Path Loss Exponent-Tuned Stanford University Interim Model For Musa Paradisiaca (Plantain) Plantation

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Abstract— In this paper, the Stanford University Interim (SUI) model is studied. Particularly, the SUI model was used to model the path loss that a 1800 GHz 3G cellular network signal will encounter while propagating through a Musa Paradisiaca (plantain) plantation located in Umuakpu in Imo state. The site measurement at the plantation was conducted in clear air condition during the heavy rain period of July 2018 when the Musa Paradisiaca plants are in their full blossom with their large green leaves covering a larger part of the spaces in the plantation. The field data on the received signal strength intensity(RSSI) and base station information for the 3G network covering the plantation area were captured and logged using site survey android application, Netmonitor 1.5.84 installed on Infinix Zero 4. Based on the measured path loss, the SUI model was tuned using the path loss exponent adjustment approach. The tuned SUI model gave very good path loss prediction for the site and the results showed that the plantation has larger path loss exponent value than the value obtained with the original SUI model parameters. The results showed that for the training dataset, the un-tuned SUI model with the un-tuned path loss exponent value, γ of 4.1675 had a prediction accuracy of 86.26 % with root mean square error (RMSE) of 17.62 dB while the path-loss exponent –tuned SUI model with the tuned path loss exponent value, γ_{tun} of 6.698735 had a prediction accuracy of 83.36 % with RMSE of 3.80 dB. On the other hand, for the validation dataset , the un-tuned SUI model with the un-tuned path loss exponent value, γ of 4.1675 had a prediction accuracy of 86.26 % with RMSE of 14.96 dB while the path-loss exponent–tuned SUI model with the tuned path loss exponent value, γ_{tun} of 6.698735 had a prediction accuracy of 97.42 % with RMSE of 3.80 dB. Based on the results, the effective SUI model for the given case study Musa Paradisiaca (plantain) plantation was derived and it had path loss exponent that is higher by a factor of 1.607375 when compared with the path loss exponent of the original SUI model.

Keywords—Pathloss, Musa Paradisiaca, Path Loss Exponent, Stanford University Interim Model, Cellular Network

I. INTRODUCTION

Wireless signals propagating through the clear air without any obstruction suffers a loss in signal strength due to spreading of the signal which is popularly called free space path loss [1,2,3,4,5,6]. Furthermore, when there are obstructions in the signal path, the signal suffers addition path loss [7,8,9,10,11,12,13]. Several mathematical models, referred to as path loss models, have been developed over the years for estimating the expected path loss any wireless signal will be subjected to when it propagates through a path with a specific set of obstructions and terrain. Some of the path loss models are designed to estimate the path loss for urban areas, suburban areas as well as rural area. In addition, some path loss models are derived for estimating path loss in areas covered with vegetation [14,15,16,17,18,19]. In this paper, the focus in on the development of optimized Stanford University Interim (SUI) model to estimate the path loss for a 3 G cellular network in a Musa Paradisiaca (plantain) plantation [20,21,22,23,24,25,26].

The SUI model was developed by the joint effort of Stanford University and the 802.16 IEEE group. The model was particularly suitable for suburban areas with light or heavy vegetation. In this paper, the focus is to use empirically measured field data collected at the case study site to optimize the SUI model so that it can give better path loss prediction performance for the site. Particularly, the SUI model is optimized by tuning the path loss exponent [27,28,29] component of the model until the minimum root mean square error is achieved. The relevant mathematical expressions and procedures for field data collection and the model optimization are presented.

II. THE STANFORD UNIVERSITY INTERIM PATH LOSS MODEL

The Stanford University Interim (SUI) model was developed from a joint research work conducted by 802.16 IEEE group and the Stanford University. The model is particularly suitable for suburban areas. However the model has provision for the urban and the rural areas as well. The path loss, $LP_{SUI(dB)}$ predicted by SUI model is given as follows [20,21,22];

$$LP_{SUI(dB)} = A + 10\gamma\left(\log_{10}\left(\frac{d}{d_0}\right)\right) + X_f + X_h + S \; for \; d > d_0 \quad (1)$$

Where,

d is the distance in meters between the mobile device and the base station antennas

f isthe frequency in MHz

d_0=100m
$X_h$is the correction for receiving the antenna height in meters
$\gamma$is the path loss exponent
$X_f$is the correction for frequency in MHz
S is the correction for shadowing in dB and its value is between 8.2 and 10.6 dB at the presence of trees and other clutter on the propagation path

The parameter A is defined as:

$$A = 20\left(\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)\right) \quad (2)$$

and the path loss exponent γ is given by:

$$\gamma = a + b(h_b) + \frac{c}{h_b} \quad (3)$$

Where, h_b is the base station antenna height in meters; its value is between 10 m and 80 m. The constants a, b and c depend upon the types of terrain, that are given in Table 1. The value of parameter γ is 2 for free space propagation in an urban area, 3 $< \gamma <$ 5 for urban non-line-o-sight environment, and γ> 5 for indoor propagation.

The values for the SUI terrain parameter

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

The frequency correction factor X_f and the correction for receiver antenna height X_h for the models are expressed as follows;

$$X_f = 6\left(\log_{10}\left(\frac{f}{2000}\right)\right) \quad (4)$$

$$X_h = \begin{cases} -10.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type A and B} \\ -20.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type C} \end{cases} \quad (5)$$

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

Type A terrain has maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities.

Type B is for flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities.

Type C terrain has minimum path loss and applies to flat terrain with light tree densities.

III. THE SUI MODEL OPTIMIZATION

The SUI model is optimized by tuning the path loss exponent, γ until the minimum root mean square error is obtained . The tuning was done sung a path loss exponent tuning parameter denoted as β_γ,such that the tunedpath loss exponent denoted γ_{tun} is given as ;

$$\gamma_{tun} = \beta_\gamma(\gamma) = \beta_\gamma\left(a + b(h_b) + \frac{c}{h_b}\right) \quad (6)$$

Hence, the path loss exponent tuned SUI model denoted as $LP_{SUItun(dB)}$is given as ;

$$LP_{SUItun(dB)} = A + 10(\gamma_{tun})\left(\log_{10}\left(\frac{d}{d_0}\right)\right) + X_f + X_h + S \; for \; d > d_0 \quad (7)$$

$$LP_{SUItun(dB)} = A + 10\left(\beta_\gamma(\gamma)\right)\left(\log_{10}\left(\frac{d}{d_0}\right)\right) + X_f + X_h + S \; for \; d > d_0 \quad (8)$$

The determination of the value of the path loss exponent tuning parameter,β_γ was done using Microsoft Excel Solver.

IV THE FIELD DATA COLLECTION

The case study Musa Paradisiaca (plantain) plantation is located in Umuakpu in Imo state with a longitude of 5.255025 and a latitude of 6.876798 (Figure 1). The site measurement at the plantation was conducted in clear air condition during the heavy rain period of July 2018. At this period the Musa Paradisiac a(plantain) plants are in their full blossom with their large green leaves covering a larger part of the spaces in the plantation. Furthermore, the case study site is a flat terrain suitable for the class B terrain in the SUI model.

The data on the received signal strength intensity(RSSI) and base station information for the 3G network covering the plantation area were captured and logged using site survey android application, Netmonitor 1.5.84 installed on Infinix Zero 4. The 3G network signal frequency is 1800 GHz. The logged field measured datasets were later loaded into the computer where they are used for the path loss analysis.

Figure 1 Google map location of the Musa Paradisiaca (plantain) plantation in Umuakpu in Imo state with a longitude of 5.255025 and a latitude of 6.876798

The measured RSSI values were converted to measured path loss based on link budget formula while Haversine formula was used to determine the distance of the base station to each of the logged data point longitude and latitude. The dataset was divided into two equal parts; one part was used for tuning of the path loss exponent in the SUI model while the second dataset was used for cross-validation of the derived optimized SUI model. The two field measured datasets are given in Figure 1.

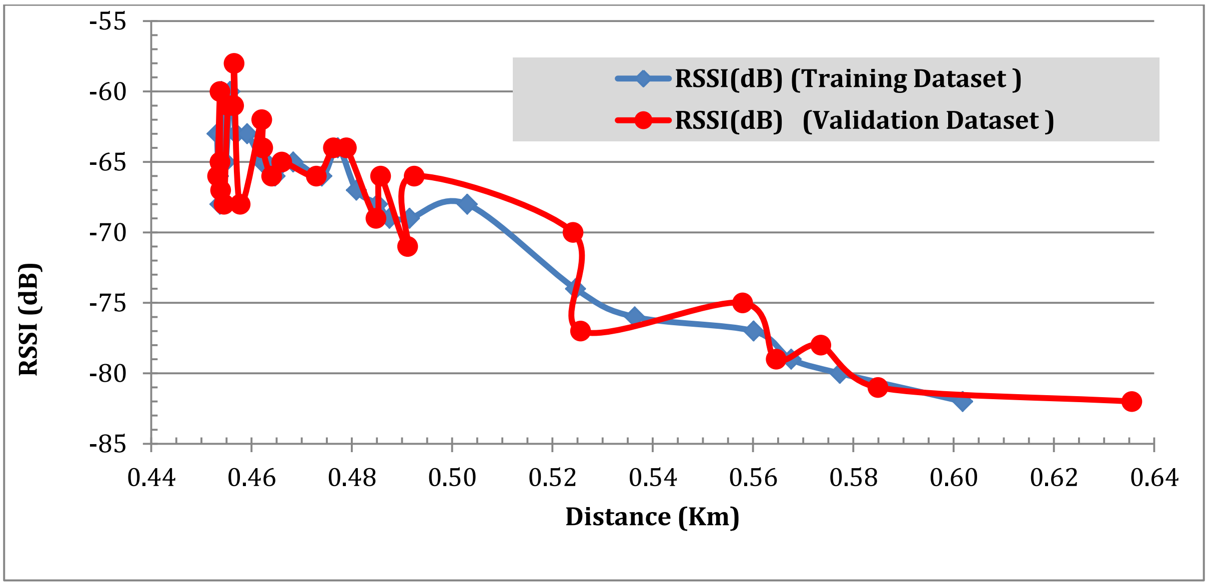

Figure 1 The two field measured datasets; the tuning dataset and the cross-validation dataset

V. RESULTS AND DISCUSSION

The class B terrain in the SUI model is adopted in the analysis since the terrain is a flat terrain. The results of the measured path loss, the SUI model predicted path loss and the path loss exponent tuned SUI model predicted path loss are given in Table 1 and Figure 3 for the training data and for the cross-validation datasets. In both the training and the validation datasets , the measured path loss values are higher than their corresponding SUI model predicted path loss values.

Table 1 The measured path loss, the SUI model predicted path loss and the path loss exponent tuned SUI model predicted path loss for the training data and for the cross-validation datasets.

TRAINING DATASET				VALIDATION DATASET			
d (km)	FIELD MEASURED PATH LOSS (dBm)	UN-TUNED SUI FOR CLASS B TERRAIN (dBm)	PATH-LOSS EXPONENT TUNED SUI FOR SUBURBAN	d (km)	FIELD MEASURED PATH LOSS (dBm)	UN-TUNED SUI FOR CLASS B TERRAIN (dBm)	PATH-LOSS EXPONENT TUNED SUI FOR CLASS B TERRAIN (dBm)
0.453	114	101	117	0.453	114	101	114
0.453	117	101	117	0.454	108	101	114
0.454	119	101	117	0.454	113	101	114
0.454	114	101	117	0.454	115	101	114
0.454	111	101	117	0.455	116	101	114
0.455	116	101	117	0.455	109	101	114
0.456	111	101	117	0.456	109	101	114
0.456	112	101	117	0.457	106	101	114
0.457	114	101	117	0.458	116	101	114
0.459	114	101	118	0.462	110	101	114
0.462	116	101	118	0.462	112	101	114
0.463	116	101	118	0.464	114	101	115
0.465	117	101	118	0.466	113	101	115

0.468	116	101	118	0.473	114	101	115
0.474	117	101	118	0.476	112	101	115
0.477	115	102	119	0.479	112	102	115
0.481	118	102	119	0.485	117	102	116
0.485	119	102	119	0.486	114	102	116
0.488	120	102	119	0.491	119	102	116
0.492	120	102	120	0.492	114	102	116
0.503	119	102	120	0.524	118	103	118
0.525	125	103	121	0.526	125	103	118
0.536	127	104	122	0.558	123	104	120
0.560	128	104	123	0.565	127	105	120
0.568	130	105	124	0.573	126	105	120
0.577	131	105	124	0.585	129	105	121
0.602	133	106	125	0.636	130	107	123

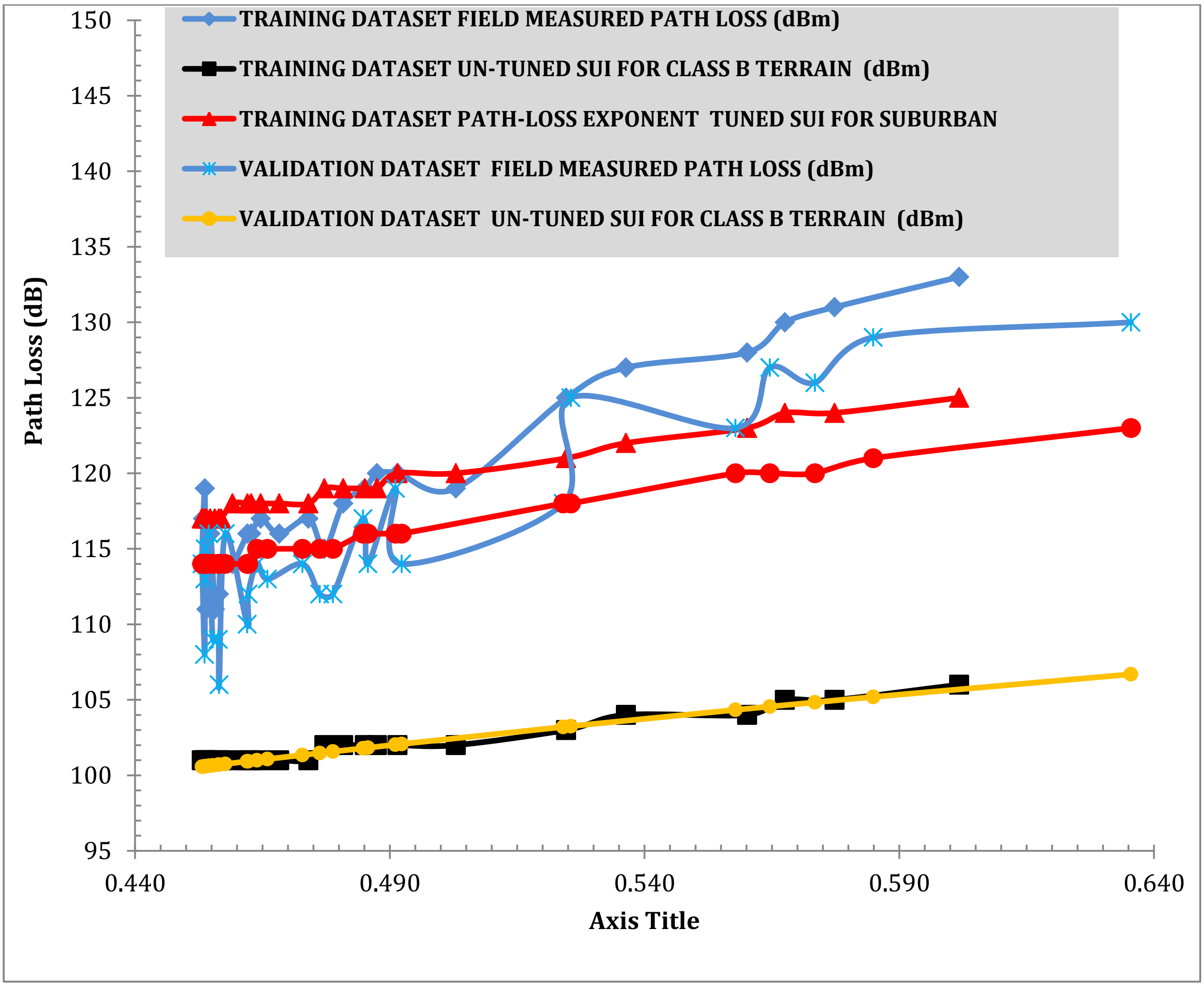

Figure 3 The measured path loss, the SUI model predicted path loss and the path loss exponent tuned SUI model predicted path loss for the training data and for the cross-validation datasets.

The results showed that for the training dataset , the un-tuned SUI model with the un-tuned path loss exponent value, γ of 4.1675 had a prediction accuracy of 86.26 % with RMSE of 17.62 dB while the path-loss exponent –tuned SUI model with the tuned path loss exponent value, γ_{tun} of 6.698735 had a prediction accuracy of 83.36 % with RMSE of 3.80 dB. On the other hand, for the validation dataset , the un-tuned SUI model with the un-tuned path loss exponent value, γ of 4.1675 had a prediction accuracy of 86.26 % with RMSE of 14.96 dB while the path-loss exponent–tuned SUI model with the tuned path loss exponent value, γ_{tun} of 6.698735 had a prediction accuracy of 97.42 % with RMSE of 3.80 dB. It means that for the given case study, the path loss increases faster with the distance that was specified by the parameters in the original SUI model. Particularly, the un-tuned SUI model parameters showed that the path loss exponent for the case study site is supposed to be 4.1675 dB/Km. However, the tuned-SUI model based on the empirical data obtained from the case study site indicated that the path loss exponent should be 6.698735 dB/Km with a path loss tuning parameter value, β_{γ} of 1.607375. Based on the results, the effective SUI model for the given case study Musa Paradisiaca (plantain) plantation located at Umuakpu in Imo state is given as follows;

$$LP_{SUItun(dB)} = A + 10(1.607375(\gamma))\left(\log_{10}\left(\frac{d}{d_0}\right)\right) + X_f + X_h + S \text{ for } d > d_0 \quad (9)$$

Finally, the path loss tuning parameter value, β_{γ} of 1.607375 shows that the effective path loss exponent for the plantation is 1.607375 times the path loss exponent indicated by the original SUI model.

VI. CONCLUSION

The Stanford University Interim (SUI) model is used to model the path loss that a 3G cellular network signal will encounter while propagating through a Musa Paradisiaca (plantain) plantation located in Umuakpu in Imo state. The study was based on empirical field measurements conducted in the case study plantation. The SUI model was tuned using the path loss exponent adjustment approach. The tuned SUI model gave very good path loss prediction for the site and the results showed that the plantation has larger path loss exponent value than the value obtained with the original SUI model parameters.

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