Performance Evaluation of Hata-Davidson Pathloss Model Tuning Approaches for a Suburban Area

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To cite this article:
Wali Samuel, Njumoke N. Odu, Samuel Godwin Ajumo. Performance Evaluation of Hata-Davidson Pathloss Model Tuning Approaches for a Suburban Area. American Journal of Software Engineering and Applications. Vol. 6, No. 3, 2017, pp. 93-98.
doi: 10.11648/j.ajsea.20170603.16

Received: January 3, 2017; Accepted: January 18, 2017; Published: June 23, 2017

Abstract: In this paper, comparative study of RMSE-base tuning and multi-parameter-based tuning of Hata-Davidson pathloss model for a suburban area is presented. The study was based on field measurement of received signal strength carried out in a suburban area for a GSM (Global System for Mobile communication) network that operates in the 1800MHz frequency band. The results show that multi-parameter-tuned Hata-Davidson model has better prediction accuracy of 98.70720432% and RMSE of 2.177522885 dB as against the RMSE-tuned Hata-Davidson model with prediction accuracy of 97.42722692% and RMSE of 4.256897001dB. However, the RMSE is quite simple and easier to implement even in embedded systems and systems with limited resource.

Keywords: Pathloss, Propagation Model, Hata-Davidson Model, Model Optimisation, Multi-Parameter-Based Tuning Method, RMSE-Base Tuning Method

1. Introduction

Pathloss models are essential in planning wireless network. The models provide mathematical expressions that enable network designers to determine the amount of pathloss that will be experienced by the signal as it transverse the given terrain [1-5]. Basically, a propagation pathloss model predicts the difference between the transmitted power and the receiver power using empirical and deterministic methods or a combination of both. Empirical models, in general, require adjusting some parameters according to field measurements made in a particular environment. Several empirical pathloss 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 they are initially built for. For instance, [6] provides the error bounds on the efficacy at predicting pathloss for eight widely used empirical pathloss 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. Faruk, Adediran and Ayeni, [7] presented similar results to that of [6] and concluded that tuning of pathloss model is necessary to minimize the RMSE value within the acceptable range. For example, Dalela, Prasad and Dalela, [9] presented tuning of COST 231 Hata model based on measurements conducted in 2.3 GHz in Western India. Also, 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. Isabona and Azi, [10] optimized Walfisch Bertoni model using least squares method. The optimized model predicts pathloss with improved accuracy of about 25-30% compared to the original model. Chen and Hsieh [11] provided a fast and precise dual least-square approach to tune the generally used propagation models, like COST231-Hata model. In this paper, two different least square optimization techniques are used for optimizing the...
Hata-Davidson model [12]. The first approach is based on addition or subtraction of the RMSE value whereas the second approach is based on the adjustment of some Hata-Davidson model parameters in such a way as to minimise the sum of square error. The performance of the two tuning approaches are compared in terms of their RMSE and prediction accuracy.

2. Method

The field measurement route is identified with respect to the Cellular Network Base Station (CNBS) selected for the study. Received Signal Strength (RSS) and spatial data (longitude, latitude and altitude) dataset are then collected along the route. Samsung Galaxy S4 mobile phone with Cellmapper android application installed is used to capture and store the RSS and spatial datasets in CSV file. The RSS is converted to the measured pathloss (PL) using the formula [13-15]:

\[ PL_{m(dB)} = P_{BUTS} + G_{BUTS} + G_{MS} - L_{FC} - L_{AB} - L_{CF} - RSS \ (dBm) \] (1)

where for each measurement location at a distance d (km)

- RSS is the mean Received Signal Strength (RSS) in dBm
- \( P_{BUTS} \) = Transmitter Power (dBm), \( G_{BUTS} \) = Transmitter Antenna Gain (dBi), \( G_{MS} \) = receiver antenna gain (dBi), \( L_{FC} \) = feeder cable and connector loss (dB), \( L_{AB} \) = Antenna Body Loss (dB) and \( L_{CF} \) = Combiner And Filter Loss (dB). The values of these parameters are given as [13]: \( P_{BUTS} = 40 \, W = 46 \, dBm, G_{BUTS} = 18.15 \, dBi, G_{MS} = 0 \, dB, L_{FC} = 3 \, dB, L_{AB} = 3 \, dB, L_{CF} = 4.7 \, dB \). Hence,

\[ PL_{m(dB)} = 53.5 \ (dBm) - RSS \ (dBm) \] (2)

Again, the Haversine formula in Eq 3 is used to compute the distances (d) between each measurement point and the base station as follows;

\[ d = 2r \sin \left( \frac{\text{LAT}_1 - \text{LAT}_2}{2} \right) + \cos(\text{LAT}_1) \cos(\text{LAT}_2) \sin \left( \frac{\text{LONG}_1 - \text{LONG}_2}{2} \right) \] (3)

Where

\[ \text{LAT} \] in Radians = \( \frac{(\text{LAT} \text{ in Degrees} \times 3.142)}{180} \) (4)

\[ \text{LONG} \] in Radians = \( \frac{(\text{LONG} \text{ in Degrees} \times 3.142)}{180} \) (5)

2.1. Hata-Davidson Propagation Model

Hata-Davidson model is one of the extensions or modified versions of Hata model. Particularly, Hata-Davidson is Telecommunications Industry Association (TIA) recommended model following modification to the Hata model to cover a broader range of input parameters. The modification consists of the addition of correction terms to the Hata model.

The following equations are used for the computation of the pathloss (in dB) according to the Hata-Davidson model:

\[ LP_{Hata-Davidson} = LP_{HATA} + K_{Davidson} \] (6)

Where

- is the pathloss prediction by the Hata model and \( K_{Davidson} \) is the correction factor introduced by Davidson. The following equations are used for the computation of pathloss (in dB) according to the Hata-Davidson model:

\[ LP_{OK.HATA(urban)} = A + B \times \log_{10}(d) \text{ for Urban} \] (7)

\[ A = 69.55 + 26.16 \times \log_{10}(f) - 13.82 \times \log_{10}(h_b) - a(h_m) \] (8)

\[ B = 44.9 - 6.55 \times \log_{10}(h_b) \] (9)

\[ C = 5.4 + 2 \times \left[ \log_{10} \left( \frac{f}{260} \right) \right]^2 \] (10)

\[ D = 40.94 + 4.78 \times \left[ \log_{10}(f) \right]^2 - 18.33 \times \log_{10}(f) \] (11)

\[ a(h_m) = [1.1 \times \log_{10}(f) - 0.7] \times h_m - [1.56 \times \log_{10}(f) - 0.8] \] (12)

Eq 8 is for small city, medium city, open area, rural area and suburban area.
Now, for large city

\[ a(h_m) = 8.28 \times \left( \log_{10}(1.54 \times h_m) \right)^2 - 1.1 \quad f \leq 200\text{MHz} \]  
\[ a(h_m) = 3.2 \times \left( \log_{10}(11.75 \times h_m) \right)^2 - 4.97 \quad f \geq 400\text{MHz} \]  

Where
- \( f \) is the centre frequency in MHz
- \( d \) is the link distance in km
- \( h \) is an antenna height-gain correction factor that depends upon the environment
- \( C \) and \( D \) are used to correct the small city formula for suburban and open areas

The following equations are used for the correction factor, introduced by Davidson:

\[ K_{Davidson} = A(h_b, d) - S_1(d) - S_2(h_b, d) - S_3(f) - S_4(f, d) \]  

Where
- \( A \), \( S_1 \) are distance correction factors, \( h_b \) is base station antenna height correction factor, \( h_m \) and \( f \) are frequency correction factors.
- \( A(h_b, d) \) and \( S_1(d) \) are distance correction factors, with \( d \) in km, \( h_b \) in m, \( h_m \) and \( f \) in MHz.

\[ A(h_b, d) = \begin{cases} 
0 & d < 20\text{km} \\
0.62317 \times (d - 20) \times 0.5 + 0.15 \log \left( \frac{h_b}{121.92} \right) & 20 < d < 64.38\text{km} \\
0.62317 \times (d - 20) \times 0.5 + 0.15 \log \left( \frac{h_b}{121.92} \right) & 20 < d < 300\text{km} 
\end{cases} \]  

\[ S_1(d) = \begin{cases} 
0 & d < 20\text{km} \\
0.174(d - 64.38) & 20 < d < 300\text{km} 
\end{cases} \]  

\[ S_2(h_b, d) = 0.00784 \times \log \left( \frac{9.90}{d} \right) \times (h_b - 300) \quad \text{for} \quad h_b < 300 \]  

\[ S_3(f) = \frac{f}{250 \left( \log \left( \frac{1500}{f} \right) \right)} \]  

\[ S_4(f, d) = \left( 0.112 \left( \log \left( \frac{1500}{f} \right) \right) \right) \times (d - 64.38) \quad \text{for} \quad d > 64.38\text{km} \]  

2.2. Performance Analysis of the Models

The statistical performance measures or goodness of fit measures for the Hata-Davidson model are defined as follows:

i) The Root Mean Square Error (RMSE) is calculated as follows:

\[ \text{MSE} = \frac{1}{n} \sum_{i=1}^{n} \left(\frac{\left| P_L(\text{measured})_i - P_L(\text{predicted})_i \right|}{\sum_{i=1}^{n} P_L(\text{measured})_i} \right)^2 \]  

ii) Then, the Prediction Accuracy (PA, %) based on mean absolute percentage deviation (MAPD) or Mean Absolute Percentage Error (MAPE) is calculated as follows:

\[ \text{PA} = \left( 1 - \frac{1}{n} \sum_{i=1}^{n} \left( \frac{P_L(\text{measured})_i - P_L(\text{predicted})_i}{P_L(\text{measured})_i} \right) \right) \times 100\% \]  

2.3. Model Optimization Process

The parameters of the Hata-Davidson pathloss model were adjusted (optimized) using least square algorithm to fit to measured data using the following process.

1) First, the residual (or error, \( e \)) between measured pathloss, and the Hata-Davidson model predicted pathloss is calculated for each location point, \( i \):  

\[ e(i) = P_L_m(dB)_i - P_L(\text{predicted})_i \]  

2) Second, the RMSE is calculated based along with sum of errors, that is .
predicted pathloss by untuned Hata-Davidson model, the optimised model is obtained by adding RMSE to each otherwise, if ≥ 0 the optimised model is obtained by subtracting RMSE from each.

3. Results and Discussions

Table 1 gives the measured Received Signal Strength (RSSI), the measured pathloss and the distance of the measurement point from the GSM (Global System for Mobile communication) base station in a suburban area of Uyo, Akwa Ibom state, Nigeria. The GSM network operates in the 1800MHz frequency band.

Table 2 and figure 1 show the measure pathloss, the predicted pathloss by untuned Hata-Davidson model, the predicted pathloss by the RMSE-tuned Hata-Davidson model and the predicted pathloss by the multi-parameter-tuned Hata-Davidson model. The results in table 2 show that the multi-parameter-tuned Hata-Davidson model has the better prediction accuracy of 98.7020432% and RMSE of 2.177522885 dB as against the RMSE-tuned Hata-Davidson model with prediction accuracy of 97.42722692% and RMSE of 4.256897001dB. According to experts, pathloss model with RMSE of less than 6dB is acceptable. In any case, the result shows that the multi-parameter tuning approach may be preferred when more accurate prediction result is required. However, the RMSE is quite simple and easier to implement even in embedded systems and systems with limited resource.

| S/N | d (km) | RSSI (dB) | Field Measured Path Loss (dBm) | S/N | d (km) | RSSI (dB) | Field Measured Path Loss (dBm) |
|-----|--------|-----------|--------------------------------|-----|--------|-----------|--------------------------------|
| 1   | 0.77263| -79       | 132.45                         | 14  | 0.900146| -89       | 142.45                         |
| 2   | 0.8038  | -83       | 136.45                         | 15  | 0.900379| -95       | 148.45                         |
| 3   | 0.8199  | -83       | 136.45                         | 16  | 0.91072 | -95       | 148.45                         |
| 4   | 0.8297  | -83       | 136.45                         | 17  | 0.911539| -95       | 148.45                         |
| 5   | 0.8404  | -83       | 136.45                         | 18  | 0.912705| -95       | 148.45                         |
| 6   | 0.8475  | -83       | 136.45                         | 19  | 0.920038| -95       | 148.45                         |
| 7   | 0.8568  | -89       | 142.45                         | 20  | 0.921517| -95       | 148.45                         |
| 8   | 0.8630  | -89       | 142.45                         | 21  | 0.92993 | -95       | 148.45                         |
| 9   | 0.8632  | -89       | 142.45                         | 22  | 0.935997| -95       | 148.45                         |
| 10  | 0.8713  | -89       | 142.45                         | 23  | 0.950936| -95       | 148.45                         |
| 11  | 0.8784  | -89       | 142.45                         | 24  | 0.96501 | -95       | 148.45                         |
| 12  | 0.8903  | -89       | 142.45                         | 25  | 0.983726| -95       | 148.45                         |
| 13  | 0.8936  | -89       | 142.45                         | 26  | 1.001317| -95       | 148.45                         |
| 14  | 0.9001  | -89       | 142.45                         | 27  | 1.011593| -97       | 150.45                         |

Table 1. The Measured Received Signal Strength (RSSI) and Measured Pathloss and Distance.

| S/N | d (km) | Field Measured Path Loss (dBm) | Pathloss Predicted By Untuned Hata-Davidson | Pathloss Predicted By RMSE-Tuned Hata-Davidson | Pathloss Predicted By Multi-parameter-Tuned Hata-Davidson |
|-----|--------|--------------------------------|--------------------------------------------|-----------------------------------------------|---------------------------------------------------|
| 1   | 0.77263| 132.45                          | 194.5315667                                | 141.4519063                                  | 133.3167896                                      |
| 2   | 0.8038 | 136.45                          | 195.1579865                                | 142.0783261                                  | 136.196652                                      |
| 3   | 0.8199 | 136.45                          | 195.4728802                                | 142.3932198                                  | 137.6443243                                     |
| 4   | 0.8296 | 136.45                          | 195.6599952                                | 142.5803477                                  | 138.5045546                                     |
| 5   | 0.8403 | 136.45                          | 195.8627504                                | 142.78309                                    | 139.4366887                                     |
| 6   | 0.8475 | 136.45                          | 195.9966457                                | 142.9169853                                  | 140.0522505                                     |
| 7   | 0.8567 | 142.45                          | 196.1682945                                | 143.088634                                  | 140.8413774                                     |
| 8   | 0.8629 | 142.45                          | 196.2825869                                | 143.2029265                                  | 141.3668182                                     |
| 9   | 0.8631 | 142.45                          | 196.286228                                | 143.2065675                                  | 141.3835574                                     |
| 10  | 0.8712 | 142.45                          | 196.4342262                                | 143.3545722                                  | 142.0639844                                     |
| 11  | 0.8738 | 142.45                          | 196.5620523                                | 143.4823019                                  | 142.6516147                                     |
| 12  | 0.8903 | 142.45                          | 196.776467                                | 143.6980666                                  | 143.6373511                                     |
| 13  | 0.8936 | 142.45                          | 196.8345553                                | 143.7548948                                  | 143.904023                                     |
| 14  | 0.9001 | 142.45                          | 196.9499155                                | 143.870255                                   | 144.4347519                                     |
| 15  | 0.9037 | 148.45                          | 196.954018                                | 143.8743576                                  | 144.4536126                                     |
| 16  | 0.9172 | 148.45                          | 197.1347703                                | 144.0551099                                  | 145.2845916                                     |
| 17  | 0.9153 | 148.45                          | 197.1489902                                | 144.0693297                                  | 145.3499651                                     |
| 18  | 0.9127 | 148.45                          | 197.1692174                                | 144.0895569                                  | 145.4429565                                     |
| 19  | 0.9200 | 148.45                          | 197.2958754                                | 144.216215                                   | 146.0252462                                     |
| 20  | 0.9215 | 148.45                          | 197.3213044                                | 144.241644                                   | 146.1421518                                     |
| 21  | 0.9293 | 148.45                          | 197.4651553                                | 144.3854949                                  | 146.8034826                                     |
| 22  | 0.9359 | 148.45                          | 197.5608686                                | 144.4884081                                  | 147.2766095                                     |
| 23  | 0.9590 | 148.45                          | 197.8187074                                | 144.739047                                  | 148.4288805                                     |
| 24  | 0.9650 | 148.45                          | 198.0512414                                | 144.971581                                  | 149.4979174                                     |

Table 2. Measure Pathloss, Predicted Pathloss By Untuned and Tuned Hata-Davidson Models.
For the multi-parameter tuning, the parameters tuned are:

(i) The constant 69.55 the expression for $A$, hence, $A$ for the tuned Hata-Davidson model is

$$A = 25.33162938 + 26.16 \times \log_4(f) - 13.82 \times \log_4\left(\frac{h_b}{P}\right)$$

(ii) The constant 69.55 the expression for $B$, hence, $B$ for the tuned Hata-Davidson model is

$$B = 175.6953369 - 6.55 \times \log_4(h_b)$$

(iii) The constant 0.00784 the expression for $S_2$, hence, $S_2$ for the tuned Hata-Davidson model is;

$$S_2(h_b, d) = 0.009022299 \left| \log\left(\frac{h_b}{d}\right) \right| (h_b - 300) \text{ for } h_b < 300$$

4. Conclusion

In this paper, comparative study of RMSE-base tuning and multi-parameter-based tuning of Hata-Davidson pathloss model for a suburban area is presented. The study was based on field measurement of received signal strength for a GSM network that operates in the 1800MHz frequency band. The results show that the multi-parameter-based tuning performs better than the RMSE-base tuning. However, the RMSE-base tuning is simpler and easier to implement in resource limited systems.

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