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INVESTIGATION OF ERROR BOUNDS OF EMPIRICAL PATH LOSS MODELS AT UHF BAND IN ONDO STATE, NIGERIA

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ABSTRACT

Predictive propagation models have been extensively employed in the prediction of radio signal coverage, interference analysis and determination of available TV white space for secondary users. Deployment of these predictive models in a different environment other than the one initially designed for has resulted in high prediction errors. Error bounds on the effectiveness of the models at predicting path loss for seven empirical path loss models is investigated for Ondo State in South West Nigeria. The models employed for the analysis are the Hata-Davison, Hata, CCIR, Cost 231, ECC33 and Okumura model and the free space path loss (FSPL) model. Measurements of the signal strengths in four major routes in the Ondo State that span through Urban, Suburban and Rural areas were conducted. The Ondo State Terrestrial TV station on channel 23 operating at 487.25 MHz in the UHF frequency band was employed for this investigation. The measurements were taken along the four routes of concern at some interval and the predicted path loss were then calculated using the five predictive models for the adopted routes and these were compared with the measured path loss. The result was used to calculate and analyse the error bound which was used to determine the mean error, predictive error, spread correlated mean square error, Spearman correlated error and the root mean square error for the adopted predictive models of the routes under consideration. Results from the investigation shows that none of the model gives an RMSE close to the acceptable range of 6-8 dB but the Hata-Davison has the closest value. Therefore, turning or optimizing Hata-Davison model would help in reducing the RMSE values within the acceptable range of 6-8 dB.

Keywords: path loss, TV white space, propagation model, geo-location data base, spectrum.

1. INTRODUCTION

Television spectrum white spaces (TSWS) are the geographical locations with little or no presence of signal from the nearby transmitting stations and this will afford frequency reuse of that propagation frequency in such locations for secondary purposes without performance degradation and interference challenge of the television (TV) broadcasting in the remaining areas and other incumbent services anywhere [1]. TV White spaces also are vacant, unused or interleaved frequencies located between broadcast TV channels in the Very High Frequency / Ultra High Frequency (VHF/UHF) spectrum, which range between 54 MHz and 806 MHz [2]. The VHF range includes channels two to thirteen (2 – 13), located between 30 and 300 MHz on the electromagnetic spectrum, while the UHF range includes channels fourteen to fifty-one (14 – 51), located at 300MHz to 3000MHz above [2].

In the recent times, there is a contention of interference inducement by white space devices (WSDs) to licensed incumbent operators in the TVWS. This in no small measure hinders the proliferation of future wireless networks in the television band, which has greater transmission range and better penetration property when compared to the higher frequency bands [3].

Extensive research is on-going to proffer solutions to this challenge. Among others is the use of geo-location databases for detection of TVWS and sophisticated propagation modelling to compute the white spaces at any given location. This detected TV white space can then be used for transmission by secondary users without interference challenge to the nearby incumbents licensed broadcasting stations [4-5].The accuracy and guaranty of geo-location databases for high protection of the incumbents spectrum from interference and determination of the protection area of the TV transmitters is largely dependent on the accuracy of the propagation models for the prediction of the TV signal attenuation (path loss) over distances [6-7].

In this paper, an investigation is conducted on the error bounds of seven empirical path loss models at UHF in Ondo State, Nigeria in a bid to establish which of them can best be used for geolocation data base approach of TVWS prediction. Field measurement was conducted in the UHF band along four major routes that spanned through the urban, suburban and rural areas. The measured field strength was converted to path loss and is compared with the path loss predicted by the empirical models. The chosen models are Free Space Path Loss model (FSPL), Hata model, Hata-Davison model, Okumura Model, CCIR model, ECC-33 Model and the COST 231 model.

2. REVIEW OF RELATED WORKS

There are myriads of past related works to which this concept is closely related. In [9], field strength measurement in VHF and UHF band in urban, suburban and rural areas of Kwara State, Nigeria, using existing empirical models was conducted. Five performance metric such as, Route Mean Square Error (RMSE), Spread Corrected Route Mean Square Error (SC-RMSE), Error Distribution and Spearman Rank Correlation Coefficient were employed to evaluate the performances of the prediction models. The path loss prediction from radio mobile software using Longley Rice Model with irregular terrain was conducted in [10]. The actual spectrum measurement and the comparison of the values of the path loss obtained from the measurement against those predicted by the propagation models at the University of the Western Cape, in Cape Town, South Africa were carried out. While the prototype of the map of available UHF channels in Nigeria using buffering and Kriging operations was developed in [11], a study on the availability of TV white space within the 470 and 790 MHz UHF band was undertaken in [12]. Performance analysis of nine empirical path loss models in VHF and UHF bands was conducted in [13], and the results were compared with those measured from four television transmitters along five routes of Osun State, Nigeria, Their results showed that Hata and Davidson models provide best fit consistently in all the measurements routes. Also, an optimized path loss model for predicting TV coverage for secondary access was proposed in[9] in which statistical analysis was employed to determine the model with least errors and further optimization work was carried out on Hata - Davidson's model for better fit. Comparative analysis of propagation path loss models with field measured data was conducted by [14] for the city of Narnaul (Haryana, India), comparative analysis of propagation path loss models was used with measured data obtained from field measurements of the city. The results showed that out of the six contending empirical path loss models, Okumura model provides a good fit in urban and suburban environments.

Investigation of radio waves propagation models in Nigerian rural and sub - urban area was also investigated by [15]. The effectiveness of the Okumura-Hata model in a typical suburban area within the northern part of Nigeria was analyzed using a GSM base station at 900 MHz band. The field measurement results were compared with Okumura-Hata model for rural and suburban area, which indicated the least variation with Okumura-Hata model for suburban areas and at the end it was concluded that there are variations between field measurement results and the existing models.

Modification of the Hata empirical propagation model for application in VHF band in Edo State, Nigeria was investigated in [16]. Quantitative measurement for Nigeria Television Authority (NTA) operating on 189.25MHz frequency in Edo State Nigeria was conducted. The result showed that the applicability and suitability of Hata propagation model in Edo State do not fit in properly as the value of the RMSE obtained is in excess of 7dB which is not allowed for radio prediction. Quantitative analysis of the available TV white space in the 470-590MHz UHF TV band for four zones in India was also conducted in [17]. An approach was presented through the use sophisticated propagation models in a senseless database driven white space network; the result shows a scalable architecture of geo-location databases that can be used for TV White space prediction in [18]. In [19] path loss model for radio wave propagation at VHF/UHF bands using electric field strength measurement over Ilorin middle belt, Nigeria was conducted. They investigated the suitability of propagation model for Ilorin, Kwara State, considering two transmitters. Results showed that the empirical models neglected the actual terrain profile for television broadcast in Ilorin with Okumura model standing as the most suitable path loss. The impact of TV viewership on TVWS was considered in [20], it was concluded that, there is a significant potential in secondary usage of TV spectrum for opportunistic access. Malawi TVWS pilot network performance analysis was conducted in [21] using basic performance metrics like throughput, latency, SNR. Investigation was conducted into the propagation profile and signal strength variation of VHF signal in Ekiti State, Nigeria in [23]. In [24], signal strength variability was conducted in Ondo State, Nigeria, but the research did not considered the propagation path loss through predictive models and the research done in other State of Nigeria cannot be adopted for Ondo State because the terrain are not the same. Propagation models cannot be generally adopted because of difference in terrain across region [25]. It is needful therefore for measurement to be conducted in Ondo State Nigeria in a bid to discover which of the predictive can best be used to predict the TVWS in the region.

3. DATA COLLECTION

The investigation was conducted in Ondo State Nigeria located between latitude 7^{0}10' North and longitude 5^{0}, 05'East with a landmass of 15,300km^{2}. The state capital is Akure. The state is characterised with complex terrain due to the presences of deep valley and mountains coupled with thick vegetation along the routes of measurement. Four routes were covered during the measurement. The routes are Akure-Ikare via Owo, Akure-Ikere via Iju, Akure-Ondo, and Akure-Idanre. All the four routes are characterised with hills, valley with heavy vehicular traffic during the measurement. Ondo State Radio-Vision Corporation (OSRC) located at Orita Obele in Akure, (Longitude 5.2^{0}E, Latitude 7.3^{0}N), was employed for the investigation. The transmission parameter of OSRC is shown in Table-1. The Dagatron TM10field strength meter was used for the measurement of the field strength at some interval while a global positioning system (GPS) Garmin MAP-76 was used to measure the latitude and the longitude at the point of measurement. This was thereafter used to calculate the distant from the base station to the point of measurements. Measurement of the signal field strength and the coordinates were conducted at regular interval and recorded in a PC along each route for further processing to compute the path loss.

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Table-1. Transmission parameters of OSRC at487.25 MHz of UHF.

Channel	23 at UHF Band
Frequency (vision)	487.25 MHz
Polarization	Horizontal
Transmitted Power	24kW
Transmitted Power Capacity	40kW
Antenna Power Gain	15dB
Height of Antenna	304m
Transmitting Aerial	Andrews ATW series

4. PATH LOSS PREDICTION METHOD

The accuracy of any particular model in a given environment depends on the fit between the parameters required by the model and those available for the area of concern. The Okumura model [26] is an empirical model based on extensive drive test measurement made in Japan at several frequencies within the range of 150 MHz -1950 MHz and further extrapolated to 3000MHz. It was developed for macro-cells with cells diameter in range of 1 km to 1000 kmtaking into account several propagation parameters such as the environment and terrain irregularity. The Hata model [27] which is an extension of the Okumura model is an empirical formulation of the graphical path loss and is valid from 150 MHz to 1500 MHz. It presented the urban area propagation path loss as a standard formula along with additional correction factors for applications in other areas such as the sub urban and rural areas.

The ECC-33 model [28] was developed by the Electronic Communication Committee. It is generally used for fixed wireless access (FWA). The frequency of measurement is up to the GHz frequency range. The COST-231 model [29] is derived from the Hata model which depends on four parameters for the prediction of propagation loss. The model is widely used for predicting path loss in mobile wireless network. It is designed for frequency band from 500MHz to 2000MHz.

The CCIR model [30] which is also a derivation from Hata Model provides supplementary correction factor for percentage of area covered by buildings. The Hata-Davison [31] is also an extension of Hata model which included six correction factors to the Hata models in which the distance correction factor extends the range to 300 km.

5. PERFORMANCE METRICS

The performance of the seven predictive models is evaluated through the following error bounds:

The prediction error

The prediction error, ε, is the difference between the measured path loss (P_i) at distance i, and model's predicted path loss ($P_{m,i}$) [25] and is evaluated as.

$$\in_i = P_i - P_{mi} \quad (1)$$

Other sub metrics are the maximum and mean prediction error of sample (nj)

$$\text{Max Error} = \max i\ (\varepsilon_i) \quad (2)$$

$$Mean\ Error = \frac{1}{n_j}\sum_i^j \in_i \quad (3)$$

Root Mean Square Error (RMSE)

Root Mean Square Error (RMSE) also known as Root Average Squared Predication Error (RASPE) is the most apparent metric for analyzing error of predictive models. The prediction error values were computed using equation (1) for each model as a function of distance from the transmitter. The overall RMSE for a given model m, for a given data set n is defined as [25];

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|\in_{m..i}\right|^2} \quad (4)$$

Spread Corrected Root Mean Square Error (SC-RMSE)

Spread Corrected Root Mean Square Error (SC-RMSE) helps to extract the impact of dispersion from the overall error. This has the effect of reducing the error associated with a noisy link. Computing SC-RMSE is similar to that of RMSE; the only deference is that the error is obtained by subtracting the standard deviation from the absolute value of the error. The SC-RMSE is computed as [25]

$$SC - RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left|\in'_{m,i}\right|^2} \quad (5)$$

where

$$\in'_{m,i} = \left|\in_{m,i}\right| - \sigma_i \quad (6)$$

The Spearman's Rank Correlation Coefficient (P)

This is a nonparametric measure of statistical dependence between the measured and predicted path losses across the links. It assesses how well the relationship between two variables can be described using a monotonic function. A perfect Spearman correlation of +1 or −1 occurs when each of the variables is a perfect monotone function of the other. The Spearman's Rank correlation coefficient is defined as:

$$P = \frac{\sum_i \left(P_i - \overline{P}_i\right)\left(P_{m,i} - \overline{P}_{m,i}\right)}{\sqrt{\sum_i \left(P_i - \overline{P}_{m,i}\right)\sum_i \left(P_i - \overline{P}_{m,i}\right)^2}} \quad (7)$$

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where, $P_i$and $P_{m,i}$are the mean measured path loss at distance i, and mean model's predicted path loss respectively.

6. RESULTS AND DISCUSSIONS

Figures 1-4 shows the graphical illustration of measured and predicted path losses along the four routes adopted for the investigation.

Figure-1 shows the comparison of the measured path loss with the models predicted path loss as a function of distance for Akure-Ondo Ore Route. It can be observed that the ECC-33, Cost 231, CCIR, Hata and Hata-Davison Models overestimated the measured path loss with a close fit by the Hata-Davison model. The FSPL and Okumura models are seen to underestimate the path loss over the region of concern. Hata-Davison model performed best with RMSE value of 16dB closely followed by the Hata model with RMSE of 17dB. The ECC-33, Cost231, CCIR, Okumura and FSPL models all perform poorly with RMSE of 20 dB, 27dB, 27dB, 22dB and 25dB respectively. In term of SC-RMSE, Hata-Davison performed best with a value of 15dB with FSPL, Okumura, Cost231, CCIR and Hata with SC-RMSE values of 16 dB, 15.7dB, 15.6 dB, 18 dB, 18.5 dB, and 15.6 dB respectively Figure-2 shows the comparison of the measured path loss with the predicted value as a function of distance for Akure-Idanre route. It can be observed from the plot that all the predictive model overestimated the path loss except the Okumura and the FSPL models. The Okumura model is seen to provide some close fit between 7.5 km and 15km of the route. However, the Hata-Davison has the best fit with RMSE of 14.3dB and SC-RMSE of 12.4 dB. The Cost 231 has the worst result with RMSE of 25.4 dB and SC-RMSE of 14.1dB.

In Figure-3, the comparison of the measured path loss with the predictive value as a function of distance is shown for Akure-Ikere route. The Okumura and the FSPL underestimated the path loss for this route while the measured path loss is seen to cut across other predictive models. Cost 231 performed better with RMSE of 16.23 dB and SC-RMSE of 15.92 dB.

The comparison of the measured path loss with the predictive value as a function of distance is shown for Akure-Owo route in Figure-4. Hata Davison is seen to have a close fit with the measured path loss between 20km and 30km while the Okumura and the FSPL is seen to underestimate the path loss in this route. The Hata-Davison provided the best fit with RMSE of 18.2dB and SC-RMSE of 17dB. The worst result is provided by the FSPL with RMSE of 40.7 dB and SC-RMSE of 20.5 dB.

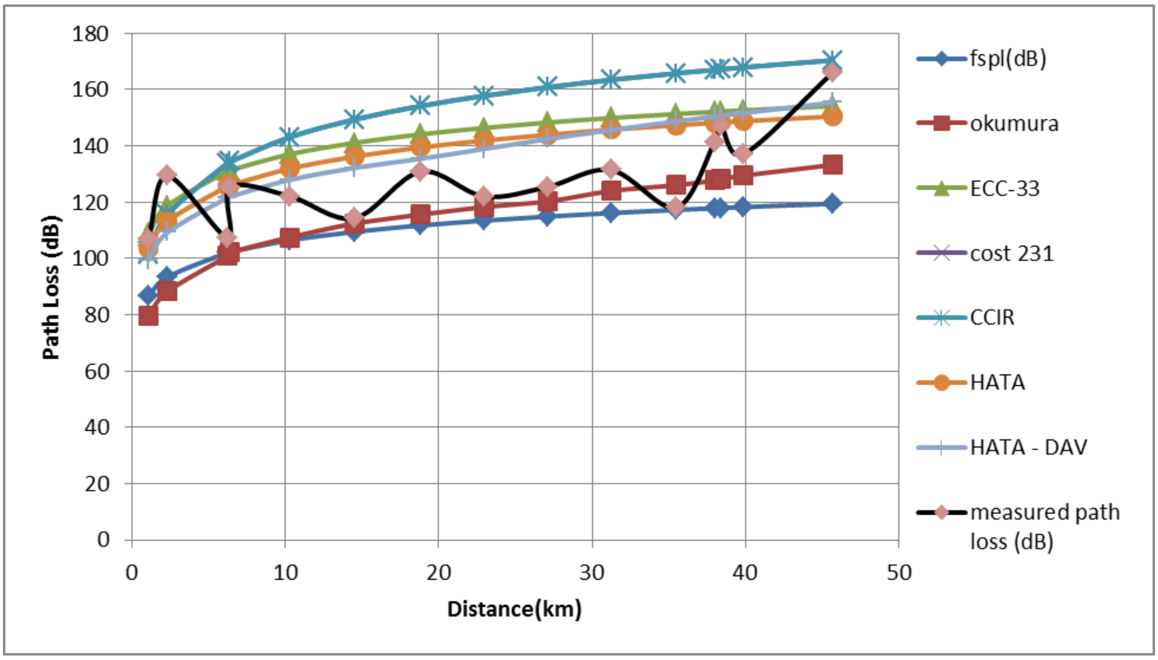

Figure-1. Path loss prediction for Akure-Ondo-Ore Route.

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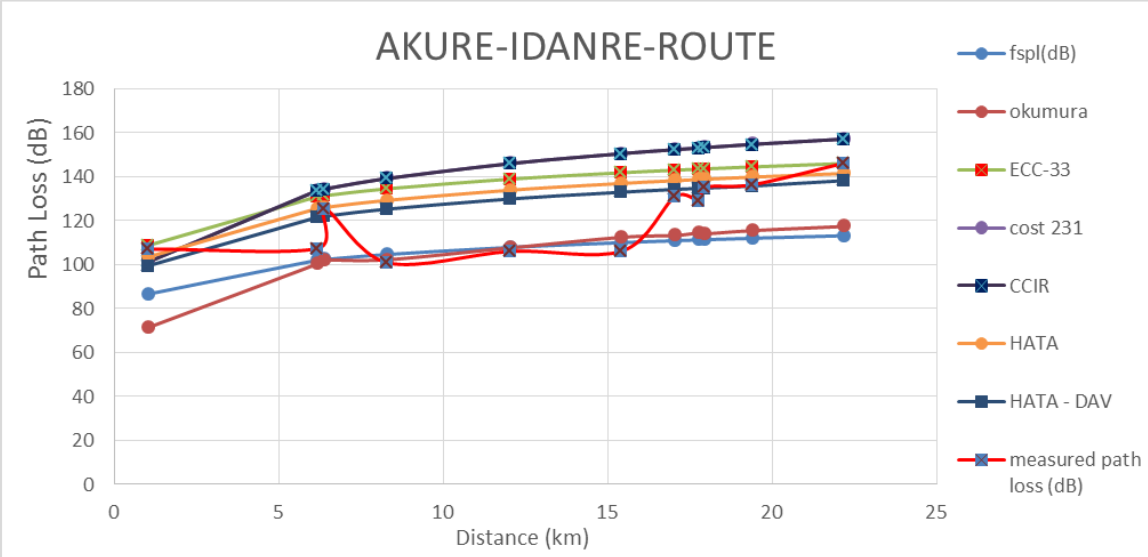

Figure-2. Path loss prediction for Akure-Idanre Route.

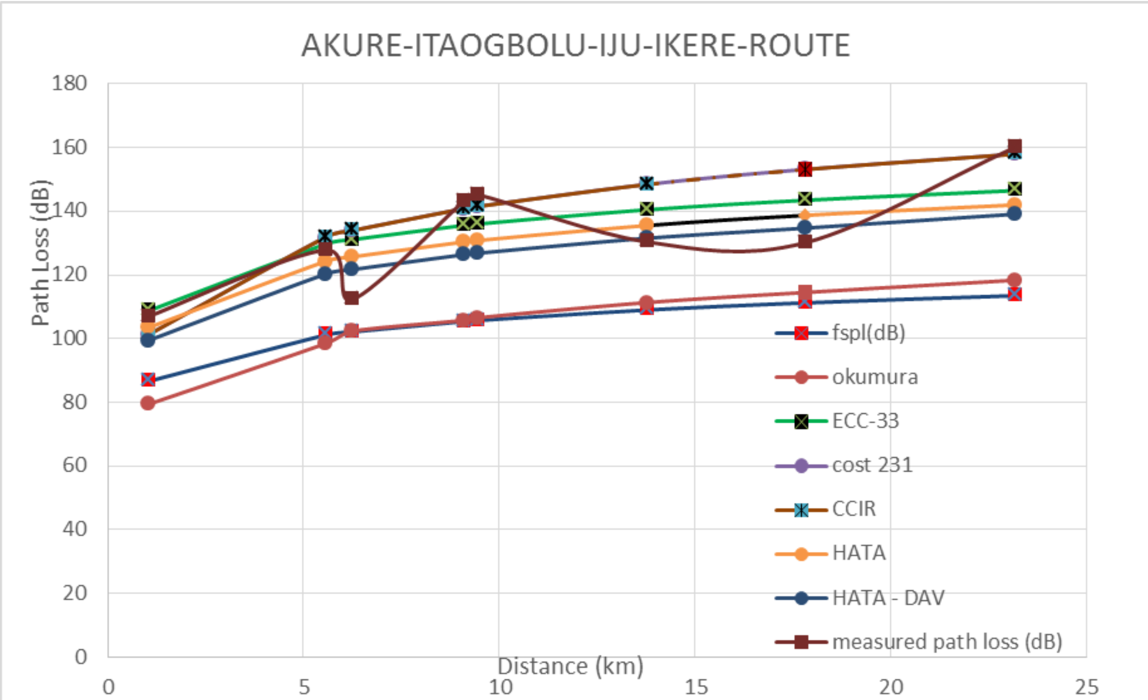

Figure-3. Path loss prediction for Akure-Ikere Route.

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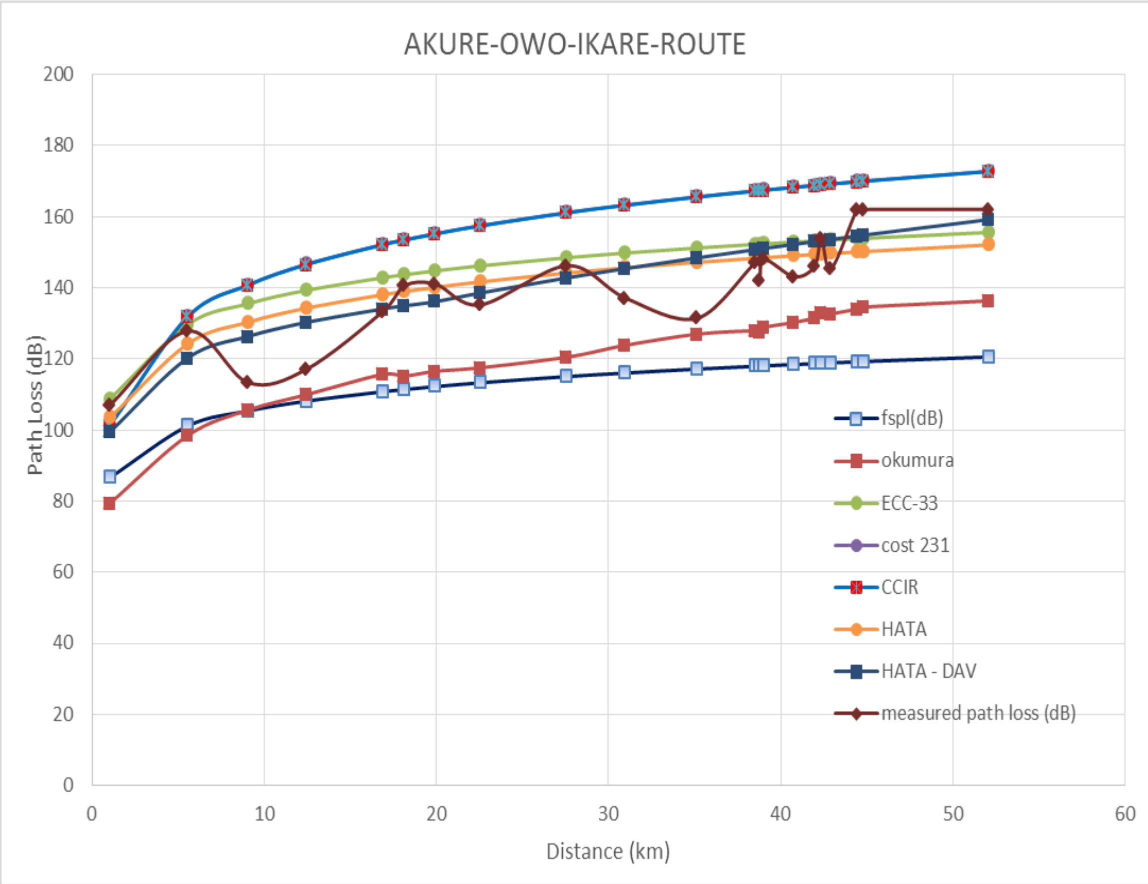

Figure-4. Path loss prediction for Akure-Owo-Ikare Route.

Figures 5 and 6 shows the statistical values of the RMSE and the SC-RMSE. It is noteworthy that in all the routes, Hata-Davison has the least values except in Akure-Ikere route where the Cost231 perform better with RMSE value of 16.2 dB.

The mean error values of all the model along the four routes is shown in Figure-7. It can be observed that Hata-Davison gives a closer value zero. Hata, CCIR, ECC-33 and Cost 231 also give fair results but the FSPL and the Okumura model give a poor result.

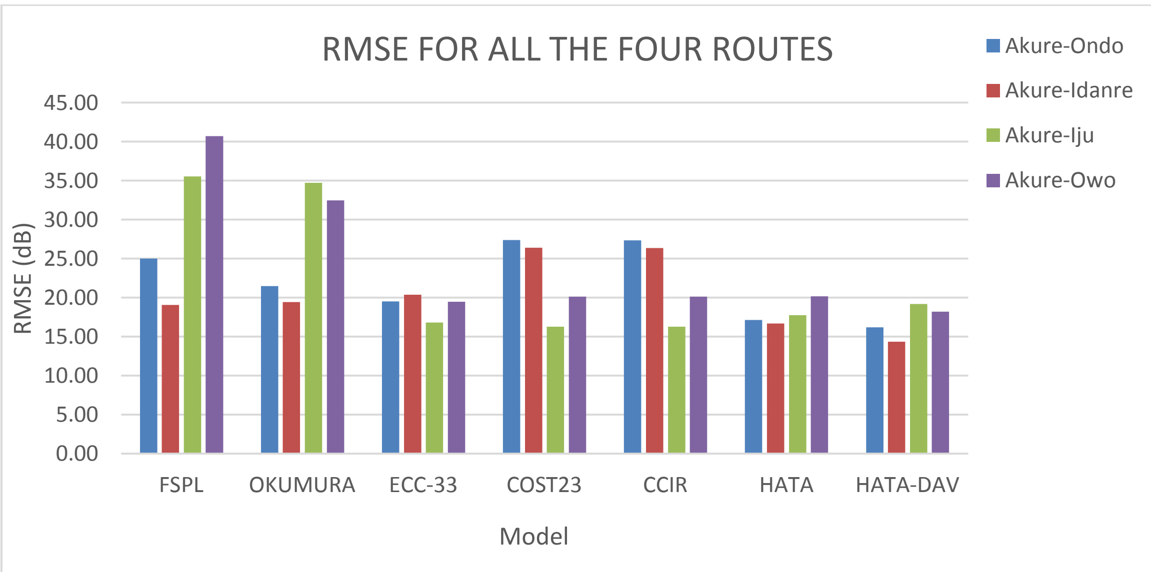

Figure-5. Root mean square error for all the four routes.

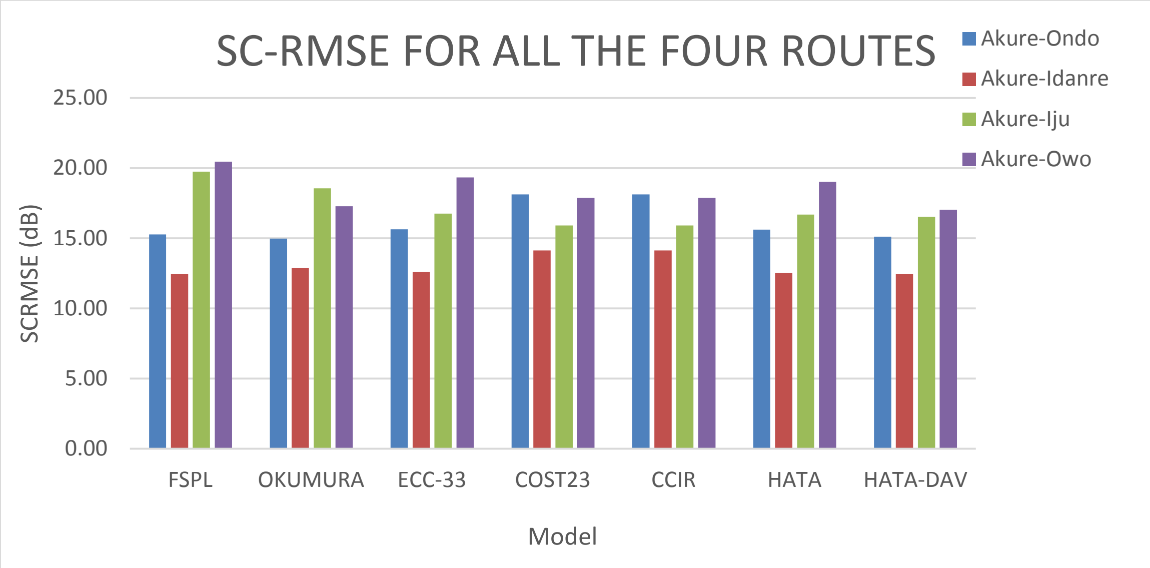

Figure-6. Spread corrected root mean square error for all the four routes.

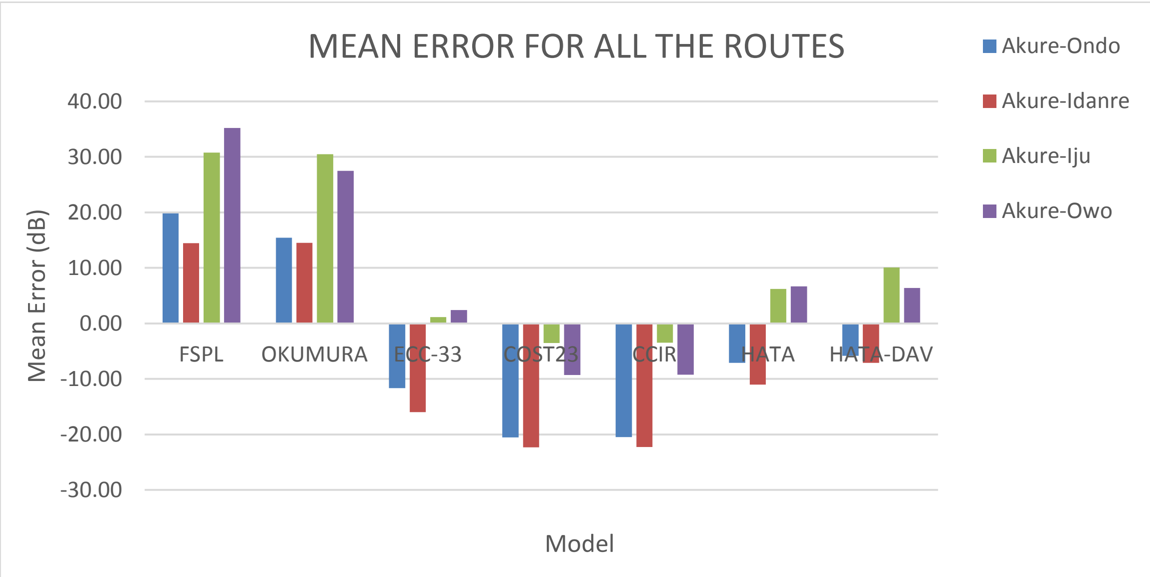

Figure-7. Mean error for all the four routes.

The prediction error as a function of distance for Akure-Ondo Ore route is shown in Figure-8. The shape of the error spread looks the same for all the models. The Okumura and the FSPL is seen to have positive error prediction error indicating they underestimated the path loss. The other models are seen to over-estimate the path loss. Also it is observed that none of the model is within the ±7 dB range.

Figure-9 gives the rank correlation between the measured and the models' predicted value. In term of this metric, the correlation is weak along AKure-Ikere routes and Akure-Ondo routes with value less than 0.5 at P< 0.001. For Akure-Idanre and Akure-Ikare routes, the correlation is fairly good with value greater than 0.5 at P<0.001. However, this metric does not provide consensus on which model that perform best at rank ordering but shows correlation between the measured and predictive path loss for all the routes.

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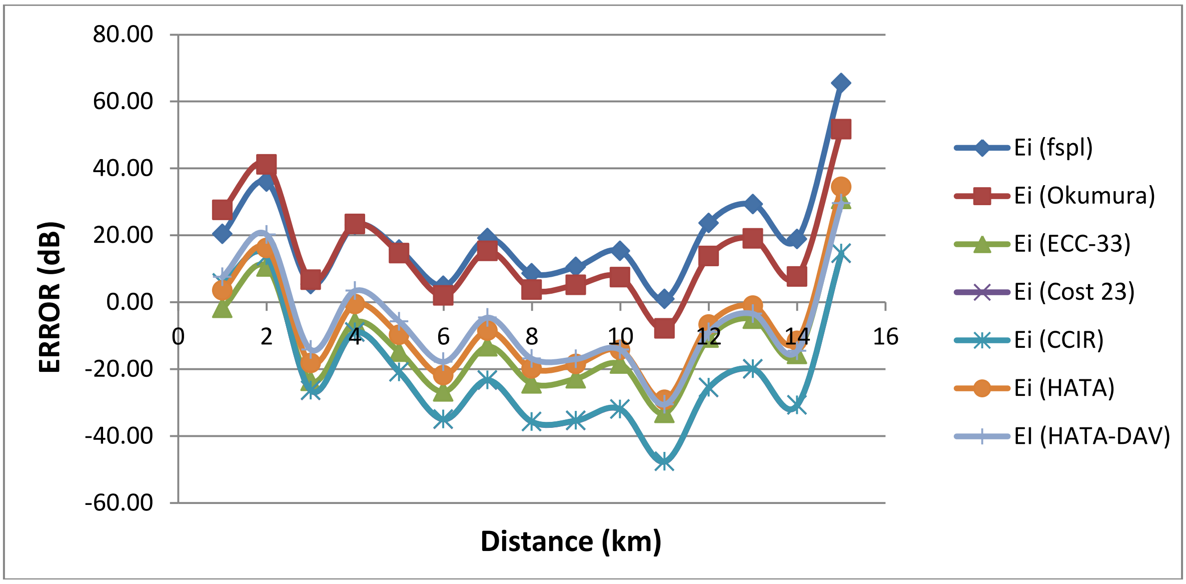

Figure-8. Prediction error for Akure-Ondo Ore Route.

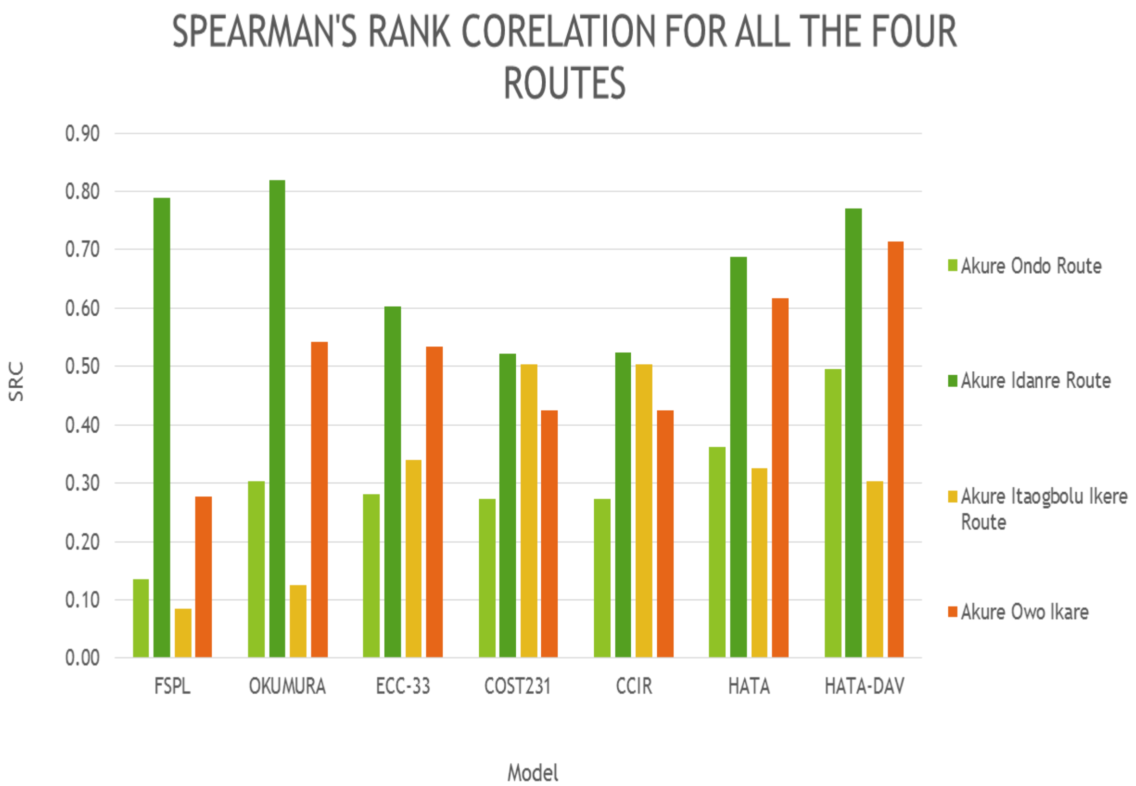

Figure-9. Spearman rank correlation for all the four routes.

7. CONCLUSIONS

In this paper, the error bound on the efficacy at predicting path loss for seven predictive path loss models based on field strength measurement along four major routes in Ondo State Nigeria at the UHF band are provided. The performance metric employed are the RMSE, SCRMSE, mean error, prediction error and the Spearman rank correlation. From the findings, the Hata-Davison models provide the minimum errors along three of the four selected routes. Further results on the error spread as a function of distance for all the routes revealed that Hata-Davison gives a better fit-over other models. In terms of mean errors, Hata-Davison give a mean values close to zero while the FSPL and Okumura give worst result. Results from the investigation shows that none of the model gives an RMSE close to the acceptable range of 6-8 dB but the Hata-Davison has the closest value. Therefore, turning or optimizing Hata-Davison model would help in reducing the RMSE values within the acceptable range of 6-8dB.

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