Assessment of Multipath and Shadowing Effects on UHF Band in Built–up Environments

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Abstract

Ultra-high frequency (UHF) bands are radio frequencies in the range of 300 MHz and 3 GHz. These bands are used for television broadcasting, mobile cellular systems, Wi-Fi, satellite communications and many others. Effective communication link in the UHF band requires direct line of sight between the transmitters and receivers. However, this is not always the case in built-up areas where diverse obstacles such as large buildings, trees, moving objects and hills are present along the communication path. These obstacles result in signal degradation as a result of shadowing (blockages) and multipath, which are two major causes of signal losses. Path loss models are used in predicting signal losses but, the accuracy of these models depend on the fitness between the model's predictions and measured loses. In this work, the multipath and shadowing effects on signal impairment were investigated through the use of empirical and semi-empirical path loss models analysis in built-up environments. Electromagnetic field strength measurements were conducted using four television transmitters at UHF bands along four major routes of Osun State, Nigeria. Experimental and simulation results indicated that the empirical models provide a better fit than the semi-empirical models. It was also found that the poor performance of the Knife Edge Model which is a semi-empirical model was traced to the bases of its formulation, which assumed point like knife edge for all obstacles on the path of radio propagation. The work therefore recommends that network planners employ empirical models found suitable for their kind of terrain when faced with coverage planning and optimization.

***Keyword**: Path loss models, Radio propagation, Terrain features.*

Introduction

Effective radio communications demand direct line of sight, but in built up areas, where diverse opaque objects are in between the transmitter and the receiver, purporting limited signal to arrive the receiver antenna, thus causing shadowing. Besides shadowing, the presence of signal's reflector object in the built up environment also creates multiple paths that a transmitted radio signal can travel. As a result, the receiver sees the superposition of multiple copies of the transmitted signal each traversing a different path. Whereas shadowing on any path of radio signal causes losses or reduction in radio signal strength, which is termed path loss. Path loss models are usually developed by the auxiliary task of predicting the signal path loss in different built-up areas. In this regard, different models exist for different types of radio links under different environmental conditions (Green & Obaidat, 2002). Generally, no single model prediction method is universally accepted as the best, but rather the accuracy of a prediction model depends on the closeness between the parameters required in a model to those available within the built-up area of concern. In this regard, prediction models are classified based on the terrain of their applicability as:-.

a) Empirical Models: - These are models based on samples of measurements conducted in a given area of interest. These models are considered to have environmental compatibility, but the main constraints are that it is time consuming to take the required measurements and also are most incompatible when used in a different environment. Typical example is the Okumura-Hata model (Surajudeen-Bakinde et al., 2012).

b) Analytical Models: - They are models guided by the law governing the electromagnetic wave propagation to determine the received signal power at a particular location. Analytical models are very cheap to formulate when compared to empirical path loss model but not as reliable as empirical models. Example includes a ray tracing model (Seker et al., 2010).

c) Semi-empirical Models: - They are partly empirical and partly analytical. These models basically have low computational requirement when compared to empirical path loss models. But the flexibility and commonality of their model parameters facilitate their usage in path loss prediction. Example includes knife edge model (Isabona. and Isaiah, 2013).

d) Deterministic Models:- These models utilize the physical environmental phenomenon to explain the propagation of radio wave signal in the area of interest. In this regard, a 3 – dimensional vector building data are used to account for the effect of the actual terrain profile in the model parameter. Generally, deterministic models are based on ray optical techniques (Greenberg and Klodzh, 2015).

Empirical, analytical and deterministic models have been researched extensively; very few of the conducted works aim to examine the performance of a semi empirical path loss model in a typical urban scenario. In this work, multipath and shadowing's effect on a semi empirical path loss model along with three widely used empirical path loss models were investigated.

Related Research Work

Research efforts have been made in the study of propagation models' applicability in different built – up - areas. The applicability of propagation model for Ilorin, Kwara State, Nigeria was investigated by (Obiyemi et al., 2012). Field measurements for two transmitters were captured and the results show that the effect of terrain profile on prediction models was negligible why Okumura model stand out as the most suitable. However, the root mean square errors (RMSEs) for Hata and SUI models of 34 dB and 33 dB were obtained in the VHF and UHF bands respectively, which are out of the acceptable range of 6 -7 dB for urban areas.

In a similar fashion, (Faruk *et al.,* 2013a and 2013b) verified the predictability of nine widely used empirical path loss models. The results show that no single model provides a good fit performance consistently, with Hata and Davidson models providing good fitness along some selected measurement routes. A quantitative measurement campaign for Nigeria Television Authority (NTA) channel 7 at VHF band with 189.25 MHz center frequency in Edo State, Nigeria was presented by (Ogbeide and Edeko 2013). The results show that the applicability and suitability of the Hata propagation model in Edo State do not fit in properly.

The error bounds on the efficacy of propagation path loss were presented by (Faruk et al., 2013d; Phillips, et al. 2011). The results show that Hata and Davidson models provide good fitness along some selected routes with measured RMSE values of less than 8 dB. International Telecommunication Unio-Recommendation Model (ITU-R P.1546-3), Walfisch Ikegami, Electronic Communication Committee Model (ECC-33), Egli model, Comite Consultatif International des Radio – Communication Model (CCIR) and Free Space Path Loss (FSPL) perform woefully, with higher RMSE and SC-RMSE (Spread Corrected RMSE) values. In terms of mean value errors, Hata, Davidson and ITU-R P.5293 models gave mean values close to zero. However, COST 231 also provides better skew, while CCIR and ECC-33 gives fair results, but ITU-R P. 1546, WI and FSPL gave a relatively bad result.

Path loss was shown to be an important parameter that one needs to know before undertaking the design or improving the existing radio frequency communication path. In order to improve coverage prediction and minimize interferences, it is necessary to use, accurate path loss model or to tune the model parameters so as to minimize errors. It is on this note, (Danladi and Natalia, 2014), modified COST 231-Hata model based on experimental data measured in the GSM 900 MHz band in Mubi, Adamawa, Nigeria.
(Faruk et al., 2013a and 2014), presented an optimized path loss model for predicting TV coverage for secondary access. In the work, errors analysis and optimization work were carried out on Hata-Davidson's model for better fit result. Significant works have been carried out in urban scenarios such as the work presented by (Jao, 1984; Ibrahim, 1982; .Ayeni et al., 2012; Emanoel, 2009), signal measurements were conducted in Global System for mobile (GSM) and Wideband Code Division Multiple Access (WCDMA) bands.

Although, (Abhayawardhana, 2005) carried out measurements in the VHF and UHF bands within the urban clutter, still, only empirical models were considered and the work did not incorporate semi-empirical models such as Knife Edge Model. Path loss models are very essential and needs to accurately be chosen for optimum spectral utilization. For example, the work presented by (Chebil *et al.,* 2013) show that a reliable prediction technique is required to accurately estimate the service contours for effective utilization of spatial TV white space for secondary transmitter.

Propagation in Built-Up Areas

Figure 1.0 shows a simple illustration of radio wave propagation in built - up – areas. The Figure reflects multipath and shadowing effect of buildings, trees and other constraints responsible for radio signal variation and degradation in built-up areas.

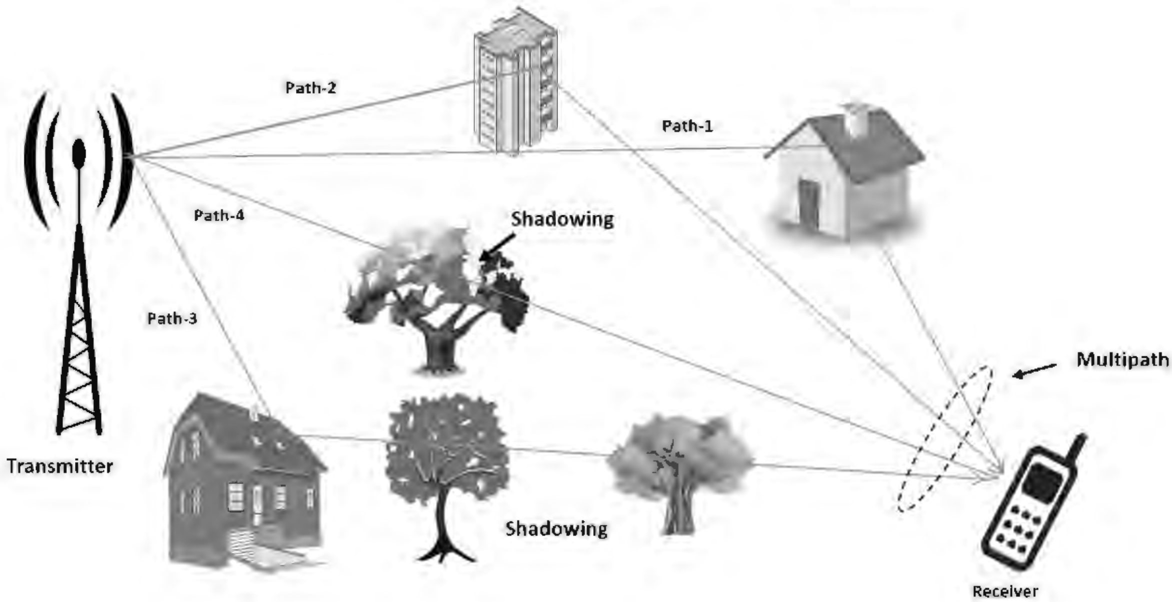

Figure 1. Radio Propagation in Built-up Areas

Terrain constraints differ from built up areas to built up areas, for instance buildings and poor channeling effect are less apparent in the rural and suburban areas, whereas foliage and trees effects are less in the urban areas as compared to rural areas (Ogundapo *et al.* 2011).

Research Methodology

The natures of the geographical and human developmental features are known to dictate the tone of radio wave propagation in any built-up setting as illustrated in figure 1.0. These settings in built-up area could either be classified as urban, suburban and rural area, depending on the six following classification factors (McLarnor, 1997):

(I.) Building density (percentage of area covered by building)
(ii.) Building size (area covered by building)
(iii.) Building height
(iv.) Building location
(v.) Vegetation density
(vi.) Terrain undulation.

Using the six factors listed in 2.2 on the context of conditional random field (CRF) in settlements classification, tall buildings, office blocks, residential building and full commercial patronage are used for the classification of an urban area, while residential buildings, garden and park classifies suburban and an open farm land with hut or shed are used for rural area (Huish and Gurdenli 1987). The nature of the build-up area has to be characterized as this will determine the rate of signal fading. In this context, the descriptions of the measurement campaign environment were characterized by tall buildings, commercial patronage, vehicular movement, trees, light foliage, garden, park and other social amenities.

Models Prediction Method

The path loss prediction models use in this work include: Davidson model (Jimoh, et al. 2015), CCIR model (Faruk et al., 2013b), Ericsson-9999 model (Abhayawardhana, 2005) and Knife edge model (Isabona. and Isaiah, 2013). These models were chosen due to their basis of formulation and commonality of their parameters.

A. Davidson's Model

The graphical path loss provide by Okumura for Hata model at a link distance of 20 km was modified to be applicable for path loss prediction at a link distance greater than 20 km. This derived model was named Davidson's prediction model and its mathematical expression is given as:

$$PL_D = L_{HATA}(dB) + A(h_{re}, d_{km}) - S_1(d_{km}) - S_2(h_{re}, d_{km}) - S_3(f_{MH_Z}) - S_4(f_{MH_Z}, d_{km}) \qquad (1)$$

where

$$L_{HATA} = 69.55 + 26.16*\log(f) - 13.82*\log(h_{re}) - a(h_{re}) + (44.9 - 6.55*\log h_{re})*\log(d) \qquad (2)$$

For a small and medium city, $a(h_{re})$ is expressed as follows:

$$a(h_{re}) = (1.1*\log(f - 0.7))h_{re} - (1.56*\log(f - 0.8))dB \qquad (3)$$

For a large city,

$$a(h_{re}) = \begin{cases} 8.29*(\log(1.54*h_{re}))^2 - 1.1; & f \le 200 \quad MHz \\ 3.2*(\log(11.75h_{re}))^2 - 4.97; & f \ge 400 \quad MHz \end{cases}$$

$$A(h_{re}, d_{km}) = \begin{cases} 0; & d < 20\ km \\ 0.62317*(d - 20)[0.5 + 0.15*\log(h_{re}/121.92)]; & 20\ km \le d < 64.38\ km \\ 0.62317*(d - 20)[0.5 + 0.15*\log(h_{re}/121.92)]; & 20\ km \le d < 300\ km \end{cases}$$

$$S_1(d_{km}) = \begin{cases} 0; & d < 20\ km \\ 0; & 20\ km \le d < 64.38\ km \\ 0.174(d - 64.38); & 64.38\ km \le d < 300\ km \end{cases}$$

$$S_2(h_{re}, d_{km}) = \{0.017484\ |\log(9.98/d)|(h_{re} - 300) \qquad h_T < 300\ m$$

$$S_3(f_{MH_Z}) = f/250 * \log(1500/f)$$

$$S_4(f_{MH_Z}, d_{km}) = [0.112*\log(1500/f)](d - 64.38) \qquad d > 64.38\ km$$

Where, d is the transmission link distance in km, $a(h_{re})$ is the correction factor for the receiver antenna height, h_{te} is the transmitter antenna height in m, h_{re} is the receiver antenna height in m, f is the transmitting frequency MHz, $A(h_{re}, d_{km})$ is the transmitter antenna gain in dB as a function of transmission link distance in km, $S_1(d_{km})$ is the distance correction factor, $S_2(h_{re}, d_{km})$ is the transmitter antenna height correction factor as a function of transmission link distance km, S_3(f, MHz) is the frequency correction factor and S_4(f, MHz, d_{km}) is the frequency correction factor as a function of distance in km.

B. CCIR Model

The empirical formulation of the CIRR model relies on the combined effects of free space and terrain induced path loss.

$$L_{CCIR} = 69.55 + 26.16 * \log_{10}(f_C) - 13.82 * \log_{10}(h_{te}) - a(h_{re}) + ((44.90 - 6.55 * \log_{10}(h_t) * \log_{10}(d) - B)) \quad (4)$$

$$a(h_{re}) = (1.1 * \log_{10}(f_C - 0.7)h_{re}) - (1.56 * \log_{10}(f_C - 0.8)) \quad (5)$$

$$B = 30 - 25 * \log_{10}(\text{\% of area covered by building}) \quad (6)$$

where, $a(h_{re})$ is the correction factor for the receiver antenna height, h_{te} is the transmitter antenna height in m, h_{re} is the receiver antenna height in m, f_c is the center transmitting frequency in MHz, d is the transmission link distance in km and B is a correction factor as regards the percentage of area covered by the building.

***C.* Ericsson 9999 Model**

Ericsson provided the following model parameters $a_{o,}$ $a_{1,}$ $a_{2,}$ and a_3 which are constants of the environment whose values are 36.2, 30.2, 12.0 and 0.1 and 43.2, 68.93, 12.0 and 0.1 for urban and suburban areas. The mathematical expression is given by:

$$PL(dB) = a_o + a_1 * \log_{10}(d) + a_2 * \log_{10}(h_{te}) + a_3 * \log_{10}(h_{te}) * \log_{10}(d) - 3.2 * (\log_{10}(11.75))^2 + g(f) \quad (7)$$

$$g(f) = 44.49 * \log_{10}(f_C) - 4.78 * (\log_{10}(f_C))^2 \quad (8)$$

where, $g(f)$ is the frequency correction factor, h_{te} is the height of the transmitting antenna in m, d is the transmission link distance in km and f_c is the transmitting frequency in MHZ.

***D.* Knife Edge Model**

Basically the model formulation assumed that objects in the path of signal propagation have a knife edge point. The model mathematical expression is given by:

$$L_{KNIFE-EDGE}(dB) = L_{FS} + L(v) \quad (9)$$

$$L_{FS}(dB) = 32.4 + 20 * \log_{10}(f_c) + 20 * \log_{10}(d) \quad (10)$$

$$v = 2\left|\sqrt{\frac{\Delta d}{\lambda}}\right| \quad (11)$$

$$L(v)(dB) = 6.9 + 20 * \log_{10}\left|\sqrt{v^2 + 1} + v\right| \quad (12)$$

where L_{FS} is the free space loss in dB, $L(v)$ is the diffraction losses in dB, □d is the different in length of the line of sight path in m, v is the diffraction coefficient, f_c is the transmitting frequency and d is transmitter to receiver distance in km

Field Measurement Campaign

The field strength measurements campaign for this study was conducted for four television transmitters at UHF band in the built up areas of Osun State, Nigeria. Four selected routes were covered during the field strength measurement campaign as shown in Figure 2. The routes spanned urban and suburban areas with altitude variations. The four television stations (Nigeria Television Authority Osogbo Channel 49 on 695.25 MHz, Nigeria Television Authority Ile Ife Channel 39 on 615.25 MHz, Osun State Broadcasting Corporation Channel 32 on 559.25 MHz and New Dawn Television Channel 22 on 479.25 MHz) frequencies were all inputted into the frequency analyzer and the drive test for the measurement campaigns were done at an average speed of 40 km/hr. Signal path losses were estimated from the measured signal field strength in dBm.

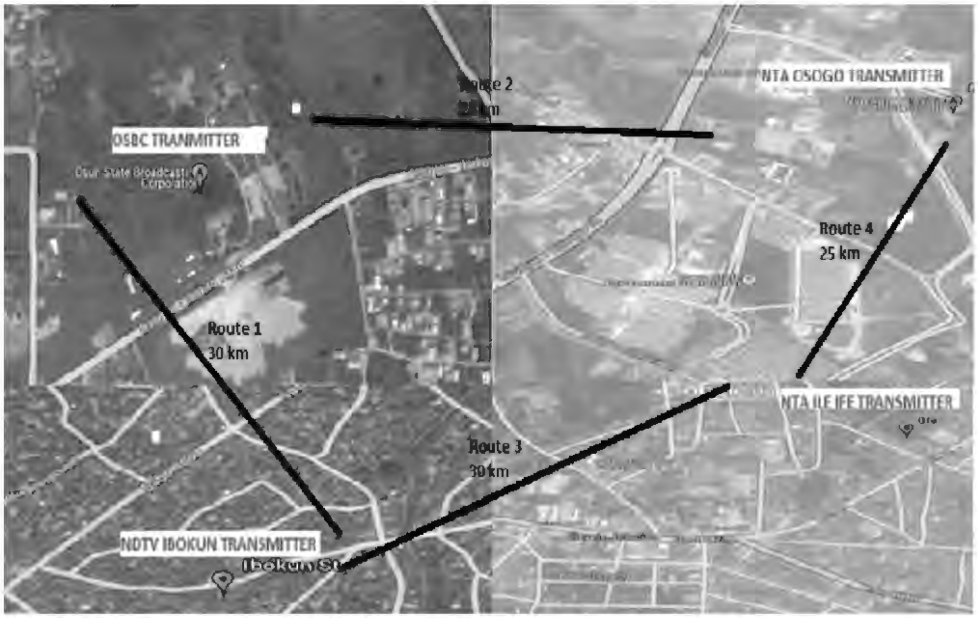

Figure 2: Transmitters position and measurement routes layout.

Results and Discussion

Figure 3 depict the path profile for the measurement routes considered in this work; the altitude measured in (m) was plotted against the radial distance from each transmitter in (km) so as to pictorially represent the altitude variation along the measurement routes.

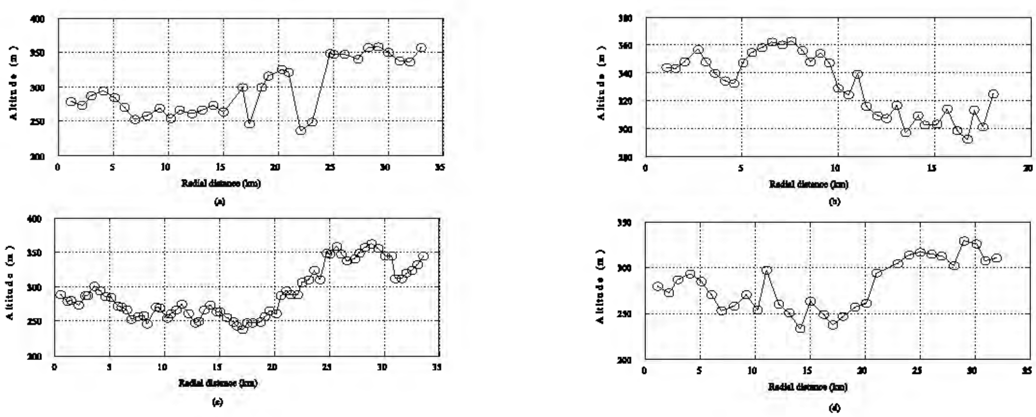

Figure 3: Graphical depiction of the terrain profile along (a) Route 1 (b) Route 2 (c) Route 3 and (d) Route 4

The altitude variation along the terrain varies between 240 m to 360 m placing the measured data to be between 120 meters of altitude variation thereby leading to changes in longitude and latitude of signal measurement points. The variation effects on measured data was observed and discussed in relation to the models' correction factors.

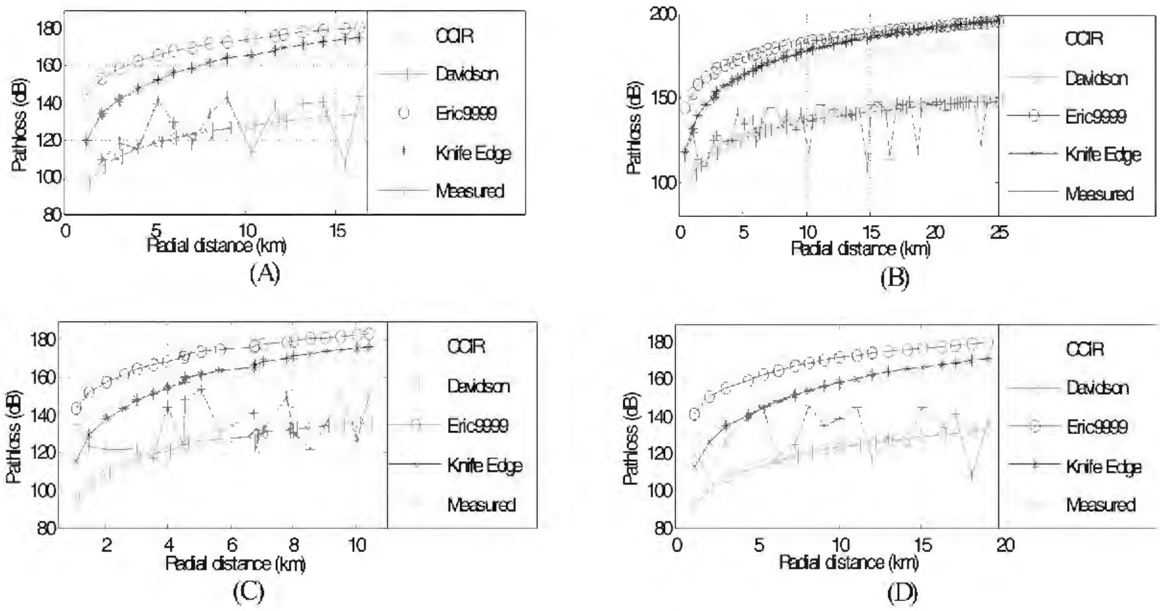

Figure 4: Graphical depiction of measured and predicted path loss along route 1 for (a)NTA Osogbo Ch. 49 (b) NTA Ile Ife Ch. 39 (c) OSBC Ch. 32 and (d) NDTV Ch. 22

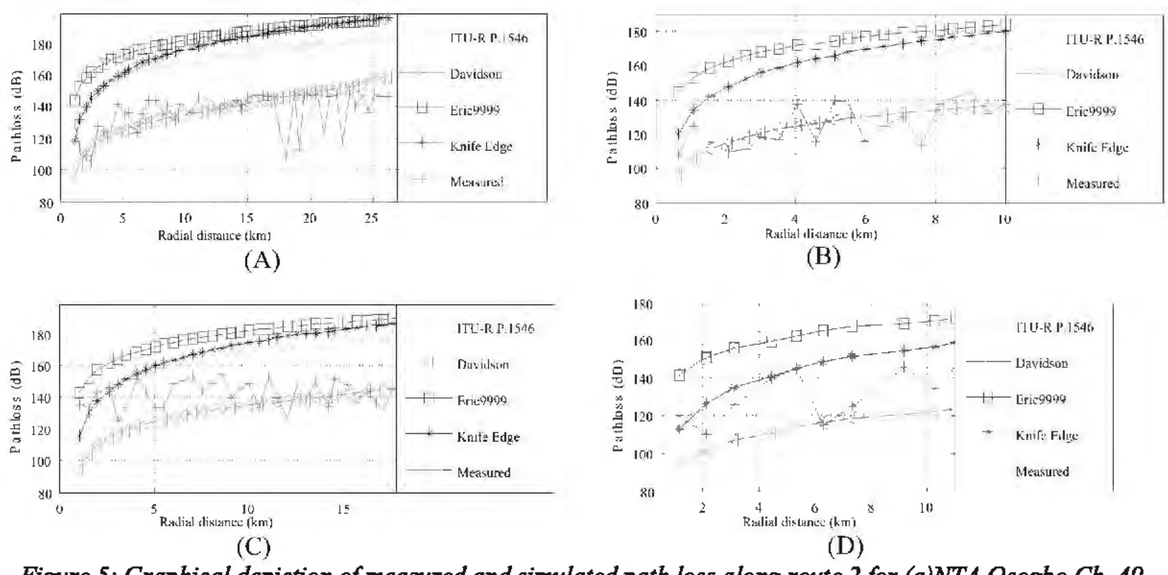

Figure 5: Graphical depiction of measured and simulated path loss along route 2 for (a)NTA Osogbo Ch. 49 (b) NTA Ile Ife Ch. 39 (c) OSBC Ch. 32 and (d) NDTV Ch. 22

Figures 4 and 5 show the graphical representation of measured and predicted path losses along routes 1 and 2. In Figures 4 and 5, Davidson path loss prediction values are more centered averagely around the measured path loss values while CCIR, Ericsson-9999 and Knife edge models predicted path loss values show over prediction of the measured path loss values. The knife edge path loss model is partly analytics and empirical, without any correction's factors incorporated into the model equation, to cater for multipath and shadowing effects which resulted from the terrain description highlighted in section 2.2. This may hinder the performance of the model. Figures 6 and 7 depict the amount of uncertainty present in the predicted values of the models in contention for the four television transmitters.

Although uncertainty computation assumed an absolute value for the mean error which nullify the over and under prediction scenario observed from the graphical depiction earlier mentioned, this assumption put the Knife edge model in better position ahead of Ericsson - 9999 model for all the transmitters, likewise Davidson model for NDTV transmitter. In this regard, the computation of the Root Mean Square Error for further clarification was necessitated for proper study of the importance of model correction's factors and its application in path loss prediction.

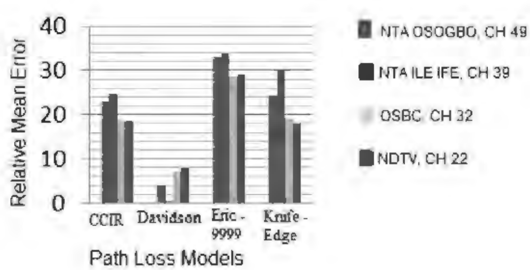

Figure 6: Relative mean error along route 1

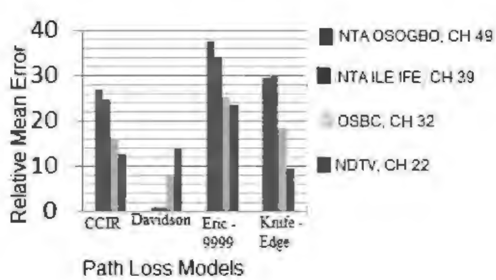

Figure 7: Relative mean error along route 2

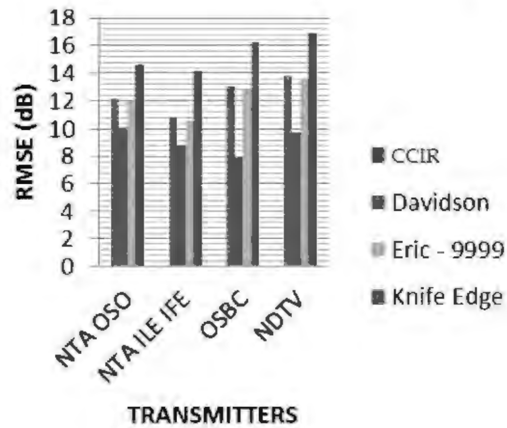

Figure 8: RMSE along route 1

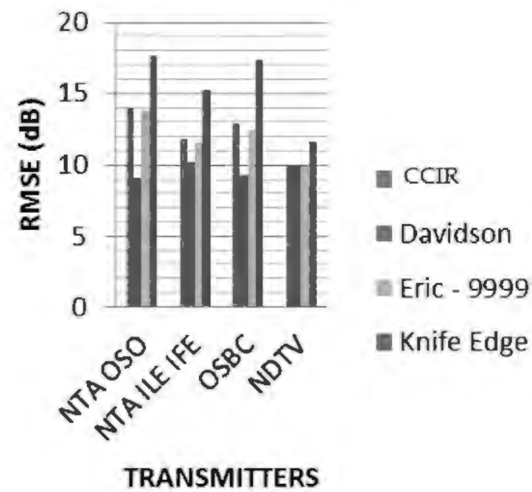

Figure 9: RMSE along route 2

The RMSE results presented in Figures 8 and 9 give the clear distinction of the efficacy of all the models in contention. An acceptable RMSE value was set to within 0 - 10 dB [12] and in Figure 8 Davidson model pass the fitness test with RMSE values 8 dB, 8.5 dB, 9.8 dB and 10 dB for OSBC, NTA Ile Ife, NDTV and NTA Osogbo transmitters respectively, while in Figure 9 Ericsson model also pass the fitness for NDTV transmitter with an RMSE value of 10 dB, in the same view the threshold value of 10 dB was used to gauge the predictability of the knife edge model and its RMSE values was found to be above 15 dB except for NTA Ile Ife and NTA Osogbo transmitters along route

1 and NDTV transmitter along route 2 where an RMSE values of 14 dB, 14.3 dB and 15 dB were observed.

Conclusion

In this work, we studied the effect of multipath and shadowing on the predictability of a semi – empirical path loss model alongside three other empirical path loss models commonly used in predicting signal path losses in the terrain of Osun State, Nigeria. Insightful use of statistical tools in analyzing the dataset was employed in the analysis of the predicted and measured path loss value along four major routes in Osun State, Nigeria. The performance criterion was based on RMSE values set within the range of 0 – 10 dB for better fitness. Although other statistical gauging tools (like Mean Error and Relative Mean Error) were employed for preliminary investigation of the model with least error. In this context, Davidson empirical model tends to have passed the fitness test among the empirical models, while Knife edge model was found to fail the fitness test within the benchmark set in this research. Some of the results presented clearly show that the basis of the formulation of knife edge model were not strong enough to contend fitness with full empirical models in a conventional environment with diverse obstacles.

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