

Application of Weissberger Model for Characterizing the Propagation Loss in a *Gliricidia sepium* Arboretum

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Abstract In this paper, the Weissberger and the Early ITU propagation loss models were used to characterize the propagation loss for a 3G cellular network. Particularly, the 3G network operates at a frequency of 1800 GHz and the case study site is a *Gliricidia sepium* arboretum which is a *Gliricidia sepium* Tree Park planted and maintained mainly for scientific study in the annex campus of University of Uyo. Cellmapper app installed on Tecno i5 mobile phone was used to capture the received signal strength; the latitude and longitude of the data capture points, as well as the time and the key cellular network base station data. The relevant mathematical models used to process the measured data and for tuning the Weissberger and the Early ITU propagation loss models were also presented. The Weissberger and the Early ITU propagation loss models were tuned using foliage depth tuning constant. The tuned models prediction performances were evaluated using cross-validation dataset. With the training dataset, the un-tuned Weissberger model had a root mean square (RMSE) value of 21.098 dB while the tuned Weissberger model had a RMSE of 3.375 dB. Similarly, with the training dataset, the un-tuned Early ITU model had a RMSE of 21.970dB while the tuned Early ITU model had a RMSE of 4.019dB. The tuned Weissberger model with the lowest RMSE was adopted for the prediction of the propagation loss in the case study *Gliricidia sepium* arboretum. Furthermore, the Weissberger model was evaluated using the cross-validation dataset and it had RMSE of 4.507dB.

Keywords Weissberger Model, Propagation Loss, Foliage Path Loss Model, *Gliricidia Sepium*, Arboretum

1. Introduction

When wireless signal propagates through the atmosphere without any obstruction, it suffers the spreading or free space propagation loss [4,5,6]. However, when wireless signal propagates through an area covered

with vegetation, it suffers an additional loss in its signal strength due to the foliage and obstructions in the signal path [7, 8, 9, 10, 11]. Consequently, a typical arboretum will cause additional propagation loss to cellular network users working within the arboretum.

Basically, an arboretum is a botanical garden with mainly plants grown for research, conservation and educational purpose [1, 2, 3]. Determination of the received signal strength at any location within the arboretum can be done using some foliage propagation loss models [12, 13, 14]. In this paper, the Weissberger and the Early ITU foliage propagation loss models are used to characterize the propagation loss within an arboretum that consists of mainly *Gliricidia sepium* trees [15, 16, 17, 18, 19]. The arboretum is located within the annex campus of University of Uyo in Akwa Ibom state, Nigeria.

Most importantly, studies have shown that no propagation loss model can fit every site. As such, in this paper, the focus is to conduct empirical field measurements of the received signal strength within the *gliricidia sepium* arboretum and then use the field measured data to tune the Weissberger and the Early ITU foliage propagation loss models so that they will provide more accurate estimation of the expected foliage propagation loss that can be experienced by the 1800 GHz wireless signal.

2. The Case Study Site and Data Collection

The study was conducted in an arboretum consisting mainly of *Gliricidia sepium* tree, Figure 1 [20, 21]. The arboretum is located inside University of Uyo annex campus in Uyo metropolis. The *Gliricidia sepium* trees are about 8 meters high and with average space of 5 meters between adjacent tree stand.

The signal strength of the 3G cellular network operating at the frequency of 1800 GHz was captured within the arboretum using Cellmapper android app running on Tecno i5 mobile phone. The Cellmapper app enabled the Tecno i5 mobile phone to capture the received signal strength; the

latitude and longitude of the data capture points as well as the time and the key cellular network base station data. The data collected by the Cellmapper android app in the phone were logged and stored in a text file which was later uploaded to a laptop for further processing and propagation loss analysis. After the field data capture, the base station location (latitude and longitude) was obtained based on the Cellmapper Google map location of the base station which was validated by a physical visit to the base station site. The online Haversine distance calculator [22] was used to determine the distance between the base station and each of the RSSI data capture points specified by their latitude and longitude stored in the text file. Furthermore, each of the measured Received Signal Strength (RSSI) value in dBm was converted to the measured path loss ($PL_{m(dB)}$) using the link budget formula;



Figure 1. Image of the case study site; the gliricidia sepium arboretum

$$PL_{m(dB)} = P_{BTS} + G_{BTS} + G_{MS} - \text{RSSI}(dBm) \quad (1)$$

$$PL_{TL}(dB) = 32.5 + 20 * \log(f) + 20 * \log(d) + \begin{cases} 0.45f^{0.284}(d_f) & \text{for } 0 \leq d_f \leq 14m \\ 1.33f^{0.284}(d_f)^{0.588} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (5)$$

The model was tuned by using foliage depth tuning constant, K_{df} , as shown in equation 6.

$$PL_{TL\text{tuned}}(dB) = 32.5 + 20 * \log(f) + 20 * \log(d) + \begin{cases} 0.45f^{0.284}(K_{df}(d_f)) & \text{for } 0 \leq d_f \leq 14m \\ 1.33f^{0.284}(K_{df}(d_f))^{0.588} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (6)$$

The value of K_{df} was adjusted iteratively using the Microsoft Excel Solver until the minimum root mean square error (RMSE) was obtained.

4. The Early Itu –Based Propagation Loss for an Area Covered with Vegetation

Similar to the Weissberger model, foliage propagation loss (in dB) based on the Early ITU model (denoted as PL_{ITU} (dB)) is given as [15,17]:

$$PL_{ITU}(dB) = \begin{cases} 0.2f^{0.3}(d_f)^{0.3} & \text{for } 0 \leq d_f \leq 14m \\ 0.2f^{0.3}(d_f)^{0.6} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (7)$$

The PL_{ITU} (dB) is tuned using a foliage depth factor, β_{fd} as follows;

$$PL_{ITU}(dB) = \begin{cases} 0.2f^{0.3}((d_f)\beta_{fd})^{0.3} & \text{for } 0 \leq d_f \leq 14m \\ 0.2f^{0.3}((d_f)\beta_{fd})^{0.6} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (8)$$

Where P_{BTS} is the transmitter power (dBm) = 20 dBm; G_{BTS} is the transmitter antenna gain (dBi) = 10 dBm and G_{MS} is the receiver antenna gain (dBi) = 10 dBm.

3. The Weissberger–Based Propagation Loss for an Area Covered with Vegetation

When a wireless signal propagates through an area covered with vegetation the total propagation loss, $PL_{TL}(dB)$ can be obtained as [15, 16, 17, 18, 19];

$$PL_{TL}(dB) = PL_{FSP}(dB) + PL_{Foilage}(dB) \quad (2)$$

Where PL_{FSP} is the free space propagation loss and $PL_{Foilage}$ is the propagation loss due to the foliage. Now, the PL_{FSP} is given as;

$$PL_{FSP}(dB) = 32.5 + 20 * \log(f) + 20 * \log(d) \quad (3)$$

Where f is the frequency f in MHz and d is the link distance in km. In this paper, the Weissberger model is used to determine the foliage propagation loss. The foliage propagation loss (in dB) based on the Weissberger model is given as $PL_{Weis}(dB)$, where;

$$PL_{Weis}(dB) = \begin{cases} 0.45f^{0.284}(d_f) & \text{for } 0 \leq d_f \leq 14m \\ 1.33f^{0.284}(d_f)^{0.588} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (4)$$

Where d_f is the depth of foliage along the LOS path in meters and f is the frequency in GHz Hence,

5. Results and Discussion

The whole measured dataset consisting of distance and RSSI was divided into two datasets obtained by picking one data point and leaving the adjacent data point. One of the two datasets, referred to as the tuning (or training) dataset was used for the tuning of the Weissberger and the

Early ITU propagation loss models while the second dataset, referred to as the validation dataset was used for cross-validation of the tuned propagation loss models. The graph plots of the model tuning (or training) RSSI dataset and the model validation RSSI dataset used for the Weissberger and the Early ITU propagation loss models tuning and validation are shown in Figure 2.

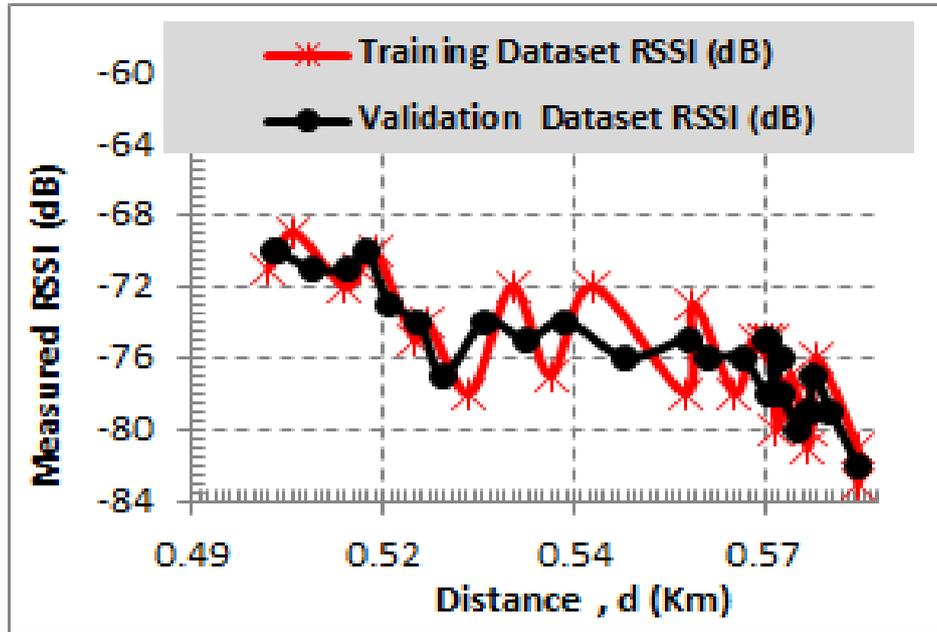


Figure 2. The graph plots of the model tuning (or training) RSSI dataset and the model validation RSSI dataset used for the Weissberger and the Early ITU propagation loss models tuning and validation

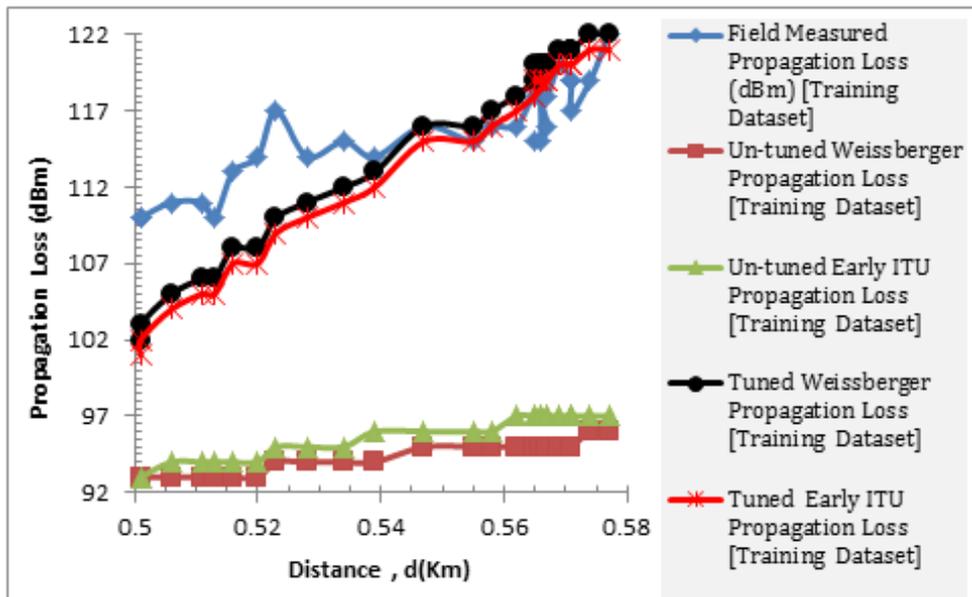


Figure 3. The training dataset results of the propagation loss prediction using the Weissberger and the Early ITU propagation loss models

The results of the propagation loss prediction using the Weissberger and the Early ITU propagation loss models are shown in Figure 3 for the training dataset. Also, the results of the propagation loss prediction using the Weissberger and the Early ITU propagation loss models are shown in Figure 4 for the validation dataset. Furthermore, the prediction performances in terms of RMSE are shown in Table 1 for the Weissberger and the Early ITU propagation loss models.

The foliage depth tuning constant for the Weissberger model is $K_{df} = 52.704$ while that of the Early ITU model is

$\beta_{fd} = 20.688$. That means, in the tuned Weissberger model, the propagation loss for the vegetation covered area is increasing faster with the foliage depth, d_f by a factor of 52.704 more than what is specified in the original Weissberger propagation loss model. Similarly, in the tuned Early ITU model, the propagation loss for the vegetation covered area is increasing faster with the foliage depth, d_f by a factor of 20.688 more than what is specified in the original Weissberger propagation loss model. So, the tuned Weissberger propagation loss model for the *Gliricidia Sepium arboretum* is given as;

$$Pl_{Tuned}(dB) = 32.5 + 20 * \log(f) + 20 * \log(d) + \begin{cases} 0.45f^{0.284}(52.704(d_f)) & \text{for } 0 \leq d_f \leq 14m \\ 1.33f^{0.284}(52.704(d_f))^{0.588} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (9)$$

Similarly, the tuned Early ITU propagation loss model for the *Gliricidia Sepium arboretum* is given as;

$$PL_{ITU \text{ tuned}}(dB) = \begin{cases} 0.2f^{0.3}(20.688(d_f))^{0.3} & \text{for } 0 \leq d_f \leq 14m \\ 0.2f^{0.3}(20.688(d_f))^{0.6} & \text{for } 14 \leq d_f \leq 400m \end{cases} \quad (10)$$

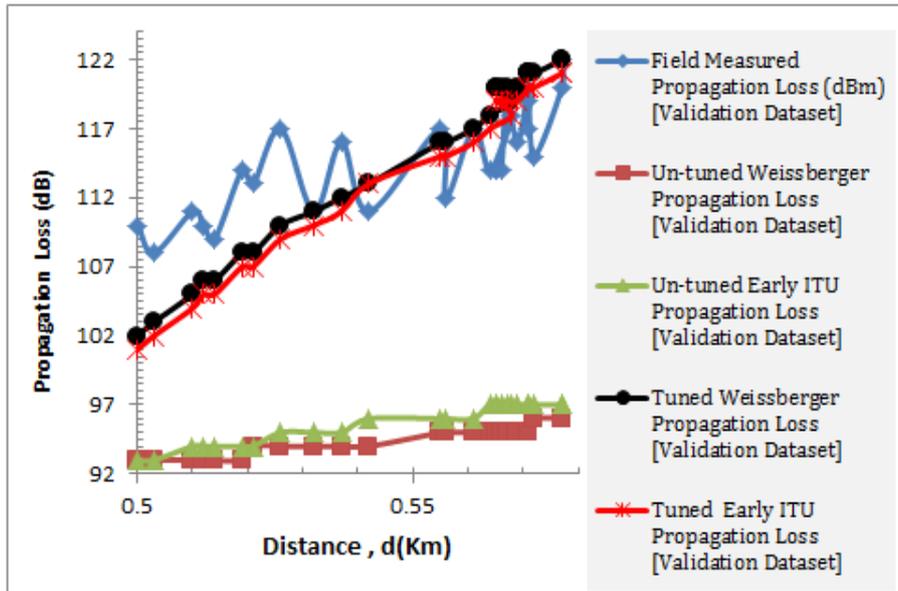


Figure 4. The validation dataset results of the propagation loss prediction using the Weissberger and the Early ITU propagation loss models

Table 1. The prediction performances in terms of RMSE for the Weissberger and the Early ITU propagation loss models

	RMSE for the un-tuned Weissberger model propagation loss prediction with $K_{df} = 1$	RMSE for the un-tuned Early ITU model propagation loss prediction with $\beta_{fd} = 1$	RMSE for the tuned Weissberger model propagation loss prediction with $K_{df} = 52.704$	RMSE for the tuned Early ITU model propagation loss prediction with $\beta_{fd} = 20.688$
RMSE (dB) based on training dataset	21.098	21.970	3.375	4.019
RMSE (dB) based on validation dataset	21.403	22.610	4.507	4.540

The RMSE of the tuned models shows that the tuned Weissberger model with the least RMSE of 3.375 dB has the best prediction performance for the case study *Gliricidia Sepium* arboretum. As such, the tuned Weissberger model of Equ 9 is recommended for the prediction of the propagation loss of the 3G cellular network signal within the *Gliricidia Sepium* arboretum.

6. Conclusions

Development of Weissberger propagation loss model and the Early ITU propagation loss model for an arboretum consisting of *Gliricidia Sepium* trees is presented. The study was for a 3G cellular network and it is based on empirical measurements conducted within the *Gliricidia Sepium* arboretum in the annex campus of University of Uyo. The models were tuned using foliage depth tuning parameters. The Weissberger and the Early ITU propagation loss models gave good prediction performances for the model training dataset and the cross-validation dataset. In all, the tuned Weissberger model had the best propagation loss prediction performance.

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