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STANFORD UNIVERSITY INTERIM PROPAGATION LOSS MODEL FOR A GMELINA ARBOREA TREE-LINED ROAD

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ABSTRACT

In this paper, the extended Stanford University Interim (ESUI) path loss model was evaluated and optimized based on empirically measured path loss obtained along a suburban road lined with Gmelina Arborea trees. The study was for a 1800 MHz cellular network located in Orlu Imo state. The field measurement was conducted in August which is in the rainy season with the entire trees blossom with their green leaves. G-NetTrack Lite 8.0 Adroid app installed on a Samsung Galaxy S8 mobile phone was then used to capture and log the received signal strength (RSSI) in dB, the geo-coordinates of the measurement points as well as the particulars of the 3G network base station. Two datasets were captured and one f the dataset was used for the model optimization while the other dataset was used for validation of the model. For the training dataset, un-tuned ESUI model had a root mean square error (RMSE) of 46.82 dB and maximum absolute prediction error of 46.64 dB whereas the RMSE-tuned ESUI model had a RMSE of 4.094dB and maximum absolute prediction error of 3.41dB. Similarly, for the validation dataset, the un-tuned ESUI model had a RMSE of 48.37dB and maximum absolute prediction error of 48.19 dB whereas the RMSE-tuned ESUI model had a RMSE of 4.39 dB and maximum absolute prediction error of 3.0 dB. In all, the tuned ESUI model was derived and it gave good path loss prediction performance for both the training and the validation datasets.

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Contribution/Originality: The paper's primary contribution is the derivation of a root mean square error-based optimized extended Stanford University Interim (ESUI) path loss model for a suburban road lined with Gmelina Arborea trees.

1. INTRODUCTION

In wireless network communication systems, accurate knowledge of the path loss in any given environment is essential for estimating the network coverage area and attainable quality of service in the area [1-6]. As such, researchers and network designers have developed several path loss prediction mathematical models that are suitable for different terrain and situations [7, 8]. In this paper, the Extended Stanford University Interim (ESUI) model developed by 802.16 IEEE group is studied [8, 9]. The ESUI model is a modified version of the Stanford University Interim (ESUI) model that was developed by 802.16 IEEE group in collaboration with Stanford University [10-15] The ESUI is particularly suitable for the suburban areas and for terrains with light to heavy vegetation.

Consequently, in this paper, the ESUI model is used to characterize the path loss in a suburban road that is lined with Gmelina Arborea trees. The ESUI model was evaluated and tuned using a field measured data collected from the case study road. The model prediction performance was expressed in terms of root mean square error and maximum absolute prediction error. The optimized ESUI model was cross-validated by a second dataset captured along the same road. In all, the relevant mathematical expressions, the field measurement campaign procedure , the ESUI model optimization process, as well as the model performance evaluation and cross-validation, are presented. The essence of the study is to derive ESUI-based path loss model that will give better path loss prediction performance for the given tree-lined suburban road.

2. THE EXTENDED STANFORD UNIVERSITY INTERIM MODEL

The Extended Stanford University Interim (ESUI) model is derived from the original Stanford University Interim (SUI) propagation loss model and it is .given as $P_{ESUI}(dB)$ where Kalu, et al. [9]; Halifa, et al. [15]:

$$P_{ESUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) & for\ d < \acute{\delta}_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\acute{\delta}_o}\right)\right) + X_f + X_h & for\ d > \acute{\delta}_o \end{cases} \qquad (1)$$

Where the path length in meters from the mobile device to the base station antennas is denoted as d , the frequency in MHz is denoted as f , the reference distance d_0=100m , the modified reference distance $\acute{\delta}_o$ is given as;

$$\acute{\delta}_o = d_0\left(10^{-\left(\frac{X_h - X_f}{10(\gamma)}\right)}\right) \qquad (2)$$

Also, the receiving antenna height (in meters) correction factor is X_h , the path loss exponent is γ, the frequency (in MHz) correction is X_f and the shadowing (in dB) correction is S where $8.2 \le S \le 10.6$ dB and A is given as:

$$A = 20\left(\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)\right) \qquad (3)$$

Also, γ which is the path loss exponent is given as:

$$\gamma = a + b(h_b) + \frac{c}{h_b} \qquad (4)$$

The path loss exponent value for different environments are as follows: for free space , $\gamma = 2$; for urban environment, $3 < \gamma < 5$ whereas for indoor situations $\gamma > 5$. Furthermore, the base station antenna height in meters, h_b value is such that $10\ m \le h_b \le 80$ m. The terrain type is used to define the values for the constants a, b and c as shown in Table 1.

Table-1. The values of the ESUI constants for the different terrains [9, 16]

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

Source: Kalu, et al. [9]; Erceg [16]

The correction factor for frequency X_f is given as;

$$X_f = 6\left(\log_{10}\left(\frac{f}{2000}\right)\right) \qquad (5)$$

the receiver antenna height correction factor, X_h is given as;

$$X_h = \begin{cases} -10.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type A and B} \\ -20.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type C} \end{cases} \qquad (6)$$

Where, the frequency, f is in MHz, and the receiver antenna height, h_m is in meter.

The ESUI model is tuned by using the root mean square error (RMSE) method whereby the RMSE . The RMSE is given as;

$$\text{RMSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n}\left|P_{m(i)} - P_{ESUI(i)}\right|^2\right]\right\}} \qquad (7)$$

Where the measured propagation loss in dB for data point i, is denoted as $P_{m(i)}$ and the ESUI predicted propagation loss in dB for data point i is denoted as $P_{ESUI(i)}$ and n is the number of measured data points considered.

The RMSE optimized ESUI model is given as;

For $\sum_{i=1}^{i=n}(PL_{m(i)} - PL_{CCIR(i)}) < 0$

$$P_{ESUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) - RMSE & for\ d < \delta_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\delta_o}\right)\right) - X_f + X_h \pm RMSE & for\ d > \delta_o \end{cases} \qquad (8)$$

For $\sum_{i=1}^{i=n}(PL_{m(i)} - PL_{CCIR(i)}) \geq 0$

$$P_{ESUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) + RMSE & for\ d < \delta_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\delta_o}\right)\right) + X_f + X_h + RMSE & for\ d > \delta_o \end{cases} \qquad (9)$$

3. THE FIELD MEASUREMENT CAMPAIGN

The study was carried out on a Gmelina Arborea [17, 18] tree-line road in the suburban site located in Orlu in Imo state. The field measurement was conducted in August which is in the rainy season with the entire trees blossom with their green leaves. The road receives signal from a 3G 1800 MHz cellular network base station that is about 400 meters from the road. G-NetTrack Lite 8.0 Android app was installed on a Samsung Galaxy S8 mobile phone and was then used to capture and log the received signal strength (RSSI) in dB, the geo-coordinates of the measurement points as well as the particulars of the 3G network base station. The field data measured RSSI was used in a link budget equation to determine the measured path loss. Haversine formula was used to determine the distance between the base station and each of the measurement points. The data capture was done two times and one of the datasets was used as the training data for optimizing the ESUI model while the second dataset was used for the cross-validation of the optimized ESUI mode. The field measured RSSI, the measured path loss and their corresponding measurement point distance from the base station for the training and validation datasets are shown in Figure 1 and Figure 2 respectively.

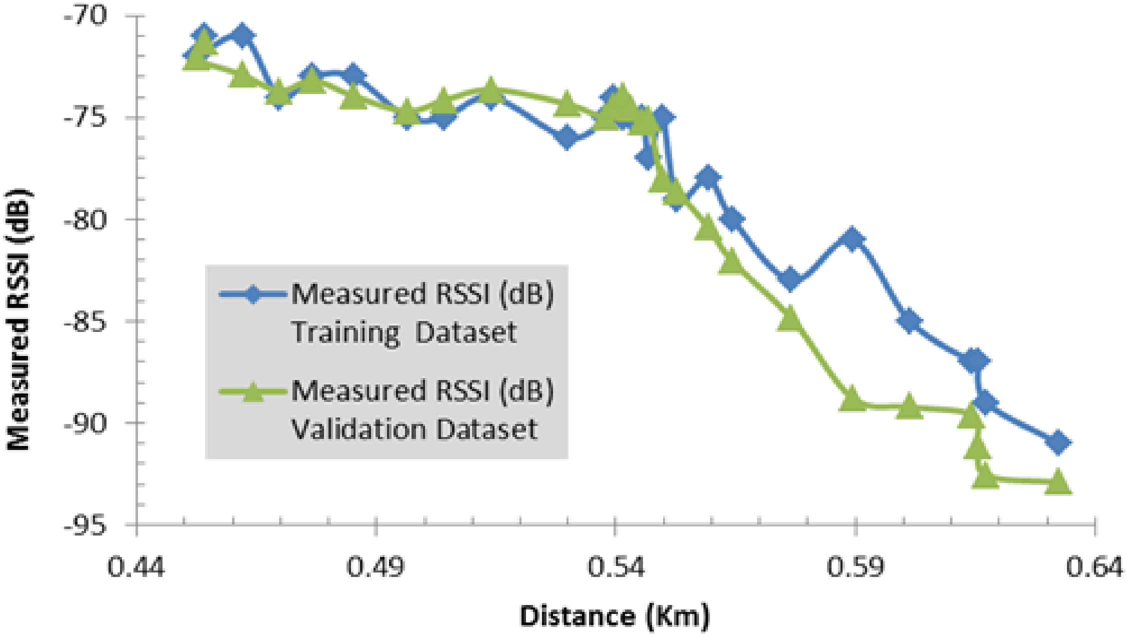

Figure-1. The field measured RSSI versus measurement point distance from the base station for the training and validation datasets

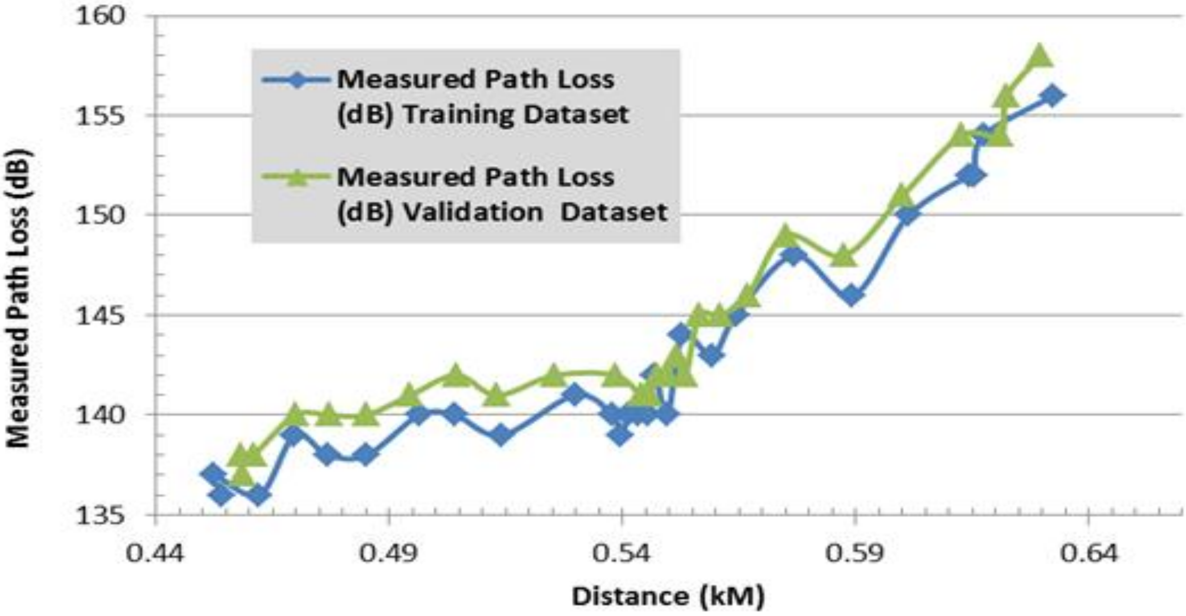

Figure-2. The field measured path loss versus measurement point distance from the base station for the training and validation datasets

4. RESULTS AND DISCUSSION

The ESUI model for the suburban area (terrain B) was used to predict path loss for each of the measurement point distance from the field data and the path los prediction performance of the model was evaluated in terms of RMSE and the maximum absolute prediction error, denoted as e_{mae} , where;

$$e_{mae} = maximum\ (PL_{m(i)} - PL_{CCIR(i)}) \text{ for all i= 1,2,3,…,n} \quad (10)$$

The result for the ESUI model predicted path loss and the optimized ESUI model predicted path loss are given in Table 1 and Figure 3 for the training dataset. According to the results in Table 1, for the training dataset, in each of the measurement points, the measured path loss values (in column 2 of Table 1) is higher than the ESUI predicted path loss (in column 3 of Table 1). The RMSE obtained is 46.82 dB for the training dataset. Consequently, the sum of error is positive, that is, $\sum_{i=1}^{i=n}(PL_{m(i)} - PL_{CCIR(i)}) \geq 0$. Then, based on equation 9, the ESUI model was tuned by adding the RMSE to the ESUI model predicted path as follows;

$$P_{ESUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) + 46.82 & for\ d < \overset{\vdots}{\delta}_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\overset{\vdots}{\delta}_o}\right)\right) + X_f + X_h + 46.82 & for\ d > \overset{\vdots}{\delta}_o \end{cases} \quad (11)$$

Essentially equation 11 is the optimized ESUI model for the given case study Gmelina Arborea tree-lined road.

Table -1. The ESUI model predicted path loss and the optimized ESUI model predicted path loss versus distance for the training dataset

d (km)	Measured Path Loss (dB)	Un-Tuned ESUI For Terrain B (dB)	RMSE-Tuned ESUI For Terrain B (dB)
0.4542	136	93	140
0.4524	137	93	140
0.4621	136	93	140
0.4697	139	94	141
0.4768	138	94	141
0.4852	138	94	141
0.4964	140	95	142
0.504	140	95	142
0.5141	139	95	142
0.5298	141	96	143
0.5379	140	96	143
0.5395	139	96	143
0.5414	140	96	143
0.5433	140	96	143
0.5455	140	96	143
0.5469	142	96	143
0.5496	140	97	143
0.5528	144	97	143
0.5592	143	97	144
0.5643	145	97	144
0.5767	148	97	144
0.5893	146	98	145
0.6013	150	98	145
0.6144	152	99	145
0.6154	152	99	145
0.6173	154	99	145
0.6324	156	99	146

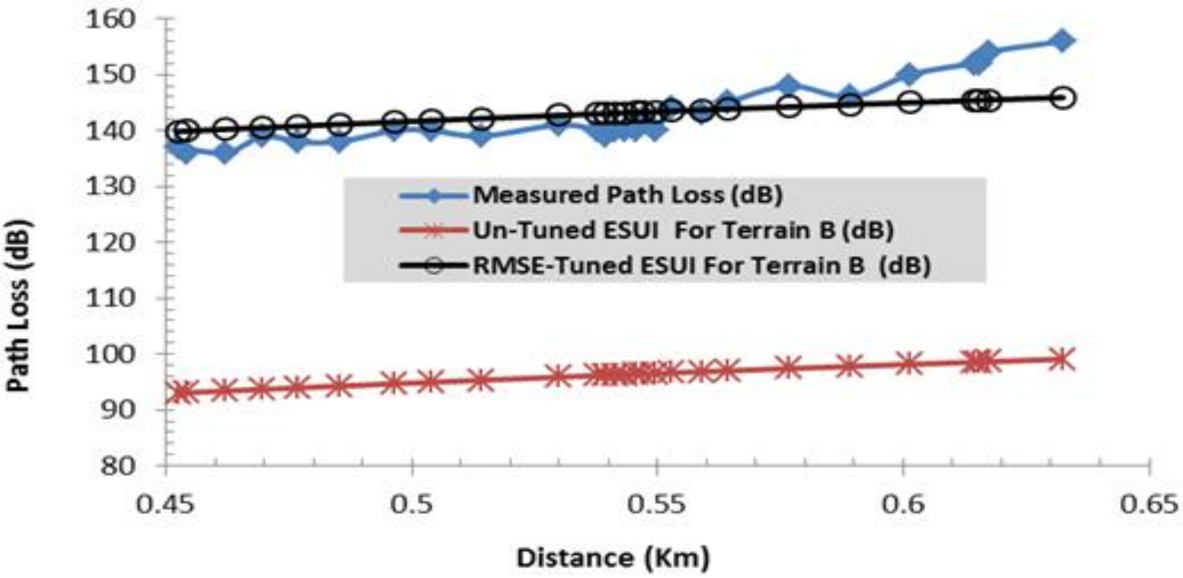

Figure-3. The ESUI model predicted path loss and the optimized ESUI model predicted path loss versus distance

The un-tuned ESUI model had a RMSE of 46.82 dB and maximum absolute prediction error of 46.64 dB whereas the RMSE-tuned ESUI model had a RMSE of 4.094dB and maximum absolute prediction error of 3.41dB . The validation dataset also gave good prediction performance the ESUI tuned with the RMSE value of 46.64 dB obtained from the training dataset. According to the validation dataset result, the un-tuned ESUI model had a RMSE of 48.37dB and maximum absolute prediction error of 48.19 dB whereas the RMSE-tuned ESUI model had a RMSE of 4.39 dB and maximum absolute prediction error of 3.0 dB .

5. CONCLUSION

The extended Stanford University Interim (ESUI) path loss model was presented. The study was for a 3G network in a suburban area along a road lined with Gmelina Arborea trees. Field measurements were conducted along the road and the measured path loss data was used to optimize the ESUI model for better path loss prediction performance. The data field capture was conducted two times and one of the datasets was used for the model optimization while the second dataset was used for the cross-validation. In all, the root mean square error tuned ESUI model gave good prediction performance for both the training and the validation dataset. Finally, the tuned ESUI model for the case study road was also derived based on the filed data results.

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