# Comparative analysis of Weissberger foliage path loss model optimization methods for a 3G network

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***Abstract*— In this paper, comparative analysis of two different path loss model tuning methods was presented for Weissberger foliage path loss model. The models are the root mean square error (RMSE)-based method and the error function of the foliage depth-based method, otherwise called EFED method. The optimised or tuned model is developed based on the empirical path loss data obtained in a Mangifera Indica (Mango) plantation located in a remote part of Uyo local government are in Akwa Ibom state, Nigeria. The study was conducted for a 3 G cellular network operating at the frequency of 1800 GHz. Two sets of field measured data on the received signal strength and foliage depth were obtained using CellMapper and My GPS location android apps installed on a Tecno Camon X Pro android phone. Haversine equation was used to determine the relevant distances while link budget equation was used to convert the measured received signal strength to the measured path loss. The results obtained with the training dataset showed that the unturned Weissberger model had a RMSE of about 11.8 dB and prediction accuracy of about 90.2 %, the RMSE-tuned model had a RMSE of about 7.04 dB and prediction accuracy of about 94.95 %, while the EFED-tuned model had the best performance with RMSE of about 2.58 dB and prediction accuracy of about 97.64 %. Also, for the cross-validation dataset, the EFED-tuned model had the best performance with RMSE of about 3.08 dB and prediction accuracy of about 97.22 %. In all, the model derived from the error function of the foliage depth-based method is the preferred model for the prediction of the path loss for 3G cellular network signal within the Mangifera Indica (Mango) plantation. The idea presented in this paper can help network designers in selecting the appropriate tuning method to use in modelling their path loss for their target network coverage area.**

***Keywords*— *Path Loss , Weissberger Model, Foliage Path Loss Model, Model Optimization, Composite Function Of Error, Foliage Depth***

## I. INTRODUCTION

Over the years, the wireless communication industry has witnessed several path loss models designed to predict the path loss which radio waves will experience at they propagates through any environment to their destination recovers [1,2,3,4,5,6,7]. Also, some foliage path loss models are designed specifically for predicting the path loss in an environment covered with vegetation [8,9,10,11,12]. Among them is the Weissberger foliage path loss model which includes the foliage depth as one of the parameters it uses to estimate the path loss as the radio waves penetrate the vegetation covered area [13,14,15,16,17,18,19,20].

In any case, studies have shown that empirical path loss models need to be optimised in order to minimise the prediction error when the models are employed in any environment other than the one from which the model was developed [21,22,23,24,25,26]. In addition, there are several methods that can be used to optimise a path loss model. However, the root means square error (RMSE) method has proven to be the most widely used [27,28,29,30,31,32,33,34]. Accordingly, the study in this paper seeks to present other relatively simple model optimisation methods that can give better path loss prediction performance than the RMSE-based method. Particularly, the alternative model tuning method considered in this paper is the error function of the foliage depth-based method. This method uses the foliage depth to estimate the path loss prediction error and then adds the predicted error to the original Weissberger foliage model predicted path loss to obtain the optimised path loss prediction. The proposed tuned Weissberger foliage model is developed in this paper based on a sample empirically measured path loss obtained within a Mangifera Indica (Mango) [35,36,37] plantation in a remote part of Uyo local government area in Akwa Ibom state, Nigeria. The path loss prediction performance of the tuned models are compared using RMSE and prediction accuracy.

## II. THE WEISSBERGER FOLIAGE PATH LOSS MODEL

The Weissberger foliage path loss model provides the extra path loss that is caused by the presence of vegetation along the signal path. Typically, the effective path loss is determined by adding the free space path loss and the additional foliage path loss by the Weissberger model. The analytical expression for the effective path loss $Pl_{ewb}$ based on the Weissberger model is as follows [13,14,15,16,17,18,19,20];

$$Pl_{ewb}\ (dB) = P_{fsl}(dB) + P_{wb}(dB) \quad (1)$$

Where the free space path los denoted as $P_{fsl}(dB)$ is given as;

$$P_{fsl}(dB) = 32.5 + 20 * \log(\mathrm{f}) + 20 * \log(\mathrm{d}) \quad (2)$$

While the additional foliage path loss by Weissberger model denoted as $P_{wb}(dB)$ is given as;

$$P_{wb}(dB) = \begin{cases} 0.45f^{0.284}(d_f) & for \quad 0 \le d_f \le 14\text{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\text{m} \end{cases} \tag{3}$$

Where d is the distance in Km from the transmitter to the receiver, $d_f$ is the foliage depth in meters and f is the signal frequency in GHz . The model path loss prediction performance can be evaluated in respect of root mean square error (RMSE) and prediction accuracy (PA) given as ;

$$\text{RMSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n} \left|PL_{m(i)} - Pl_{ewb(i)}\right|^2\right]\right\}} \tag{4}$$

$$\textbf{PA} = \left(1 - \left(\frac{1}{n}\left(\sum_{i=1}^{i=n}\left|\frac{|PL_{m(i)} - Pl_{ewb(i)}|}{PL_{m(i)}}\right|\right)\right)\right) * 100\ \% \tag{5}$$

Where $PL_{m(i)}$ is the measured path loss at data point i and $Pl_{ewb(i)}$ is the Weissberger model-based predicted effective path loss at data point i.

## III. THE MODEL OPTIMISATION

The prediction accuracy of the Weissberger foliage path loss model can be enhanced in some ways. One of the most popular ways is the RMSE–Based tuning which is done as follows;

Let the sum of errors for the n data points be SME where ;

$$\text{SME} = \sum_{i=1}^{i=n}\left(PL_{m(i)} - Pl_{ewb(i)}\right) \tag{6}$$

Then, the RMSE-tuned Weissberger foliage path loss model prediction for data point i is denoted as $P_{wb(i)RMSE}$ where;

$$P_{wb(i)RMSE} = \begin{Bmatrix} 0.45f^{0.284}(d_f) & for \quad 0 \le d_f \le 14\text{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\text{m} \end{Bmatrix} + RMSE \ for \ SME \ge 0 \tag{7}$$

$$P_{wb(i)RMSE} = \begin{Bmatrix} 0.45f^{0.284}(d_f) & for \quad 0 \le d_f \le 14\text{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\text{m} \end{Bmatrix} - RMSE \ for \ SME < 0 \tag{8}$$

Where $PL_{m(i)}$ is measured propagation loss (dB) data point i, $PL_{CCIR(i)}$ is the Weissberger model predicted path loss (dB) for data point i .

The second approach employed in tuning the Weissberger foliage path loss model is the error function of the foliage depth-based method, otherwise called EFED method. In this method, a composite function denoted as f(e of $d_f$) that estimates the prediction error based on the foliage depth of the location is derived and so for every predicted path loss , the expected error is also estimated and added to the predicted path loss to obtain the effective predicted path loss. The EFED-tuned Weissberger foliage path loss model is denoted as $P_{wb(i)EFED}$ and is expressed mathematically as follows;

$$P_{wb(i)EFED} = \begin{Bmatrix} 0.45f^{0.284}(d_f) & for \quad 0 \le d_f \le 14\text{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\text{m} \end{Bmatrix} + \text{f(e of } d_f) \tag{9}$$

The f(e of $d_f$) is a function of error , $e_i$ at any given path loss data point i, where;

$$e_i = PL_{m(i)} - Pl_{ewb(i)} = a\left(d_f^{\frac{1}{2}}\right) - b \tag{10}$$

Where a and b are constants that are determined from the empirically measured path loss data, the path loss prediction error and the foliage depth in meters. Hence,

$$P_{wb(i)EFED} = \begin{Bmatrix} 0.45f^{0.284}(d_f) & for \quad 0 \le d_f \le 14\text{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\text{m} \end{Bmatrix} + a\left(d_f^{\frac{1}{2}}\right) - b \tag{11}$$

## IV. THE FIELD MEASUREMENT

The optimised or tuned model is developed based on the empirical path loss data obtained in a specific case study site which is a Mangifera Indica (Mango) plantation in a remote part of Uyo local government are in Akwa Ibom state, Nigeria. The study was conducted for a 3 G cellular network operating at the frequency of 1800 GHz. Two sets of field measured data on the received signal strength and foliage depth were obtained using CellMapper and My GPS location android apps installed on a Tecno Camon X Pro android phone. Particularly, the received signal strength intensity, RSSI, the GPS coordinates as well as the cellular network base station information are captured with the phone and stored in comma-separated values (CSV) files which were later loaded into a laptop computer for further processing. From the measured RSSI values, the measured path losses were computed using the link budget equation. Also, Haversine equation was used to determine the relevant distances from the longitude and latitude data obtained during the field measurements. One of the two field measured path loss data was used for the model training or tuning while the second data set was used for the cross-validation of the model. The graph plot of the RSSI versus foliage depth for the model training data and cross-validation data set are shown in Figure 1.

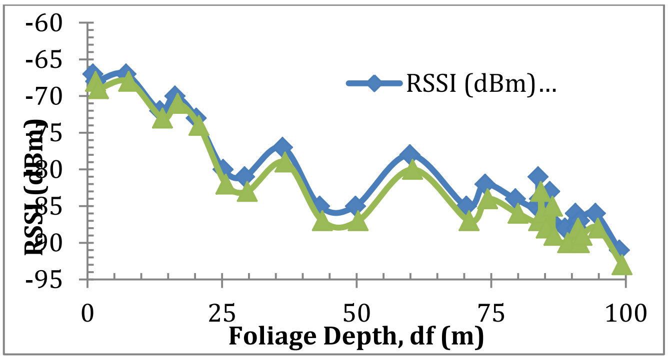


Figure 1 The graph plot of the RSSI versus foliage depth for the model training data and cross-validation data set

### V. RESULTS AND DISCUSSIONS

The prediction error for each foliage depth in the training is computed. Next, the RMSE is computed and used to tune the Weissberger model. Also, the composite function, f(e of $d_f$ ) that estimates the prediction error based on the foliage depth is derived and then used to further optimise the Weissberger model. The results of the measured path loss, the unturned Weissberger model predicted path loss, the RMSE-turned Weissberger model predicted path loss and the EFED-turned Weissberger model predicted path loss for the training dataset are shown in Figure 2. The composite function, f(e of $d_f$) obtained for the training dataset is given as ;

$$e_i = PL_{m(i)} - Pl_{ewb(i)} = 2.216741286\left(d_f^{\frac{1}{2}}\right) - 6.301331953 \qquad (12)$$

$$P_{wb(i)EFED} = \begin{Bmatrix} 0.45f^{0.284}(d_f) & for \quad 0 \le d_f \le 14\text{m} \\ 1.33F^{0.284}(d_f)^{0.588} & for \quad 14 \le d_f \le 400\text{m} \end{Bmatrix} + 2.22\left(d_f^{\frac{1}{2}}\right) - 6.30 \qquad (13)$$

The prediction performance of the models for the training dataset are shown in Figure 2. According to the result, the unturned model had a RMSE of about 11.8 dB and prediction accuracy of about 90.2 %, the RMSE-tuned model had a RMSE of about 7.04 dB and prediction accuracy of about 94.95 %, while the EFED-tuned model had the best performance with RMSE of about 2.58 dB and prediction accuracy of about 97.64 %.

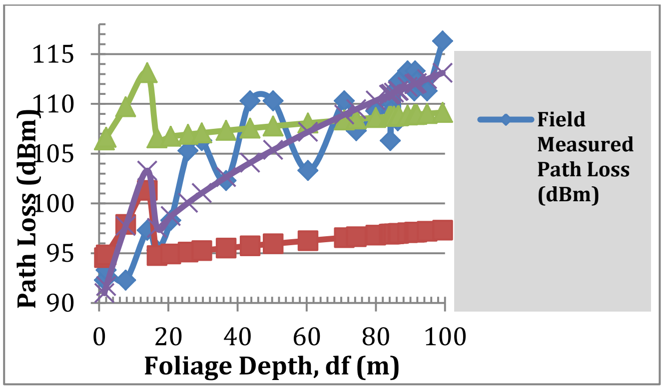


Figure 2 The results of the measured path loss and predicted path loss for the training dataset

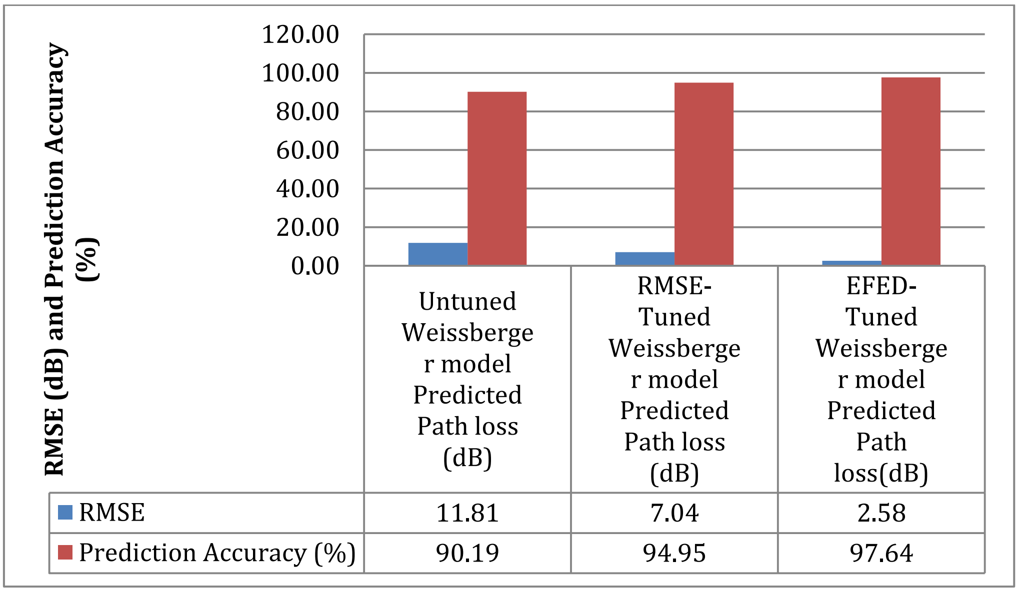


Figure 2 The prediction performance of the models for the training dataset

The RMSE of 7.04 dB from the training dataset was used to tune the model for the cross-validation dataset and also, the composite function of equation 12 which was obtained from the training dataset was used to tune the model for the cross-validation dataset and the results are shown in Figure 3 while the prediction performance results are shown in Figure 4. Again, for the cross-validation dataset, the EFED-tuned model had the best performance with RMSE of about 3.08 dB and prediction accuracy of about 97.22 %. In all, the model derived from the error function of the foliage depth-based method is the preferred model for the prediction of the path loss for 3G cellular network signal within the Mangifera Indica (Mango) plantation.

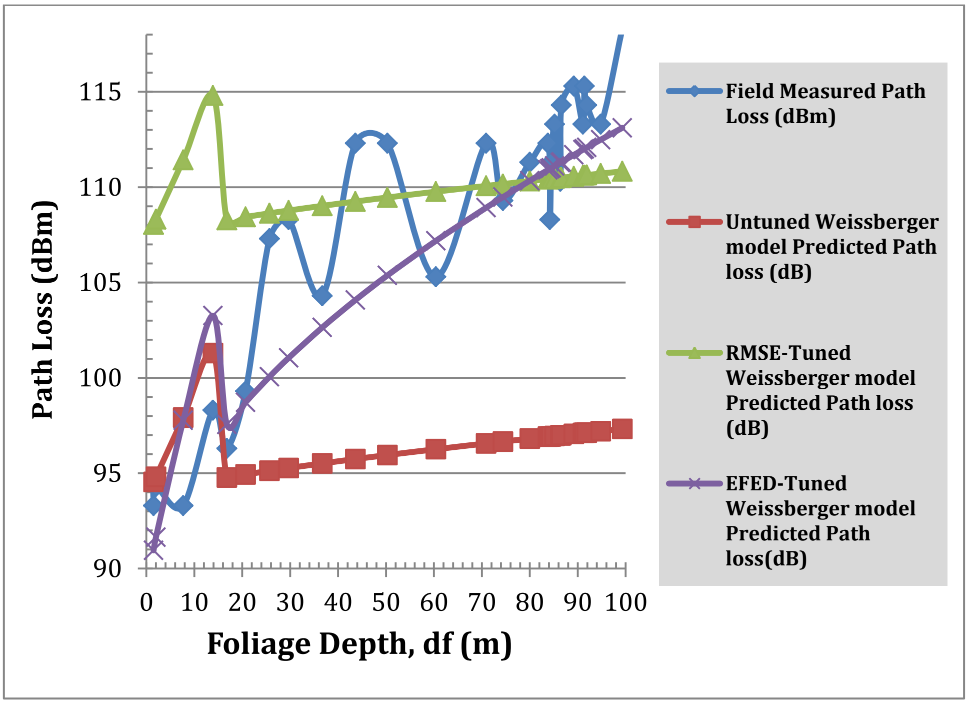


Figure 3 The results of the measured path loss and predicted path loss for the cross-validation dataset

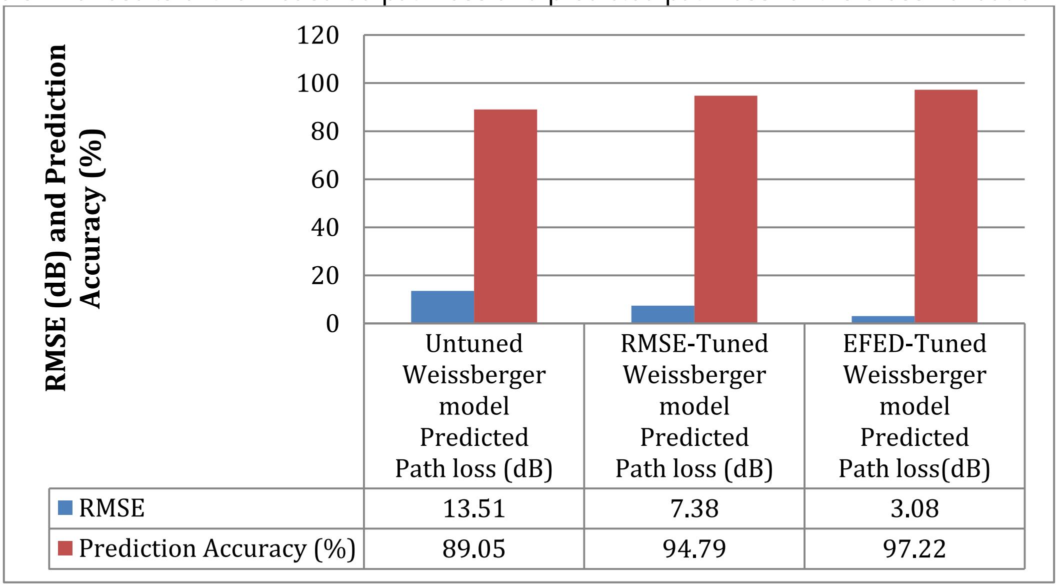


Figure 4 The prediction performance of the models for the cross-validation dataset

## VI. CONCLUSION

Two different methods for optimization of Weissberger foliage path loss model were presented. The first method is the popular root mean square error (RMSE)-based method and the second method is the error function of the foliage depth-based method, otherwise called EFED method. The study was based on empirically measured data for a 3G cellular network operating at 1800 GHz and the site of the study was with a Mangifera Indica (Mango) plantation located in a remote part of Uyo local government area, in Akwa Ibom State, Nigeria. In all, a composite error function of the foliage depth was developed based on the measured training dataset and was then used to optimise the Weissberger foliage path loss model. The model prediction performance was cross-validated with another measured dataset. Furthermore, the prediction performance of the proposed model was compared with the performance of the popular RMSE-based tuning method. The results showed that for the training and the cross-validation dataset, the EFED-based tuning method performed better than the RMSE--based tuning method. The idea presented in this paper can help network designers in selecting the appropriate tuning method to use in modelling their path loss for their target network coverage area.

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