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PRACTICAL ERROR BOUNDS OF EMPIRICAL MODELS AT VHF/UHF BANDS

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ABSTRACT

Empirical path loss models are widely used to predict signal propagation behavior in an environment. In this paper, a multi-transmitter scenario was used to bound the errors of five widely used empirical propagation path loss models in predicting radio waves propagation in the UHF and VHF bands in Ilorin metropolis, Nigeria. A drive test was conducted using a dedicated Agilent N9342C spectrum analyzer along seven different routes that span urban and open areas. Three transmitters were utilized in the campaign (National Television Authority NTA Ilorin, Harmony FM and Unilorin FM). The prediction error, root mean square error (RMSE), skewness of the error distribution and the relative error were further computed and presented. Furthermore, the performance of the models were also correlated with their design parameters and constraints. The analysis reveals that, of the five models investigated, the error bounds of the ECC model is very high, hence its accuracy for Ilorin terrain, while the three models of Cost-231, Hata and Ilorin (a localized model) were below the acceptable tolerable values for the metrics used and the Egli model falls within a reasonable range of the acceptable values of 6-7dB for urban areas and 10-15dB for Suburban and rural areas. For example, while the ECC model recorded RMSE values of 54.11dB, 52.23dB and 52.41dB for the three transmitters, the corresponding values for the Hata model were; 7.9 dB, 8.37 dB and 10.13 dB, for the COST 231 model: 8.46 dB, 10.09 dB and 9.66 dB and for the Ilorin model, the RMSE values were; 8.51 dB, 8.50 dB and 10.57 dB. The RMSE values obtained for the Egli model are 16.77 dB, 14.50 dB and 10.90 dB respectively. Finally, it was found that the error distribution for each model followed the terrain profile of the routes.

Keywords: Error bound; path-loss; VHF; UHF; Ilorin Model

1. INTRODUCTION

Empirical path loss or propagation models have been widely used to characterize radio wave propagation in different wireless network. The characterization of radio signal is a very exercise in wireless network design, deployment, tuning, optimization and expansion, hence the importance placed on accuracy of methods or techniques adopted to determine it. Since propagation models are mathematical, or in some instance, graphical formulation, intended to approximate actual signal characteristics, there exist differences between the actual and the approximated, predicted or estimated signal characteristics. These differences between the actual and predicted exist for many reasons. One of such reason is that several physical phenomena that impacts on the propagation of signal, all of which is practically impossible to model to produce the exact replica of the actual physical characteristics. Also these physical phenomena vary even within different areas of a geographical environment. Thus, there is bound to be even more pronounced prediction errors when this propagation models are used to characterize signal profile of environments other than the one they are formulated for.

Since propagation models are just predictions of radio signal characteristics, there is the need to determine the suitability of these predictions for an environment. To this end, over the years, there have been different researches carried out in different parts of the world, to determine the suitability of propagation models in profiling signal behavior with emphasis on signal attenuation or path loss in an environment. The value of error between the predicted signal characteristics and the actual is thus an appropriate performance metrics to determine the accuracy and/or suitability of a particular model to the environment of interest. The magnitude of prediction error for each propagation model in an environment need to be determined not only to determine the most accurate model for the environment but also to establish the margin of error of the models.

In this work, five propagation models are used to predict radio signals of two FM radio and one commercial Television broadcasting stations. A measurement campaign along seven different routes in the Ilorin metropolis was conducted to capture radio signal levels at different points along the routes. The measured signal levels were used as the yard stick against which the predicted signal levels (by the propagation models) were compared. Different statistical metrics were also employed in the analysis and determination of the error bounds for each of these models. The chosen models are the ECC, Egli, COST 231, Hata and the Ilorin model. The first four models are widely used for signal prediction globally while the last model is a localized model obtained based on optimizing an existing pathloss model for the environment under consideration.

2. RELATED WORK

The paper in (Ayeni and Owolabi, 1995), discusses the radio propagation aspect of the cellular mobile communication. Authors of (Erceg et al., 1999), using experimental data collected across the United States, presented a statistical path loss model, using a linear curve fitting the decibel path loss to the decibel-distance with a Gaussian random variation about that curve due to shadow fading. Using a simple stochastic model, based on the theory of random walks, the authors of (Franceschetti, Bruck and Schulman, 2004), were able to quantify power losses, using an exponential path loss formula, in place of existing empirical formulae. Four propagation path loss models were compared with measured path loss in sub-urban and rural environments of Mauritius in (Armoogum et al., 2007). The results show that the Hata and extended cost 231 model maintains consistent prediction across the investigated environments.

The author of (Shabbir, 2011), compared the different candidate propagation models for the LTE, using different terrains. They found that the lowest path loss was incurred with the Stanford University Interim model with the COST-231 Hata, the highest in the urban area while the COST-231 and Walfisch-Ikegami incurred the highest path losses in the sub-urban and rural terrains. A review of some empirical path loss models over frequency range of 800-2000MHz was conducted in (Ayeni, et al., 2012) and a comparison of their predicted path loss with measured path loss was done. The results obtained revealed that, of all the investigated path loss models COST-231 is most suitable for Kano. The authors of the study reported in (Bakinde et al, 2012), also did a comparison of the empirical models in some selected urban areas. They found that path loss varies, directly, with frequency and that Hata and COST 231 compete, for predictability throughout their measurements.

The research work of (Faruk, Adediran and Ayeni, 2013a) used ten different propagation models to predict path loss in Ilorin. The work investigated the path loss estimated by each, and by comparison with measured path loss, determined by what magnitude a model over-estimates or under-estimates path loss. The RMSE, spread corrected RMSE (SC-RMSE) and skewness were used in the performance metrics while also presenting the mean error distribution histogram. However, the work did not provide route-specific performance for each model. In (Faruk, Adediran and Ayeni, 2013b), nine (9) different empirical path loss models and five (5) metrics were employed to determine their suitability to predicting TV signal. An extensive field strength measurement was conducted at the VHF/UHF bands along six (6) different routes in the rural, suburban and urban areas of Kwara state of Nigeria. The research shows that no single model provides consistent prediction accuracy along all the routes. However, it should be mentioned that, along some selected routes, Davidson and Hata met the recommended accuracy by the International Telecommunication Union Radiocommunication sector (ITU-R).

The work presented in (Faruk, Adediran and Ayeni, 2013c), used seven (7) empirical models to predict TV coverage in a bid to obtain an accurate prediction/estimation of service contours to facilitate non-interfering effective utilization of TV white space by secondary users. The work revealed divergence between the predictions of the widely known empirical models and the measured model. The researchers in (Faruk, Adediran and Ayeni, 2013d), while investigating the behavior of TV signals, obtained the path loss exponent, standard deviation and partition loss for the city of Ilorin at the VHF/UHF band. In (Faruk, Adediran and Ayeni, 2013e), an algorithm for predicting service contour and determining the availability of TV whitespace was developed. Four path loss models were then used to determine the effective DTV coverage and the no-talk width. Using data obtained from, field strength measurements in urban, suburban and rural areas of Kwara State, Nigeria, the suitability of eight (8) widely used empirical models was determined [Faruk et al., 2014]. The Hata-Davidson's model, as the most suitable was optimized to obtain an improved model called *'Ilorin model'*.

A performance analysis of this optimized model relative to the other model in the study reveals better performance. (Isabona and Obahiagbon, 2014), conducted measurements of received power levels, over a distance, from a fixed WLAN AP, used the values of power levels, so obtained, with some path loss model equations, with a view to obtain the path loss exponent of 1.85, mean path loss intercept of 84 dB. The authors of (Nadir and Suwailam, 2014) determined the RMSE of path loss estimation using Hata model when compared with measured path loss. A comparative analysis of received signal strength prediction models using Okumura-Hata, Cost-231-Hata and Standard Propagation model was the focus of (Oseni et al., 2014). It was concluded that the standard propagation model is most suitable for the city of Ilorin in the GSM 900MHz band.

(Heydari et al., 2014), compared some empirical path loss prediction models with measured received signal strength in the 900 MHz band. Result show that Okumuru- Hata model is the best for the investigated environment. The research work of (Nalineswari and Rakesh, 2015) was aimed at investigating the effect of shadowing on the propagation characteristics of a typical urban environment. Results obtained from measurements done was compared with some empirical models and it was deduced that the Bertoni model is the best for predicting path loss in such an environment. The work of (Siyu, Muqing, and Xiangli, 2015) was an investigation and evaluation of wireless wideband communication in LTE-R system, specifically wireless channel modelling in specific scenario in a passenger railway line. They investigated various fading effects such as Doppler effect, shadow fading, time delay spread and path loss.

3. METHODOLOGY

This section is divided into two. The first part describes the measurement set up and the second part describes the empirical models adopted in the work.

3.1. Measurement Campaign.

The propagation measurements were conducted in Ilorin (Long 4^o 36’ 25”E, Lat 8^o 25’ 55’’N) within Kwara State, Nigeria. Seven routes (Routes 1-7) were covered during the measurement campaign. The routes are as presented in figure 1.

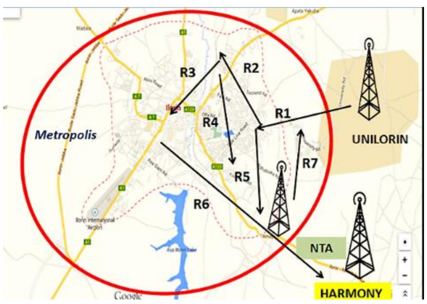

Figure 1: Measurement Routes

Table 1 provides details of the transmitters. For each route, the prediction error for COST 231, Egli, HATA, ECC and Ilorin models was obtained and also profiled over the terrain for some selected routes. The prediction error is the difference between the measured path loss at given distance *i*, and the model’s predicted path loss. HATA model for large city was used in this work. While the transmission is going on, a dedicated Agilent N9342C 100 Hz-7 GHz spectrum analyzer having a GPS (Global Positioning System) device was placed inside a vehicle while the GPS device was attached to the roof on the vehicle and was driven at an average speed of 40 km/h along these routes, during broadcast. Field strength was measured continuously and stored in an external drive for subsequent analysis. Table 1 provides details on the transmitters.

3.2. Prediction Models Used.

This section provides the mathematical formulation of the empirical path loss models used in this study**.**

3.2.1 *The COST -231 Hata Model*: This is an improved Hata model for applicability to frequency up to 2.0 GHz. COST 231 (1991). It widely used for signal path loss prediction at VHF / UHF band.

$$L = 46.3 + 33.9\log f_c - 13.82\log h_t - a(h_r) + (44.9 - 6.55\log h_t)\log d + C_m \quad (1)$$

where C_m is 0 dB for medium-sized city and suburban areas and 3 dB for metropolitan centres.

3.2.2 The Electronic Communication Committee (ECC-33) Model: This is a modified Okumura model to suit fixed wireless systems. The model gives correction factors for urban and medium cities. It is recommended for European cities and is defined in Abhayawardhana (2005).

$$P_L(dB) = A_{fs} + A_{bm} - G_r - G_t .... (2)$$

$$A_{fs} = 92.4 + 20\log(d) + 20\log(f)$$

$$A_{bm} = 20.14 + 9.83\log(d) + 7.894\log(f) + 9.56\log(f)^2$$

$$\mathrm{G_t} = \log(h_T / 200)\{13.958 + 5.8[\log d]^2\}$$

For medium size city,

$$\mathrm{G_r} = [42.57 + 13.7\log f_c][\log h_r - 0.585]$$

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3.2.3 *The Hata Model*: This is mathematical formulation of graphical path loss curves provided by Okumura. The model's equation is written by Hata (1980) :

$$L_{Hata} = 69.55 + 26.16 * \log f_c - 13.82 * \log h_t - a(h_r) + (44.9 - 6.55 \log h_t) * \log d \quad (3)$$

For a small and medium city,

$$a(h_r) = (1.1 * \log f_c - 0.7) h_r - (1.56 * \log f_c - 0.8) \text{dB}$$

3.2.4 *The Ilorin Model*: The Ilorin model is an optimized Hata-Davidson empirical model; the model has been found to best fit in path loss signal prediction in Ilorin Kwara State of Nigeria.

$$L_{ilorin}(\text{dB}) = 73.56 + 26.16 * \log f_c - 13.82 * \log h_t - a(h_r) + 30.5 * \log d + C \quad (4)$$

where C are the correction factors defined in Davidson model (Faruk *et al., 2014).*

3.2.5 *The Egli Model:* This model is terrain model formulated from measurement data obtained of UHF and VHF television transmissions for various cities. It is used for line of sight outdoor transmission (Egli, 1957).

$$P_{LdB} = G_b G_m \left(\frac{h_b h_m}{d^2} \right)^2 \left(\frac{40}{f} \right)^2 \quad (5)$$

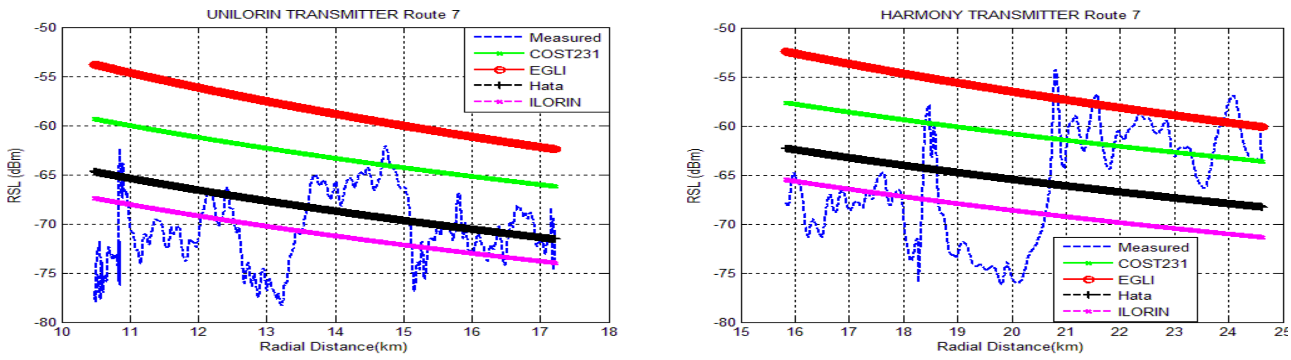
G_b and G_m are the gains of the base station and Mobile station antenna respectively while h_b and h_m are the heights of the base station and the mobile station respectively.

Table 1: Measurement Equipment and Configuration During Validation

Spectrum Analyzer N9342C Agilent, 100 Hz- 7 GHz	
Displayed average noise level (DANL)	-164 dBm/Hz
Preamplifier	20 dB
Resolution bandwidth (RBW)	10 kHz
Impedance	50 Ω
Centre frequency (NTA) Centre frequency (UNILORIN) Centre frequency (HARMONY FM)	203.25 MHz 89.30 MHz 103.5 MHz
Receiver Antenna: Diamond RH 795	
Frequency range	70 MHz-1 GHz
Form	Omni directional
Height	1.5 m
Gain	2.51 dBi

4. RESULTS AND ANALYSIS

Figure 2 shows how the propagation models performed when estimating received signal level. Each of the propagation models exhibit similar pattern for all the routes and investigated transmitters. The Egli model tends to estimate higher signal level and also results in higher prediction error in most instances. The ECC propagation model even performs worse than Egli (see Figure 3). The Ilorin model tends to estimate the lowest received signal level out of the considered propagation models, the Hata model's estimated signal level is slightly higher than it, while the COST 231 model is next to the Egli model in descending order. However, a quick glance at the prediction error in figure 3 reveals that the size of signal level estimation does not necessarily translate to accuracy or otherwise of the model. While the ECC and Egli with the highest estimated signal level also has higher prediction error, the same cannot be said of the remaining three models. Even though the Ilorin model has the lowest estimated signal level, it did not have the lowest prediction error in all the routes, in fact as the graph in figure 3 shows, the COST 231 and Hata has lower prediction error (indicated by the thickness of the prediction error plot) even though their estimated signal level is higher than the Ilorin model.



(a) **(b)**

Figure 2: Measured and Estimated Received Signal strength along Route 7 for (a) UNILORIN and (b) Harmony transmitter

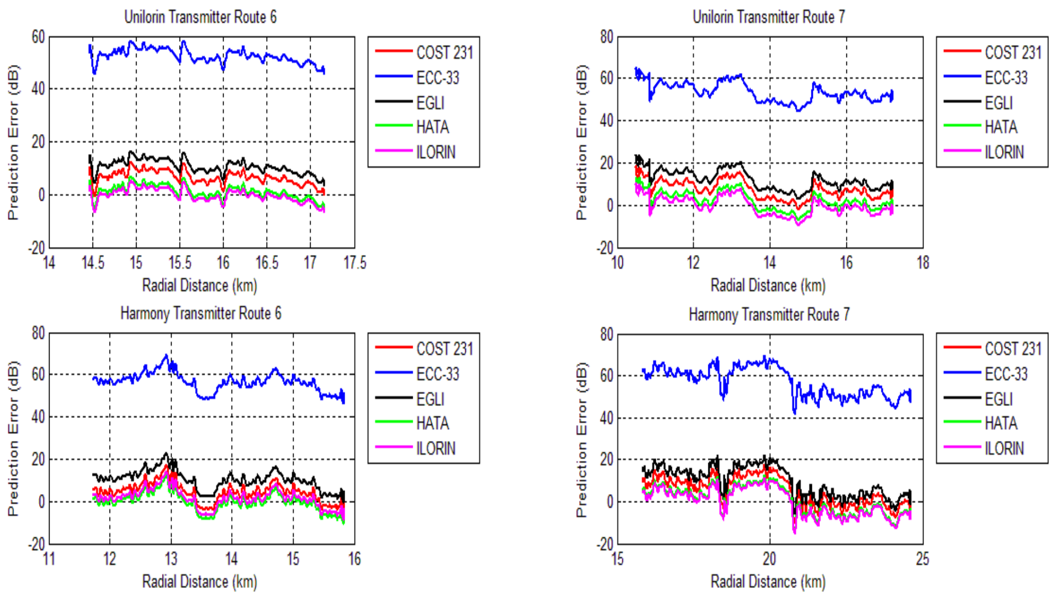


Figure 3: Prediction Error of the five propagation models for (a) UNILORIN Transmitter along route 6 (b) UNILORIN Transmitter along route 7 (c) Harmony transmitter along route 6 and (d) Harmony transmitter along route 7

Figure 3c and 3d show the mean prediction error as a function of distance. As indicated from both graphs, there is a consistent similarity in the pattern exhibited by the five models investigated. The rate of change of the mean prediction error with distance follows similar trends and approximately equal gradient even for the ECC model that has characteristically large magnitude of prediction error. Figure 3d is even more revealing on the performance of the models. The mean prediction error for all the models reached the maximum positive value at approximately 20 km distance from the transmitter, while it subsequently drops and crosses the zero point to the negative for the three models of Cost -231, Hata and Ilorin. For these three models, the implication of this observed phenomenon is that the models overestimate signal level up to 20 km and underestimates at distance greater than 20 km. This trend in the models' performance can be attributed to the constraint of the models. The Cost-231 model was designed to predict signal level for transmitter- receiver distance up to 20 km and not beyond. This explains the sharp drop in its estimation of signal level beyond the 20 km distance mark. Same reason can also be attributed for the Hata model of which the Cost 231 is a derivative of. In fact, the Cost 231 mainly extends the range of frequency of the Hata model to 2000MHz from 1500MHz. Similarly, the Ilorin Model is a derivative of the Davidson model, which is also an extension of the Hata model. This explains the marked similarity in the performance of the three models in most of all the routes and the metrics used in this work. The Egli model is a non-regular terrain model designed mainly for Line of Sight LOS communication with no vegetative obstruction. Considering the fact that with increasing transmitter-receiver distance, LOS communication becomes more difficult, it is understandable that at higher distance, the signal level prediction of the model reduces significantly when compared to the actual measured signal level. This study only provides a clue that the LOS conditions significantly depreciates at about 20Km separation between the receiver and the transmitter. The values in Table 2 quantifies the prediction error of all the five propagation models for the three transmitters along all the seven routes presented in this paper. The Ilorin model under estimated the signal level in five(5), six(6) and six(6) routes for each of the NTA, Unilorin and Harmony transmitters respectively, out of the total 7 routes. Hence the overall cumulative average prediction error of this model for all the routes is negative. The Hata model for the Harmony FM transmitter under predicts the signal level in 6 of the 7 routes but fluctuates between over prediction and under prediction for the other two transmitters. Thus while the overall average prediction error for all the routes is positive for NTA and Unilorin it is negative for the Harmony transmitter. The COST 231 also records some under prediction but over predicts for most of the routes for the three transmitters. Expectedly, both the Egli and ECC models generally over predicts the signal level. Figure 4 graphically depict the above observation

.

Table 2: Prediction and Mean Errors of Propagation Models

Transmitters		COST 231	HATA	EGLI	ECC	ILORIN
NTA	R1	7.5	5.1	19.9	75.6	0.7
	R2	5.5	3.1	16.2	73.5	-1.4
	R3	-0.3	-2.7	9.6	-0.3	-7.2
	R4	7.4	5	18.7	75.4	0.6
	R5	1.8	-0.6	13.2	69.8	-5.1
	R6	0.3	-2.1	11.3	0.3	-6.6
	R7	1.3	-1.1	15.5	69.3	-5.4
	Avg	***3.36***	***0.96***	***14.91***	***51.94***	***-3.49***
UNI	R1	5.5	0.1	15	51.4	-3.2
	R2	-1.2	-6.6	4.7	45.2	-9.3
	R3	6	0.6	12.5	52.5	-2.2
	R4	5.5	0.1	10.7	51.8	-0.5
	R5	6.3	0.9	10.9	52.5	-0.6
	R6	6.7	1.3	10.8	52.7	-0.2
	R7	9.1	3.8	13.9	55.3	1.2
	Avg	***5.41***	***0.03***	***11.21***	***51.63***	***-2.11***
HAR	R1	-3.4	-8.1	1.5	48.6	-6.2
	R2	-14.6	-19.2	-10.7	37.2	-22.3
	R3	1.6	-3	5.6	53.4	-6.1
	R4	3.7	-0.9	7.6	55.5	-1
	R5	2.9	-1.8	6.6	54.6	-0.9
	R6	4.3	-0.4	10	56.4	1.3
	R7	5.5	0.9	9.9	57.4	-0.1
	Avg	***1.2E-16***	***-4.64***	***4.36***	***51.87***	***-5.04***

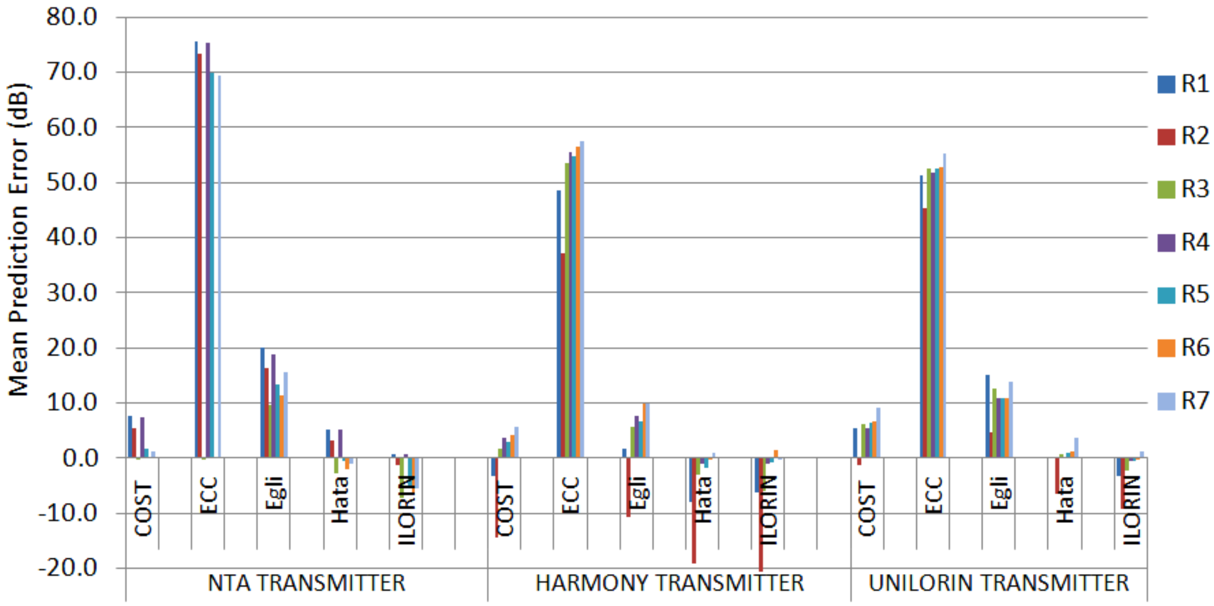


Figure 4: Mean prediction error of each propagation models across all routes for the three transmitters

From figure 4, we could see that generally, for most of all routes, the Cost 231, Hata and Ilorin model's prediction error hovers around $\pm 7.5dB$ except in route 2 for the Harmony transmitter, where all three models significantly under predicts signal level beyond this value with prediction error of $-14.6dB$, $-19.2dB$ and $-22.3dB$ respectively. Interestingly, while the ECC and Egli models over estimates the signal level across all routes, the Egli model under estimates signal level in route 2 for the Harmony transmitter with surprisingly lower prediction error than the other three models of Cost 231, Hata and Ilorin. This is likely connected with the topography of the route. The likelihood of this assertion is buttressed by the fact that the model was developed for irregular terrain. Furthermore, as Figure 4 shows, while there is marked similarity between the prediction error values of Cost 231, Hata and Ilorin, the Ilorin Model, generally under predicts the signal level for all three transmitters, the Hata model generally over predicts for the Unilorin transmitter, generally under predicts for the Harmony transmitter and fluctuates between over prediction and under prediction for the NTA transmitter. The Cost-231 model generally over estimates for all transmitters.

Another interesting observation is the inconsistent pattern of prediction error recorded for route 2 across the three transmitters and five models. For the Harmony FM transmitter, while the prediction error for route 2 of the other four models is highest, the ECC record the lowest prediction error for route 2. Also, for route 2, the Ilorin and Hata Model seems not to perform very well for the Unilorin FM and Harmony FM transmitters as it recorded a significantly higher prediction error than other routes. This pattern is not noticed in the NTA transmitter. On the other hand, the ECC model shows lowest prediction error in route 2 for the harmony FM and Unilorin FM transmitter. Egli and Cost -231 exhibit similar pattern; lowest prediction error for route 2, of the Unilorin FM transmitter, highest prediction error for the Harmony FM and third highest for the NTA transmitter. These inconsistencies can be attributed to several constraints imposed by the design of the models, which might include but not limited to terrain topography, transmitter-receiver distance, antenna height, types of obstacles between transmitter and receiver, frequency of transmission and other engineering parameters of the transmitters.

For four of the prediction models, the maximum error deviation across all routes is 3.8dB for NTA transmitter (recorded by Egli model) and 3.5dB for Unilorin FM for all the five models (recorded by Ilorin Model). These value shows the prediction error value by these models are closely distributed hence providing a good measure of consistency in the prediction values along the seven routes investigated. In fact, the error spread across all the seven routes is within $\pm 5dB$ for all the models and the three transmitters except for the ECC model that recorded a high deviation of 35.6dB for the NTA transmitter. A second look at Figure 4, reveals that this high deviation in the error spread is due to route 3 and route 6 having unusually low prediction error as compared to the remaining other routes with very high prediction error. We can therefore conclude that if these two routes are discounted, the error deviation of the ECC model for this transmitter will be similar to the other models. This claim is corroborated by the error deviation recorded for the other two transmitters which fall within the same range of the other four models. Also for the Harmony transmitter, the error deviation of the models across the seven routes ranges from 7.0dB to 8.2dB. More precisely, for the three transmitters; Cost 231 and Hata has exactly the same error deviation (3.2dB and 7.0dB for Unilorin FM and Harmony FM respectively), while the Ilorin Model share the same error deviation value of 3.4dB with these two models for the NTA transmitter. The ECC and Egli models also shared the same value of error deviation except for the NTA transmitter where the unusually high value earlier explained was recorded.

Table 3: RMSE and SC-RMSE of Propagation Models

Transmitters		COST 231		HATA		EGLI		ECC		ILORIN	
		RMSE (dB)	SC-RMSE (dB)	RMSE (dB)	SC-RMSE (dB)	RMSE (dB)	SC-RMSE (dB)	RMSE (dB)	SC-RMSE (dB)	RMSE (dB)	SC-RMSE (dB)
NTA Tx	R1	11.2	8.4	9.8	8.9	21.7	14.2	76.0	67.7	8.4	11.3
	R2	8.2	6.2	6.8	6.8	17.3	11.8	73.7	67.6	6.3	9.7
	R3	7.1	10.3	7.6	12.1	11.9	7.5	7.1	10.3	10.1	16.0
	R4	9.5	6.1	7.8	6.0	19.7	14.1	75.7	69.7	6.0	8.0
	R5	7.6	9.3	7.4	10.9	15.2	9.4	70.2	62.8	9.0	14.5
	R6	6.2	8.5	6.5	10.3	12.9	8.0	6.2	8.5	9.0	14.2
	R7	9.4	12.4	9.4	14.0	18.7	11.6	69.9	60.7	10.8	17.5
Average		**8.46**	**8.7**	**7.90**	**9.9**	**16.77**	**10.9**	**54.11**	**49.6**	**8.51**	**13.0**
UNI Tx	R1	17.8	20.4	16.9	23.8	26.6	23.1	53.3	39.7	16.4	25.2
	R2	6.3	9.6	9.0	14.1	7.8	6.4	45.6	39.5	11.2	16.6
	R3	9.4	7.3	7.2	9.7	14.5	9.0	53.0	45.9	7.5	11.8
	R4	9.4	7.9	7.6	10.7	13.1	8.2	52.3	44.8	7.7	11.2
	R5	8.5	5.8	5.8	7.5	12.3	7.7	52.8	47.1	5.8	8.6
	R6	8.1	5.1	4.8	5.7	11.8	7.7	52.9	48.3	4.6	6.7
	R7	11.1	6.9	7.3	6.8	15.4	9.9	55.7	49.4	6.3	8.0
Average		**10.09**	**9.0**	**8.37**	**11.2**	**14.50**	**10.3**	**52.23**	**45.0**	**8.50**	**12.6**
HAR Tx	R1	9.2	14.7	11.8	18.7	8.4	10.7	49.3	41.0	10.6	17.1
	R2	15.8	21.5	20.1	26.0	12.3	17.8	37.7	31.8	23.1	29.0
	R3	8.1	10.1	8.5	13.5	9.7	8.3	54.0	46.2	10.0	16.2
	R4	8.6	8.7	7.8	11.7	10.8	7.8	56.0	48.4	7.8	11.7
	R5	7.7	8.3	7.3	11.4	9.7	7.1	55.1	48.1	7.1	10.7
	R6	8.3	7.6	7.1	10.3	12.3	7.7	56.8	49.8	7.2	9.1
	R7	9.9	8.7	8.3	11.1	13.1	8.6	58.0	49.8	8.2	11.7
Average		**9.66**	**11.4**	**10.13**	**14.7**	**10.90**	**9.7**	**52.41**	**45.0**	**10.57**	**15.1**

Consequently, as table 3 reveals, the Hata model has the lowest RMSE error of 7.9 dB and 8.37dB for the NTA and Unilorin transmitters while the COST 231 has the lowest RMSE of 9.66 dB for the Harmony transmitter. The Ilorin model has the third lowest RMSE values of 8.51dB and 10.57dB behind the Hata and COST 231 for NTA and Harmony transmitters respectively while the RMSE value of 8.50dB for the Unilorin Transmitter was second behind Hata model. The ECC model record significantly high RMSE values of 54.11dB, 52.23dB and 52.41dB for the three transmitters. The Egli model records slightly higher RMSE value especially for the NTA transmitter and hence the mean RMSE value of 16.77dB is slightly higher than the maximum acceptable value of 15dB. According to [16], the acceptable RMSE values are 6-7dB for urban areas and 10-15dB for Suburban and rural areas. However, several researchers have claimed that RMSE up to about 10dB could still be acceptable in the urban areas and the network planners will have to tradeoff between complexity and accuracy of the models. Correlating this with the obtained values we see that with the exception of the ECC model every other model performed reasonably well in predicting signal level with good accuracy in the studied environment.
Expectedly, from the foregoing pattern, the relative error for the three models of COST 231, Hata and Ilorin are similar with the Hata model recording the lowest cumulative average relative error across all routes of 0.10 for the NTA and Unilorin transmitters. The Ilorin model recorded 0.12 and 0.11 for the NTA and Unilorin transmitters respectively and Cost-231 recorded 0.11 for both transmitters. The relative error of a measurement gives an indication of how good a measurement is, relative to the size of the measured object or phenomenon. When expressed in percentage, it provides the degree of accuracy of the measurement method used in relation to the actual value been measured. In this instance, it is a measure of the tolerance level for the five propagation models in signal level prediction along the seven routes under investigation. Consequently, the lower, the relative error, the better the performance or higher the accuracy of the models. A look at the relative error per routes will reveal that for the two transmitters mentioned above, the values are equal to or less than the 10% commonly adopted as the acceptable level of good fit of the measurement method. For the Harmony transmitter, with a slightly higher cumulative average relative error of 0.15, 0.16 and 0.17 for the Cost-231, Hata and Ilorin Models was due to the earlier anomalous pattern of route 2 earlier noted. A considerable number of the routes still recorded a relative error close to 0.1 or 10%. The relative error for the ECC model recorded an all high of 85%. This a gross over estimation of propagation signal level.

Table 4: Skewness (α) and Relative Error (η) of Propagation Models

Transmitters		COST 231		HATA		EGLI		ECC		ILORIN	
		α	η	α	η	α	η	α	η	α	η
NTA	R1	-0.4	0.14	-0.4	0.12	-0.4	0.29	-0.5	1.16	-0.4	0.11
	R2	0.4	0.09	0.4	0.07	0.4	0.23	0.4	1.08	0.4	0.08
	R3	0.0	0.09	0.0	0.10	0.0	0.15	0.0	0.09	0.0	0.14
	R4	0.1	0.11	0.1	0.09	0.2	0.27	0.1	1.10	0.2	0.07
	R5	0.2	0.10	0.2	0.10	0.3	0.20	0.2	1.12	0.2	0.13
	R6	0.3	0.08	0.3	0.09	0.3	0.18	0.3	0.08	0.3	0.13
	R7	0.0	0.15	0.0	0.15	0.2	0.28	0.0	1.31	0.0	0.18
Average			***0.11***		***0.10***		***0.23***		***0.85***		***0.12***
UNI	R1	2.8	0.10	2.8	0.13	3.1	0.13	2.3	0.84	2.8	0.17
	R2	0.2	0.09	0.2	0.14	0.2	0.10	-0.1	0.79	0.2	0.18
	R3	0.1	0.12	0.1	0.10	0.1	0.20	0.1	0.85	0.1	0.11
	R4	-0.2	0.11	-0.2	0.10	-0.1	0.16	-0.2	0.78	-0.2	0.10
	R5	0.1	0.10	0.1	0.07	0.1	0.15	0.1	0.76	0.1	0.07
	R6	0.2	0.09	0.2	0.05	0.2	0.15	0.2	0.74	0.2	0.05
	R7	-0.1	0.13	-0.1	0.08	0.0	0.19	-0.1	0.77	-0.1	0.07
Average			***0.11***		***0.10***		***0.15***		***0.79***		***0.11***
HAR	R1	0.2	0.15	0.2	0.20	0.2	0.12	0.2	0.88	0.2	0.18
	R2	0.5	0.33	0.5	0.43	0.5	0.25	0.5	0.78	0.5	0.49
	R3	0.0	0.11	0.0	0.12	0.0	0.12	0.0	0.84	0.0	0.14
	R4	-0.2	0.11	-0.2	0.10	-0.2	0.13	-0.2	0.84	-0.2	0.10
	R5	0.1	0.09	0.1	0.09	0.1	0.11	0.1	0.83	0.1	0.09
	R6	0.3	0.11	0.3	0.10	0.2	0.16	0.3	0.94	0.3	0.09
	R7	-0.2	0.12	-0.2	0.11	-0.3	0.16	-0.2	0.86	-0.2	0.11
Average			***0.15***		***0.16***		***0.15***		***0.85***		***0.17***

The skewness of the error distribution shown in table 4. In statistics, skewness is a measure (both direction and amount) of the symmetry or more accurately the lack of it of a distribution about a centre point usually its mean. It is expressed as either positive skew or right tailed (if the mass of the distribution is concentrated to the left side) or negative skew or left tailed (if the mass of the distribution is concentrated to the right side). It could also be zero, in which case the distribution is symmetric around its mean or when the right and left tails cancels each other out. It is also expressed as highly skewed (when it is less than −1 or greater than 1), moderately skewed (if it is between ±1 and ±0.5) or approximately symmetric (if it is between −0.5 and 0.5). The skewness of the error distribution also tends to follow similar pattern for the five models, except in route 2 of the Unilorin transmitter where the ECC recorded a negative skew while other models recorded a positive skew. It should however, be noted that generally, for the three transmitters, there is a predominant positive skewness of the error distribution by all the models across the seven routes. Surprisingly, despite the sharp deviation of the ECC model from the other models, the degree or magnitude of skewness was similar across all the routes for the three transmitters. The implication of this is that error distribution of all the models follow the same pattern of symmetry/asymmetry.

5. CONCLUSION

The error bounds of five different propagation models using three transmitters in the UHF/VHF bands was provided in this study. From all the five models examined the ECC model records very high deviation in its estimation of received signal level for all the three transmitters, suggesting unsuitability of the model to the studied environment. The COST-231 Model at transmitter-receiver distance less than or equal to 20 km and the Egli also consistently over estimated received signal level for the environment while the Ilorin model under estimated for large portion of the routes. It was also discovered that, at distances greater than 20 km, there is a significant reduction in signal level estimation by all the five models, which invariably leads to consistent under estimation by the Ilorin, Hata, and Cost-231 models. The relative error recorded also shows that, of all the five models, the ECC model grossly overestimate the signal level recording 85% for two transmitters and 79% for one transmitter.

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