known as the Okumura-Hata model for being a modified version of the Okumura mode. It is valid for frequency range of 150MHz to 1500MHz. It is a most widely used radio frequency propagation model for predicting the behaviour of mobile wireless base station. It predicted the median path loss for a maximum distance of 20Km and transmitter height is from 30m to 200m while the receiver antenna height is from 1m to 10m in built up areas. It further incorporated the effects of diffraction, reflection and scattering caused by city structures (Hata, 1980), (Oyetunji & Alowolodu, 2013), (Fagbohun, 2014). It is most applicable in the urban area and allowed modification for sub-urban and rural areas. It is suitable for both point-to-point broadcast transmissions and it is based on extensive empirical measurement taken (Parsons, 2000). Median path loss is given by:

$$P_L = 69.25 + 26.16\log_{10}(f) - 13.82\log_{10}(h_t) - a(h_r) + \begin{bmatrix}44.99 \\ -6.55\log_{10}(h_t)\end{bmatrix}\log_{10}(d) \quad (10)$$

where; P_L = path loss in urban (dB), h_t = Height of the base station antenna (m), h_r = Height of the receiver (mobile station) antenna (m), f = Transmission Frequency (MHz), d= distance between transmitter and $a(h_r)$= antenna height correction factor for the receiver antenna

— **Hata-Okumura Extended Model**

It is also called ECC-33 model. It is most applicable in empirical propagation model for UHF band. It is recommended by ITU-R P.529 that the maximum frequency for this model is 3GHz. The path loss model is given by:

$$P_L = A_{fs} + A_{bm} - G_b - G_r \quad (11)$$

Where, A_{fs}= free space attenuation, A_{bm}=basic median path loss , G_b= transmitter antenna height gain factor, G_r= receiver antenna height gain factor. All these parameters are given as follow:

$$A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f) \quad (12)$$

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 7.894\log_{10}(f) + 9.56[\log_{10}(f)]^2 \quad (13)$$

$$G_b = \log_{10}\left({}^{h_b}/_{200}\right) \times \{13.958 + 5.8[\log_{10}(d)]^2\} \quad (14)$$

$$G_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(d) - 0.585] \quad (15)$$

— **Walfisch-Ikegami Propagation Mode**

It is also called empirical COST-Walfisch-Ikegami model. It is the combination of J Walfisch and F. Ikegami empirical models developed by the COST-231 project, (Jhon, 2005). It is most accurate and applicable to urban environment due to the fact that it's considered only the buildings between the transmitter and the receiver antennas. The frequency range from 800Hz to 2000MHz, height of the transmitter antenna range from 4 to 50m while the height of receiver antenna range from 1 to 3m.

The distance between the transmitter and receiver are divided into two, the line of sight (LOS) and the non-line of sight (NLOS). For this paper, the measurement taken are for NLOS which is given by

$$P_L = \{L_{FSL} + L_{rts} + L_{msd} \text{ for urban \&sub} - \text{urban } L_{FS} \text{ if } L_{rts} + L_{msd} > 0\} \quad (16)$$

where, L_{FSL}= free space loss, L_{rts}= roof top to street diffraction, L_{msd}= multiscreen diffraction loss

3. RESULTS AND DISCUSSIONS

The measured data of received power and pat loss of the transmitted signals were statistically computed wit distance in (km) and compared with the empirical path loss models. Using the distance in Km, path loss values pertaining for all the eight models for the TV station propagation characteristics of the link were obtained. The data obtained were analysed.

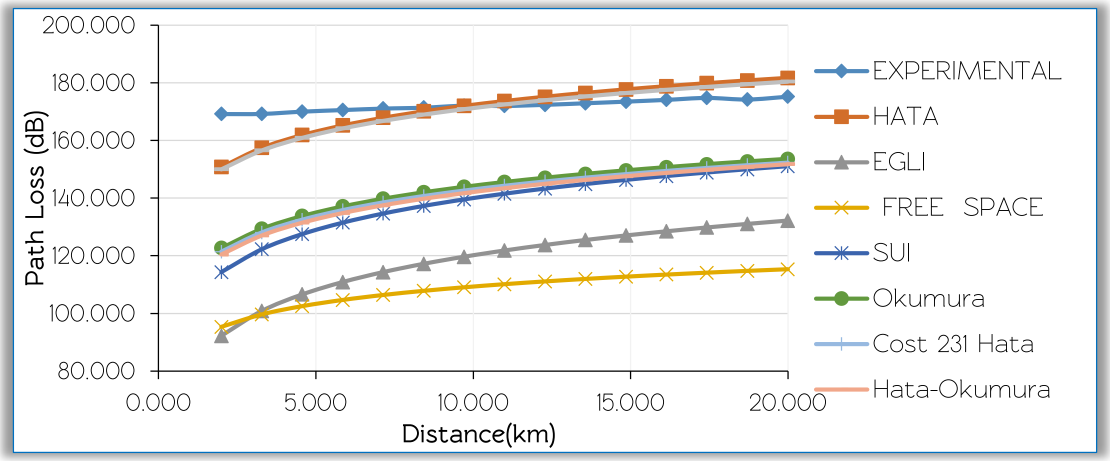

Figure 1: Comparison of measured and simulated path losses

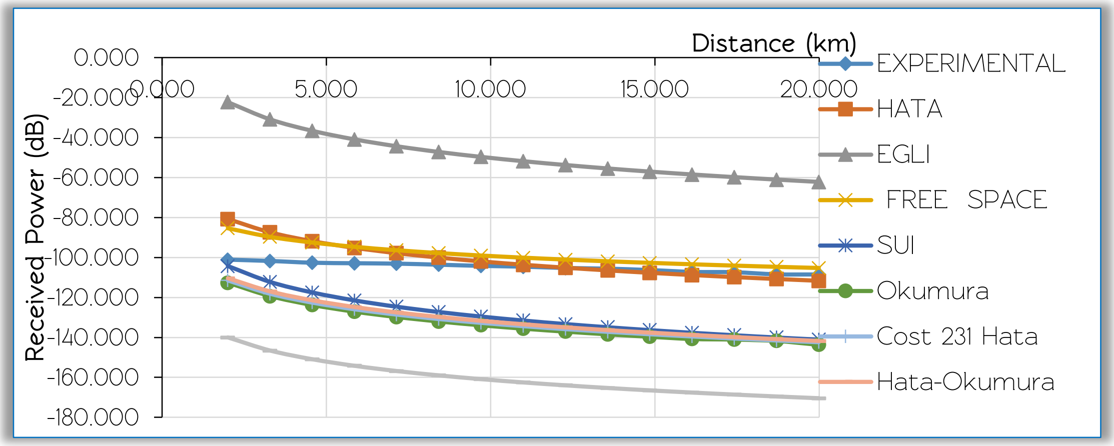

Figure 2: Comparison of measured and simulated received power

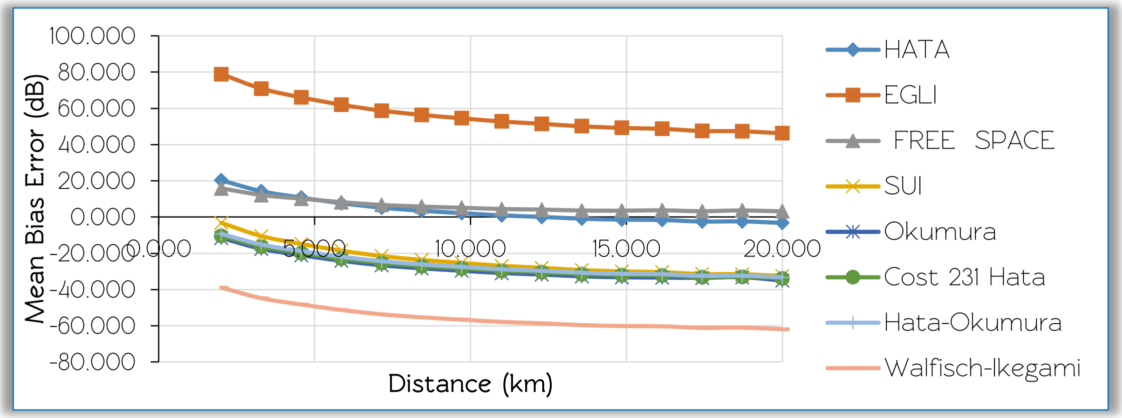

Figure 3: Comparison between mean bias errors of the empirical path loss models of received power

Figure 1 shows the Comparison of measured and simulated path losses for the eight models, while that of received power is shown in Figure 2.

From Figure 1, Hata model and Walfisch-Ikegami model simulated results are closed to the experimental values for the path loss measurement than all other models. The model has similar pattern and tend to move farther as the distance increases. However, the plots indicate that more losses are incurred with increase in the coverage area.

From Figure 2, free space model, Hata model and SUI model simulated results had better performance in predicting the power received and are closed to the experimental values of power received than all other models. The model has similar pattern and tend to move farther as the distance increases. However, each plot shows that increase in the coverage area yield a corresponding decrease in the filed strength of the received signal.

Figure 3 shows the mean error of the eight models. The best model must plot closer to horizontal axis. From Figure 3, Hata model and Walfisch-Ikegami model are closer to the axis, hence, as least mean error values. The two models are best in predicting pathloss for NTA Oshogbo for the three propagation models.

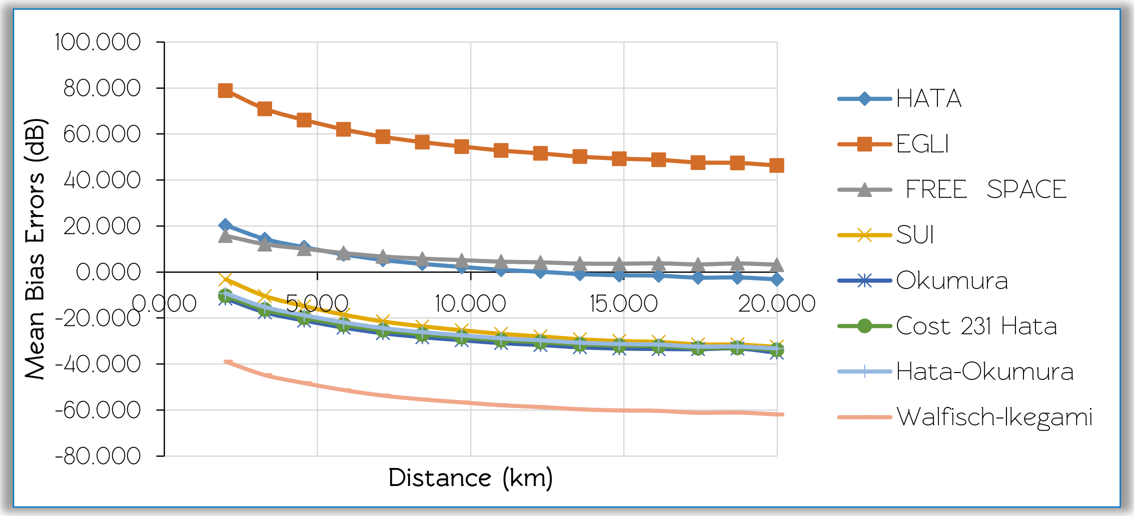

Figure 4: Comparison between mean errors of predicted received power of eight models

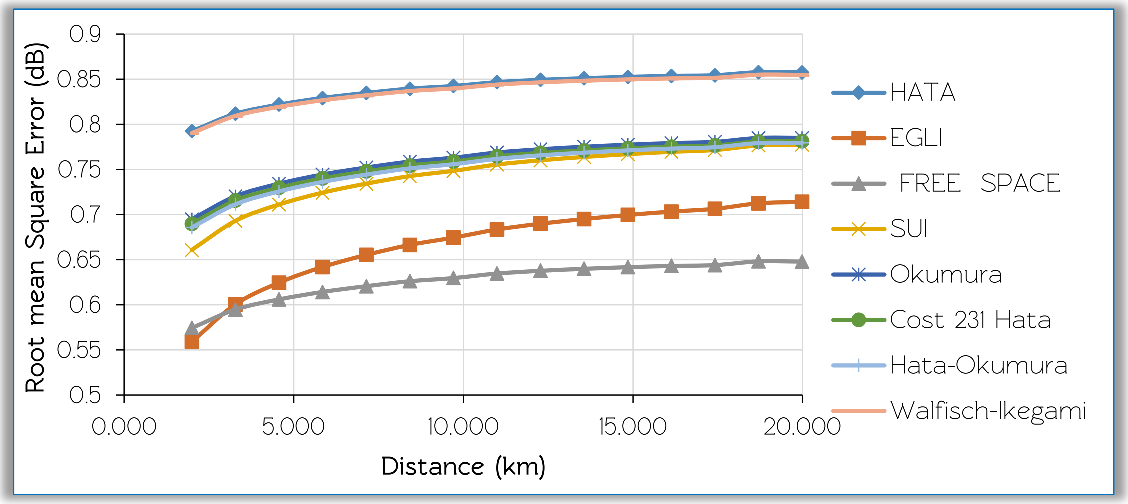

Figure 5: Comparison of Path loss root mean square error value for the eight models

From Figure 4, it is observed that the free space model and Hata model yielded the least mean error compared with other models, making them the most suitable among the eight models. Also, the mean error for Hata model decreases from 16.38 to 3.44 with reference to distances 2.0km to 13.6km, and tends to approximate error above 13.6km to 20km.

From Figure 5 shows the error function, the closer to the best the model. Walfisch-Ikegami model and Hata model yielded the values closer to 1. Thus, making the two models suitable for a long distance signal transmission. Hata model and Wilfisch-Ikegami model have least standard error precision values and so therefore, are the best among the eight models for the prediction of path loss of NTA Osogbo TV station.

In NTA Osogbo TV station, it is observed that for all distances, Hata and free space and Walfisch-Ikegami models for predicting the received power signal strength are best predicting models among the eight compared models. Among the three models, Hata model has the best performance while free space model has the least performance. It was observed that the received power strength decreases with distance.

Similarly, for path loss prediction only Hata and Wilfisch-Ikegami models predicted closed to the experimental values, the standard error precision is almost zero above 13.5km. The path loss of the signal increased with distance. Are less than the experimental losses while greater than the losses predicted by Hata model. For path loss prediction, free space has the best standard error precision and as a result performs woefully

4. CONCLUSION

This study reveals that the efficiency of communication base station depended on the distance and environmental channel. Different simulation tools were used to estimate the coverage of the radio signal, path loss and received power. These helped in determining the distance at which repeaters should be placed in order to enhance the signal and localize the sensor node from its received signal strength. With an increasing number of physical obstructions, the path loss index increases, resulting in the total loss of signal beyond a particular range. Therefore, in predicting path loss for NTA, Oshogbo, eight models were used for the prediction of received power and path loss, and compared with experimental values. Hata and Wilfisch-Ikegami models are best suitable. Although estimation of path losses using Hata model are slightly greater than the experimental path losses and Walfisch-Ikegami model is slightly lower. Free Space model shows greater error in but stations with all its prediction less than the actual scenario.

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