Error Bounds of Empirical Path Loss Models at VHF/UHF Bands in Kwara State, Nigeria

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Abstract—Propagation models are used extensively in signal prediction and interference analysis. Peculiarity of these models gives rise to high prediction errors when deployed in a different environmental other than the one initially built for. In this paper, we provide the error bounds on the efficacy at predicting path loss for 10 empirical widely used path loss models. The results show that no single model provides a good fit consistently. However, Hata and Davidson models provide good fitness along some selected routes with measured RMSE values of less than 8 dB. ITU-R P.1546-3, Walfisch Ikegami, ECC, Egli, CCIR and 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 give mean values close to zero. However, COST 231 also provides better skew, while CCIR and ECC gives fair results but ITU-R P. 1546, WI and FSPL give worst results. The prediction errors for Davidson are nearly distributed symmetrically around the mean error of 2.15 dB. It was also observed that, the Gaussian error distribution within the window of ±5 dB dominates the frequency counts. However, the error counts for CCIR model are quite high but spread along the distribution but HATA, FSPL, Walfisch Ikegami and ITU-R P. 5293 models does not follow normal distribution.

Keywords: Error Bound, Path loss, Propagation model, Hata model, Davidson model

I. INTRODUCTION

Today, propagation models are used extensively in coverage planning and optimization, signal prediction, and is found very useful for interference analysis. Path loss models are applied in cellular environments, fixed wireless access systems and TV broadcast systems. It is to be used here for the prediction of television coverage. The success of digital switch over (DSO) solely depends on how careful planning of both frequency and transmits power to be used in DTV transmission. Most studies employ the use of propagation curves such as the ITU Radio communication sector (ITU-R) P.1546-2, P.1546-3 and Hata model for predicting the DTV coverage. These models are built based on measurement conducted in regions that are different from Nigeria and suitability in terms of usage may therefore vary due to environmental factors and terrain profile. Also, peculiarity of these models give rise to high prediction errors when deployed in a different environment other than the one initially built for. These errors may consequently affect secondary operations. It is however not very clear which models give the best fit and what the penalties are for using the models outside the intended coverage area. Interference is not the only issue; the error could also have significant impacts on the deployments of secondary network. For instance Camp et al [1] show that wireless mesh network planned with a given path loss model can massively under or over provisioned as a results of small change in model parameters. Therefore, it is necessary to have accurate assessment of the propagation model in order to choose a better model or to modify so as to achieve high performance.

In this paper, we provide the error bounds on the efficacy at predicting path loss for 10 empirical widely used path loss models. In order to achieve these, field strength measurement was conducted in the VHF and UHF frequencies along seven different routes that spanned through the urban, suburban and rural areas. The measurement results were converted to path losses and are compared with the model’s prediction path loss. The chosen models are Hata [2], COST 231 [3; 4], Walfisch Ikegami [5], Egli [6], ITU-R P.529-3 [7], ITU-R P.1546-3 [8], ECC-33 [9], CCIR [10], Davidson [11] and FSPL [12].

This paper is organized as follows; Section I provides introduction; Section II present the related work; Method of data collection is presented in Section III; Section V presents the results and finally Section VI concludes the paper.

II. RELATED WORK

There are lots of published research that worked on analyzing the efficacy of path loss models. In such cases, the authors often collect measurement data in an environment of interest and make an assessment of whether the models fit in. [13] and [14], provide practical lower bounds on the prediction accuracy of path loss models. In the work, 30 propagation models that have been published in the last 70 years were considered. A large scale measurement was conducted in the diverse set of rural and urban environments. In the end, it was concluded that no single path loss model is able to predict path loss consistently. In [15], a comparative assessment of five models was presented with respect to the
data collected in the urban and suburban environments at 910 MHz. However, the paper does not provide a conclusion about which model gives the best results. [9], provides a comparison of empirical propagation path loss models for fixed wireless access systems based on measurement conducted in Cambridge, UK. It was found that, among the contenders, the ECC-33 model, the Stanford University Interim (SUI) models, and the COST-231 model show the most promise and that SUI model shows a quite large mean path loss prediction error. [16], present a similar results to that in [9]. Also [17] conduct a mobile propagation path loss studies at VHF/UHF bands in Southern India. In the work, field strength was measured at 200, 400 and 450 MHz and their result shows that Hata’s prediction method gave better agreement in all cases. This work is similar to that presented by [18]. Achtzeh et al [19], analyse the accuracy of three widely used path loss models in predicting TV signal strength using data carried out in a medium-sized central European city. In the work, spatial statistics based technique was employed for estimating the coverage. Also in [20], three empirical path loss models i.e. ITU-R P.1546, Hata and ETRI, were used to calculate propagation distances for safe operation of TETRA system on ITU-R P.1546, Hata and ETRI, were used to calculate coverage. Also in [21], three empirical path loss models i.e. ITU-R, Hata and ETRI, were used to calculate propagation distances for safe operation of TETRA system on DTV white space. In [21], IRT model was used to determine the present analogue television coverage in some selected states of Nigeria. The study provides absolute error for ITU-R, IRT and modified ITM models. For all the considered measurement locations, IRT model provides minimum error while ITU-R P.1546-3 has the highest errors compared with the IRT and ITM model within the measurements taken in all the states considered. The study however, doesn’t provide error bound for other widely used models such as Hata. The work presented in this paper is the first of its kind in Nigeria that carries out an extensive analysis of large number of propagation models using large amount of data set produced from real time measurements.

III. DATA COLLECTION METHOD

The propagation measurements were conducted in Ilorin (Long 40°36’ 25”E, Lat 8°25’ 55”N) and its environs within Kwara State, Nigeria. Ilorin is a large city characterized by a complex terrain due to the presence of hills and valleys within the metropolis. Outside the metropolis, the routes are covered with thick vegetation. The altitude of the transmitter’s location is 403.7 m, the altitude can be as low as 150 m when driving within and outside the city. Seven routes were covered during the measurement campaign. The routes are; Olorunshogo via ASADAM, University of Ilorin (UNILORIN) via Pipeline, GAMBARI via Agaka, MURTALA mohd way, Old Jebba RD, OGBOMOSO and BODE-SA’adu.

ASADAM route has regular building structure with dual carriage way. The traffic along the route is relatively fair; however, the route is characterized with complex terrain with varying altitudes. 12, 712 data points were taken along this route. UNILORIN route spans from suburban to urban area. It has very complex terrain; some areas are very high whereas, some parts are very low. Within the University, the road is covered by heavy trees and there was line of sight clearance to the transmitter at some certain interval distance. Immediately after the university gate, there is non-LOS due to the presence of building structures and vegetation. Along the Pipeline, the road is very narrow with average two storey buildings. A total of 24,310 data sample were collected. GAMBARI route is a dense urban area. It is an historical area with very old irregular buildings around. It is very busy commercial area and the roads are narrow. 26,634 samples were collected. MURTALA route has a regular building structure with average of three storey buildings with dual carriage. OLD JEBBA also has a regular building structure with average of two story building with two lane road. BODE-SA’ADU route spans from the urban to rural areas. It has regular building structure with average of two storey building within the city, then outside the city hotspots villages at an average distance of 15 km interval. The route length was 60 km. Ogbomoso route also has regular building structure with average of 2 story building within the city, then outside the city hotspots villages and town at an average distance of 6 km interval. The route length was about 50 km.

NTA Ilorin and Kwara TV transmitters were utilized. NTA transmits on channel 5 at 203.25 MHz while Kwara TV transmits on channel 35 at 583.25 MHz. While the transmission is taking place, a dedicated Agilent spectrum analyzer was placed inside a vehicle and driven at an average speed of 40 km/h along the routes. Field strength was measured continuously and stored in an external drive for subsequent analysis. Total route length and number of points were 169 km and 314,914 respectively. Table I provides details of the analyzer and transmitter.

<table>
<thead>
<tr>
<th>Spectrum Analyzer Agilent N9342C 100 Hz-7 GHz</th>
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<tbody>
<tr>
<td>Displayed average noise level (DANL)</td>
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<tr>
<td>Preamplifier</td>
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<tr>
<td>Resolution bandwidth (RBW)</td>
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<td>Center frequency (f1)</td>
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<td>Center frequency (f2)</td>
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**Antenna Type, Diamond RH799**

| Frequency range | 70 MHz-1 GHz |
| Form | Omni directional |
| Height | 1.5 m |
| Gain | 2.51 dBi |

**NTA Ilorin Transmitter**

| Power | 2.4 kW |
| Frequency | 203.25 MHz |
| Antenna height above the ground | 185 m |
| Cable Type | RFS HEL FEX 512 |
| Impedance | 50 ohms |
| Coordinates | 4°36’ 25”E, 8° 25’ 55”N |
IV PATH LOSS PREDICATION METHODS

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 concerned. The Hata model [2] is an empirical formulation of the graphical path loss data provided by Okumura and is valid in the range 150MHz to 1500MHz. The model transmission distance is up to 20 km and has been widely used to predict analog TV signal. The European co-operative for scientific and technical research formed the COST 231 committee to develop an extended version of the Hata model such that applicability to 2 GHz is possible. This combination is called “COST 231 Model” [3]. COST 231 subgroup proposed a combination of Walfisch [4] and Ikegami [5] models (WI). The model is aimed to improve path loss estimation by including several parameters similar to those of Walfisch-Bertoni [5]. The model distinguishes between the line-of-sight (LOS) and non-line-of-sight (NLOS) and is valid for 800-2000 MHz. Egli [6] model is valid for 90 MHz to 1000 MHz over irregular terrain. ECC-33 model [9] extrapolates the original measurements by Okumura and modified the model parameters to suit fixed wireless systems. The model gives correction factor for urban and medium cities.

ITU-R P.1546-3[8] is a recommendation that describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz. It can be used for calculating field strengths over land paths, sea paths and/or mixed land-sea paths between 1-1 000 km lengths for effective transmitting antenna heights less than 3 000 m. This model has been specifically designed for the purpose of analog TV broadcasting planning.

ITU-R P.5293[7], CCIR[10] and Davidson [11] models were derivative of the Hata model. Hata model had a transmission distance of 20 km; thereafter prediction error becomes higher when used to predict path loss for distance greater than 20 km. ITU-R P.5293 extends the Hata model to a distance of 200 km. The CCIR the model provides supplementary correction factor for percentage of area covered by buildings. In Davidson model, six correction factors were included in Hata model in which the distance correction factor extends the range to 300 km, interestingly for all the three models (i.e. ITU-R P.5293, CCIR and Davidson) path losses at distance of less than 20 km equate to Hata model.

V. RESULTS AND DISCUSSION

Figures (2) to (5) provide the graphical depictions of measured and prediction path losses along the four predefined routes. Fig 2 shows the comparison of the measured path loss with the models predicted path loss as a function of distance for ASADAM route. Within the first 2 km along the route, CCIR model agreed with the measured path loss thereafter, ECC and CCIR over estimates the path loss. Walfisch Ikegami, ITU-R.P.1546-3 and Egli models underestimates the path loss throughout the range of interest. ITU-R P.5293, Hata, Davidson and COST 231 models give better results. For the overall route, COST 231 model provides the best result with RMSE value of 0.4 dB however is fantastic result. For the fact that ITU-R.P.15293 and Davidson models were actually derivative of Hata and the results is expected to be the same for distance of less than 20 km. Hata model turns out to give RMSE value of 10.7 dB and SC-RMSE value of about 4 dB as shown in Fig 6 and Fig 7. in the other hand, ITU-RP.1546-3, Walfisch Ikegami, ECC, Egli, CCIR and FSPL models perform woefully, with higher RMSE and SC-RMSE values of 61.39 dB, 84.8 dB, 70.26 dB, 67.61 dB, 51.13 dB and 113.19 dB respectively.
Fig 4 shows the comparison of the measured path loss with the predicted path loss as a function of distance for BODE SA’ADU route. Within the first 10 km, Hata, Davidson and ITU-R P.5293 models give a good fit with the measured path loss. The recorded mean path losses for the measured, Hata, Davidson and ITU-R P.5293 models are 146.09 dB, 139.63 dB, 144.23 dB and 138.74 dB respectively. However, Egli model underestimates the path loss over the period of the measurements with a mean path loss of 129.96 dB. Within the 10 km, CCIR and ECC models overestimate the path loss. Beyond 10 km, the deviation was high. Similar results were obtained along OGBOMOSO route where Hata, Davidson and ITU-R P.5293 models give a good fit with the measured path loss up to 20 km distance from the transmitter as shown in Fig 5. Fig 6 and Fig 7 show the statistical values for the root mean square error and spread corrected root mean square error. It is noteworthy that for all the measurement routes, Hata, Davidson and ITU-R P.5293 models gives the best RMSE values, except for BODE route where Davidson and CCIR perform better with RMSE values of 14.408 dB and 16.510 dB respectively. Fig 8 shows the mean values for all the models along all the routes. The interpretation of this metric is hard to know whether the model underestimate or overestimates the path loss. However, if the model provides equal amounts of underestimation and overestimation will result to zero mean value or the resulting skewness will be zero. It can be seen that Hata, Davidson and ITU-R P.5293 models give mean values close to zero. However, COST 231 also provides better skew, while CCIR and ECC give fair results but ITU-R P. 1546, W1 and FSPL give worst results. Fig 9 shows prediction error as a function of distance for ASADAM route. The shape of the error spread looks the same for all the models, but COST 231, Hata, Davidson and ITU-R P.5293 fall within the window of ±7 dB. While ECC and CCIR provide high negative prediction error values and ITU-R P.1546, W1 and Egli models give high positive predication errors.
Fig. 8. Mean error

Fig. 9. Prediction error as a function of distance for ASADAM

Fig. 10. Distribution histogram of prediction error for four models
Fig 10 depicts the distribution histograms of the prediction error for four empirical models, in order of fitness. The solid line is the probability density function of a Gaussian (Normal) random variable. In this scenario, Davidson and CCIR models show similar shapes of their probability density functions (PDFs). In Fig 10(a), the prediction errors are nearly distributed symmetrically around the mean error of 2.15 dB. It can be observed that the error distribution within the ±5 dB window dominates the frequency counts. This indicates good fitness of the model in terms of predicting path loss in the region. On the other hand, CCIR model which is the second model that performs better along the route, the prediction error closely follows normal distribution with a mean error of -6.37 dB as shown in Fig 10 (b). The error counts are quite high and spread along the distribution. Hata and ITU-R P. 5293 Model does not follow normal distribution. Despite the mean error for Hata model was found to be 2.2 dB this is comparable with that of Davidson, Davidson model gives a better spread in the error distribution. Therefore, it can be concluded that Davidson model may be found suitable for path loss prediction for the kind of environment under consideration.

VI. CONCLUSIONS

In this paper, we provide the error bounds on the efficacy at predicting path loss for 10 empirical widely used path loss models based on field strength measurement along seven routes in Kwara State, Nigeria. The performance criteria are based on prediction error, RMSE, SCRMSE and mean error. From our findings, Hata and Davidson models provide good minimum errors along some selected measurement routes with measured RMSE values of less than 10 dB. ITU-R P. 5293, 1546-3, Walfisch Ikegami, ECC, Egli, CCIR and FSPL perform woefully, with higher RMSE and SC-RMSE values. Further results on the error spread as a function of distance for ASADAM route revealed that Davidson model gives better fit over Hata; this is perhaps expected since Hata model is only valid for transmission distance of 20 km. In terms of mean value errors, Hata, Davidson and ITU-R P. 5293 models give mean values close to zero. However, COST 231 provides better skew, while CCIR and ECC give fair results but ITU-R P. 1546, WI and FSPL give worst results. The models give small error values within a short range distance. Conclusively, these results indicate that no single model provides a good fit consistently. Therefore, tuning or optimizing Davidson model would help in reducing the RMSE values within the acceptable range of 6-8 dB.

REFERENCES