OPTIMIZATION OF DAVIDSON MODEL BASED ON RF MEASUREMENT CONDUCTED IN UHF/VHF BANDS

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Abstract

In this paper, field strength measurements were conducted at 203.25 MHz and 583.25 MHz frequencies along six different routes that spanned through the urban, suburban and rural areas of Kwara State, Nigeria. The measurement results were converted to path losses and were compared with path loss prediction of eight widely used empirical models. Least squares and linear iterative methods were employed to optimize Davidson model. The predictions of the tuned model are compared with other models in terms of relative error, prediction error, mean error and skewness. Results of the simulations indicate that the optimized model gives smaller values for the metrics used.

Keywords- Path loss, HATA model, Davidson model, Least Squares method, Linear iterative method

1. INTRODUCTION

With the advent of digital switch-over, more spectrum will be freed as white space and, as such, there would be rapid development of wireless communication systems operating at VHF and UHF bands. Path loss propagation models are required in coverage planning and optimization, and signal prediction, and would be used for interference analysis to ensure coexistence between the services. 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. Several empirical models have been proposed, such as the ITU-R P.1546-4 [1] for predicting the radio coverage at VHF and UHF bands. Empirical models have been given attention for decades due to their accuracy and environmental compatibility. However, peculiarities of these models give rise to high prediction errors when deployed in a different environment other than the one initially built for. For instance, [2] provides the error bounds on the efficacy at predicting path loss for eight empirical widely used path loss models based on field strength measurements conducted in the VHF and UHF frequencies in Kwara State, Nigeria. It was concluded that no single model would provide a good fit consistently. [3] presents similar results to that of [2] and concludes that tuning of Davidson model, which is one of the models that show better fits at least, along some selected routes, is necessary to minimize the RMSE values within the acceptable ranges. In this paper, we present optimization technique using least squares approximation [4][5] and linear iterative tuning method [6] for Davidson model which shows good performance compared with other empirical models examined in [2] and [3], and also supports wider range path loss prediction up to about 300 km which would be suitable for TV coverage prediction. Researchers have shown great efforts towards model tuning to achieve minimal error for a given environment of study. For example, [6] provides tuning of COST 231 Hata model based on measurements conducted in 2.3 GHz in Western India. Linear iterative method was used in tuning the model and it was found that the tuned model achieved better root mean square errors as compared with the conventional COST 231 Hata model. [7] optimizes Walficsh Bertoni model using least squares method. The optimized model predicts path loss with improved accuracy of about 25-30% compared to the original model. [8] provides a fast and precise dual least-square approach to tune the generally used propagation models, like COST231-Hata model. The experiment was conducted within the Banciao city. The tuned model, called Banciao model, has been verified in static Monte-Carlo simulation and proved to be more optimal for local environment area.

This paper is organized as follows: Section I provides introduction; Section 2 presents the method of data collection; Section3 presents Davidson model; Least squares formulation is presented in section 4; Section 5 presents the results and, finally, Section 6 concludes the paper.

2. DATA COLLECTION METHOD

The propagation measurements were conducted in Ilorin (Long 4° 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. Six routes were covered during the measurement campaign. 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.

3. DAVIDSON MODEL

Davidson model [9] is a derivative of the Hata model [10] which is an empirical formulation of the graphical path loss data provided by Okumura and is valid in the range 150 MHz to 1500 MHz. The model transmission distance is up to 20 km and has been widely used to predict analog TV signal. Hata model has a transmission distance of 20 km; thereafter, prediction error becomes higher when used to predict path loss for distance greater than 20 km. The prediction error is obvious from the work of [3]. In the work, the performance of Davidson and Hata models was examined by plotting the variation of error spread as a function of distance for a 60 km route. It was however noted that Hata and Davidson prediction models show symmetry up to about 30 km with slight divergence between 24 km and 30 km, after which Hata model under-predicts the path loss. Davidson model provides six correction factors which extend the range to 300 km. Path loss equation for Davidson model is given in [9] as follows:

$$L_D(dB) = L_{Hata}(dB) + A(h_T, d_{km}) - S_1(d_{km}) - S_2(h_T, d_{km}) - S_3(f_{MHz}) - S_4(f_{MHz}, d_{km}) \tag{1}$$

where $L_{Hata} = 69.55 + 26.16 \log f_c - 13.82 \log h_T - a(h_r) + (44.9 - 6.55 \log h_t) \log d$ (2)

and a(h_r) is the correction factor for the receiver height and is computed as follows:

For a small and medium city

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

For a large city,

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

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

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

$S_2(h_T, d_{km}) = 0.00784|\log(9.98/d)|(h_T - 300)$ for $h_T < 300$ m

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

$S_4(f_{MHz}, d_{km}) = [0.112 \log(1500 / f)](d - 64.38)$ for $d > 64.38$ m

$A(h_T, d_{\mathrm{km}})$ and $S_1(d_{km})$ are distance correction factors, $S_2(h_T, d_{km})$ is base station antenna height correction factor, and $S_3(f_{\mathrm{MHz}})$ and $S_4(f_{\mathrm{MHz}}, d_{\mathrm{km}})$ are frequency correction factors.

4. LEAST SQUARES FORMULATION

Let $E(f,h) = 26.16 \log f_c - 13.82 \log h_T - a(h_r)$, $x = \log d$ and $\gamma = (44.9 - 6.55 \log(h_T))/10$

Then equation (2) can be written as:

$$L_{Hata}(\mathrm{dB}) = ax + b \qquad (3)$$

where $b = E_0 + E(f,h)$ and $a = 10\gamma$

E_0 is the path loss initial offset value which is 69.55 and it is fixed for both Hata and Davidson models, γ is the path loss exponent. The least squares approximation of degree *N* to *f* over [a,b] is that polynomial $p \in \prod_N$ satisfying

$$\|f - p\|_2^2 = \int_a^b [f(x) - p(x)]^2 dx \qquad (4)$$

$$= \min_{q \in \prod_N} \int_a^b [f(x) - p(x)]^2 dx$$

$$= \min_{q \in \prod_N} \|f - p\|_2^2$$

Given the measured path loss data (x_1, y_1), . . . , (x_N, y_N), where y_1 is the path loss (dB) at a distance x_1 (km) and *N* is the number of measurement points, equation (4) can be decomposed in the discrete form as: $y_i = y(x_i)$ for *i*= 1, 2, . . . , *N*

Then, the least squares polynomial approximation of degree at most *M*, is then the polynomial $p \in \prod_N$ which minimizes the error;

$$E(a,b) = \sum_{i=1}^{N} [y_i - p_M(x_i)]^2 \qquad (5)$$

In the optimization algorithm, we seek for parameters *a* and *b* which minimize the difference between the measured and the predicted path losses.

$$\min\ E(a,b) = \sum_{i=1}^{N} [y_i - (ax_i + b)]^2 \qquad (6)$$

The main goal is to tune the values of *a* and *b* that minimize the error. Differentiating $E(a,b)$ in equation (6) with respect to *a* and *b,* and setting these derivatives to zero leads to the corresponding normal equation given in equation (7).

$$\begin{pmatrix} \sum_{i=1}^{N} x^2{}_i & \sum_{i=1}^{N} x_i \\ \sum_{i=1}^{N} x_i & \sum_{i=1}^{N} 1 \end{pmatrix} \begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^{N} x_i y_i \\ \sum_{i=1}^{N} y_i \end{pmatrix} \qquad (7)$$

or,

$$\begin{pmatrix} a \\ b \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^{N} x^2{}_i & \sum_{i=1}^{N} x_i \\ \sum_{i=1}^{N} x_i & \sum_{i=1}^{N} 1 \end{pmatrix}^{-1} \begin{pmatrix} \sum_{i=1}^{N} x_i y_i \\ \sum_{i=1}^{N} y_i \end{pmatrix} \tag{8}$$

Let *A, B* and *C* represent the matrices. Then the minimal mean vector $\vec{A}$ can be obtained as

$$\vec{A} = B^{-1}C \tag{9}$$

5. RESULTS AND DISCUSSION

By substituting the measurement path loss data for a route using equations (6) and (9), the optimized values of E_0's and γ's were obtained for each route. Table 1 shows the results.

Table 1: Initial offset and path loss exponent for each route.

Route ID	Initial offset value (E_0)	Path loss exponent (γ)
1	56.348	2.15
2	69.013	4.10
3	72.104	2.78
4	65.363	3.10
5	70.581	3.05

Table 1 shows the optimized initial offset values and path loss exponent for each route examined. It is however noted that these values vary for each route and each value gives different RMSE error value for varying route. But initial offset within the 65-71 window gives the optimum results. In this regard, we employed the linear iterative tuning method by developing a code to compute the corresponding path losses for the offset values within the window (i.e., 65-71) in step of 0.5. Following the work presented in [11], it was found that the path loss exponent for Ilorin city varies from 1.4 to 4.94 with an average value of 2.80. We used 3.0 as path loss exponent value during the optimization process. For each output, we evaluate the corresponding RMSE (Root Mean Square Error), Relative Error between the measured and the model's predictions, Mean prediction error and Skewness for all the routes. It was found that offset of 70.56 gives the optimum results though, for few routes the conventional Hata model offset value provides less prediction error as compared with that calculated offset.

Fig (1) to (3), show graphically the measured and predicted path losses along routes 1, 2 and 6. Fig 1 shows the comparison of the measured path loss with the models predicted path loss as a function of distance for route 1. We can see that Hata, COST 231, ITU-R P.1546-4 and the optimized models perform well. It is found that the performance of the optimized Davidson model is the best as the relative error is the lowest compared to other models as shown in Table 2, while Walfisch Ikegami (WI), ECC and CCIR models give higher relative errors.

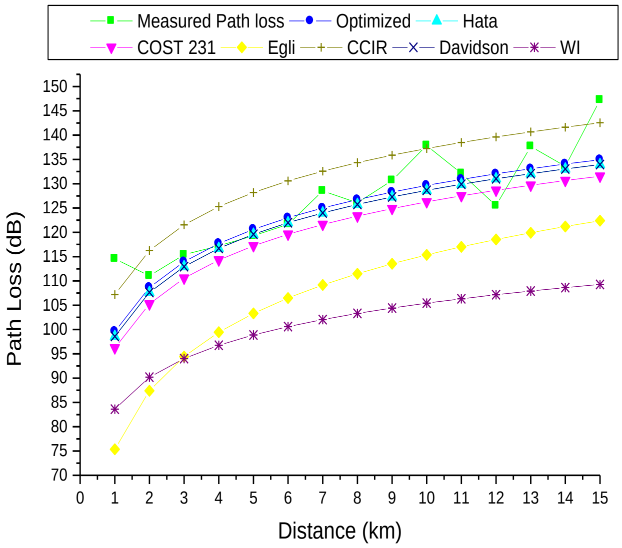

Figure 1. Comparison of the optimized model with measured path loss along route 1

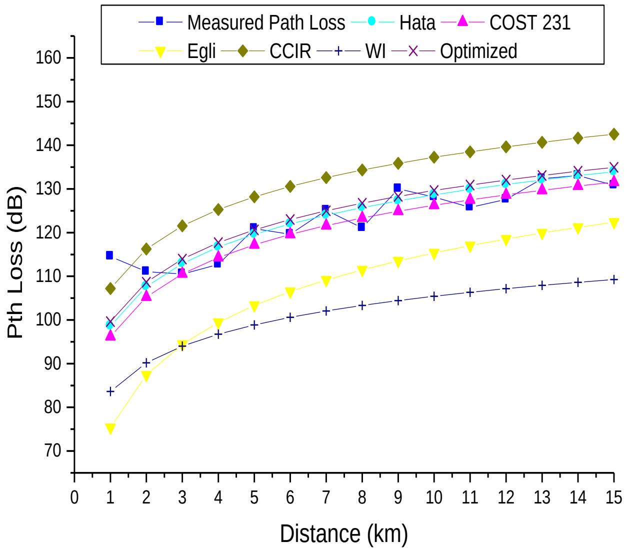

Figure 2. Comparison of the optimized model with measured path loss along route 2

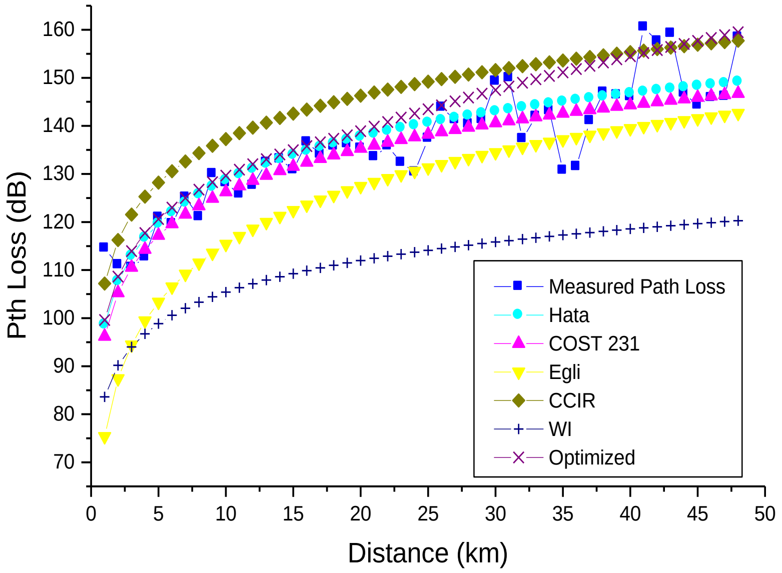

Figure 3. Comparison of the optimized model with measured path loss along route 6

Table 2. Relative errors

ROUTE	OPTIMIZED	HATA	COST 231	WI	EGLI	ECC	CCIR	ITUR P.1546-4
ROUTE 1	0.03905	0.05859	0.05336	0.15559	0.12658	0.12962	0.10006	0.09666
ROUTE 2	0.01014	0.06491	0.0655	0.16681	0.16956	0.11367	0.08578	0.11718
ROUTE 3	0.04575	0.04822	0.05164	0.17715	0.14935	0.10241	0.07707	0.11955
ROUTE 4	0.04856	0.05636	0.07286	0.21291	0.20227	0.05744	0.04201	0.16518
ROUTE 5	0.04881	0.0546	0.06547	0.19867	0.17349	0.07472	0.05228	0.13978
ROUTE 6	0.02711	0.05375	0.06383	0.22077	0.11165	0.08576	0.04344	0.24311

AVERAGE	0.03657	0.05607	0.06211	0.18865	0.15548	0.09393	0.066773	0.14691

Table 3. Mean Prediction Error

ROUTE	OPTIMIZED (dB)	HATA (dB)	COST 231(dB)	WI (dB)	EGLI (dB)	ECC (dB)	CCIR (dB)	ITU-RP.1546 (dB)
ROUTE 1	-1.1375	-2.2996	0.08616	18.08095	14.41531	-14.9807	-10.9014	13.08934
ROUTE 2	0.4824	0.2402	2.62609	18.94244	18.97953	-12.5017	-8.36146	15.27793
ROUTE 3	-0.59705	0.8300	3.21593	21.21072	17.54509	-11.851	-7.77161	16.21912
ROUTE 4	3.36145	6.6682	9.05405	26.21635	24.38724	-6.04368	-1.93349	21.89127
ROUTE 5	3.17003	4.3973	6.78321	24.77799	21.11236	-8.28369	-4.20434	19.78639
ROUTE 6	0.85014	2.2275	4.61338	25.09168	15.9473	-10.3554	-6.37416	20.2398
AVERAGE	1.021578	2.0106	4.39647	22.38669	18.73114	-10.6694	-6.59108	17.75064

Fig 3 gives results for route 6 which spans from the urban to rural areas. It has regular building structures with average of two-storey buildings within the city, then hotspots villages outside the city at an average distance of 15 km interval. The route length was 60 km. This route was chosen because Hata had maximum transmission distance of 20 km. We can see that the relative and mean prediction errors of the optimized model show significant improvement. In Table 3, the mean prediction error is 0.85 dB and 2.23 dB for the optimized model and Hata model respectively, representing about 62% decrease in mean prediction error of the optimized model compared to the Hata model.

Table 4.Comparison between Hata, Davidson and Optimized model for Route 6

ERROR	OPTIMIZED (dB)	HATA (dB)	DAVIDSON (dB)
Maximum error	14.93731494	19.20778	15.94731
Mean Error	0.850142174	6.47016	1.860142
Skew	51.00853041	388.2096	111.6085

Table 4 shows the comparison between Hata, Davidson and Optimized Davidson models in terms of maximum prediction error, mean error and skewness. The skewness is a measure of symmetry or asymmetry in error prediction. Skew value closer to zero indicates better skew. We compute the skewness by summing the prediction error as a function of distance for the optimized, Hata and Davidson model. The results are shown in Table 4. It is however noted that for all these metrics, the optimized model shows better result as compared with the other two performing models.

6. CONCLUSION

In this work, we have presented an optimization procedure using least squares method and linear iterative technique to optimize Davidson model. The approach has proven efficient by achieving minimal errors. Although simulation results indicate that the tuned model parameters are very close to those of the conventional model, the optimized model provides least error values for all the metrics considered. In terms of skewness, the optimized model provides a significant improvement of about 54.5% and 86.8% respectively when compared with Davidson model and Hata model. However, this work could be extended by validating the proposed model in a dense tropic region also there is need for rigorous analysis of the RMSE of the measured path loss and the proposed model.

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