

# Optimization of Hata Pathloss Model Using Terrain Roughness Parameter

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**Abstract:** In this paper, an approach for optimizing Hata pathloss model based on terrain roughness parameter is presented. The study is based on field measurement of received signal strength and elevation profile obtained in a suburban area for a GSM network in the 800 MHz frequency band. Mostly, standard deviation of elevation is used to characterize terrain roughness. However, in this paper, the mean elevation and the standard deviation of elevation are used separately to minimize the error using least square method. The results show that the untuned Hata model has a RMSE of 44.58 dB and prediction accuracy of 65.07%. On the other hand, both the pathloss predicted by the mean elevation tuned Hata model and the pathloss predicted by the standard deviation of elevation tuned Hata model have the same RME of 6.23 dB and prediction accuracy of 96.06%. Also, the terrain roughness correction factors are the same value (that is,  $C_{TSDV} = C_{TMean} = 44.13848$ ). Finally, with the RMSE of about 6 dB, it can be concluded that the terrain roughness parameter-based tuning approach can effectively be used to minimize the prediction error of the Hata model within the acceptable value which is about 7dB to 10 dB for urban and rural areas.

**Keywords:** Hata Model, Pathloss, Terrain Roughness Parameter, Least Square Method, Empirical Pathloss Model

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## 1. Introduction

Hata pathloss model is one of the most popular empirical pathloss models use to estimate the pathloss that can be experienced by signal in a given terrain [1-10]. Like other empirical pathloss models, the prediction performance of the Hata model is not adequate when applied to different environment other than the one where it was originally developed from. As such, Hata pathloss model is always tuned with respect to empirical data obtained in the particular terrain where the model is to be employed [11, 12].

In several published works, the root mean square error (RMSE)-based least square method is used for the Hata model optimization [13-17]. This approach, though simple, does not always yield acceptable prediction performance for the Hata model. Besides, there are other model tuning approaches that can give better prediction performance. One of such is multiple model parameter tuning which requires careful adjustment of some parameter coefficients so as to minimize the model's pathloss prediction error.

Yet another approach is the use of terrain roughness parameter. The concept of terrain parameter is based on the variations in the elevation profile of the measurement points obtained from the field measurement carried out in the case study area. In this case, the standard deviation of the elevation data or the mean elevation can be used for the model tuning task. In this paper, bother parameters are used separately to tune Hata pathloss model. Then, the results obtained are compared with the RMSE-based tuning of the Hata model. The study is based on field measurements carried out for 800 MHz GSM network in a suburban area.

## 2. Methodology

### 2.1. Drive Test Measurement Campaign and Data Processing

The received signal strength (RSS) and the spatial data (longitude, latitude and elevation) are captured using Samsung

I9500 Galaxy S4 mobile phone. The Samsung I9500 Galaxy S4 has CellMapper and MyGPS coordinates android applications installed. Specifically, the data captured by the CellMapper comprises the GSM/CDMA/UMTS/LTE current and neighbouring cells' RSS in decibels (dB), the current cell's cell ID (CID), local area code (LAC). Another android application, MyGPS Coordinates is used to capture the longitude and the latitude of the measurement points. The RSS along with the respective longitudes and latitudes are recorded at each measurement (receiver) point. In addition, the GSM base station (transmitter) was located, and its longitude and latitude are recorded. The elevation data for each

measurement point is obtained by using online GPS Visualizer tool which loads the text file of the latitude and longitude of the measurement points and returns their elevation above sea level.

The measurements are carried out in a suburban area in Uyo, Akwa Ibom state of Nigeria. After the measurements, Haversine formula was used to determine the distance between the mast (transmitter) and each of the measurement locations. The RSS value recorded at each of the measurement point is converted to measured pathloss ( $PL_m$  (dB)) by using the link budget equation:

$$PL_m \text{ (dB)} = (\text{PBTS} + \text{GBTS} + \text{GMS} - \text{LFC} - \text{LAB} - \text{LCF}) - \text{RSS} \text{ (dBm)} \quad (1)$$

where

$PL_m$  (dB) is the measured pathloss for each measurement location at a distance  $d$  (km) from the base station.

PBTS = Base transceiver station power (dBm),

GBTS = Base transceiver station antenna gain (dBi),

GMS = Mobile station antenna gain (dBi),

LFC = Feeder cable and connector loss (dB),

LAB = Antenna body loss (dB) and

LCF = Combiner and filter loss (dB).

The values of these parameters are given by as:

$$P_{\text{BTS}} = 40 \text{ W} = [30 + 10 \log_{10} 40] = 46 \text{ dBm} ;$$

$$\text{GBTS} = 18.15 \text{ dBi},$$

$$\text{GMS} = 0 \text{ dBi}, \text{LFC} = 3 \text{ dB}, \text{LAB} = 3 \text{ dB}, \text{LCF} = 4.7 \text{ dB}.$$

Hence,

$$PL_{m(\text{dB})} = 53.5 \text{ (dBm)} - \text{RSS}(\text{dBm}) \quad (2)$$

## 2.2. Hata Pathloss Model

The following equations are used for the computation of the path loss (in dB) according to the Hata model [9]:

*for Urban Area*

$$LP_{\text{HATA}(\text{urban})} = A + B * \log_{10}(d) \quad (3)$$

*for Suburban Area*

$$LP_{\text{HATA}(\text{suburban})} = A + B * \log_{10}(d) - C \quad (4)$$

*for Open Area/Rural*

$$LP_{\text{HATA}(\text{open/rural})} = A + B * \log_{10}(d) - D \quad (5)$$

$$A = 69.55 + 26.16 * \log_{10}(f) - 13.82 * \log_{10}(h_b) - a(h_m) \quad (6)$$

$$B = 44.9 - 6.55 * \log_{10}(h_b) \quad (7)$$

$$C = 5.4 + 2 * \left[ \log_{10} \left( \frac{f}{28} \right) \right]^2 \quad (8)$$

$$D = 40.94 + 4.78 * [\log_{10}(f)]^2 - 18.33 * \log_{10}(f) \quad (9)$$

$$a(h_m) = [1.1 * \log_{10}(f) - 0.7] * h_m - [1.56 * \log_{10}(f) - 0.8] \quad (10)$$

Eq 10 is for small city, medium city, open area, rural area and suburban area.

*for large city  $f \leq 200\text{MHz}$*

$$a(h_m) = 8.28 * [\log_{10}(1.54 * h_m)]^2 - 1.1 \quad (11)$$

*for large city  $f \geq 400\text{MHz}$*

$$a(h_m) = 3.2 * [\log_{10}(11.75 * h_m)]^2 - 4.97 \quad (12)$$

Where

- $f$  is the centre frequency  $f$  in MHz
- $d$  is the link distance in km
- $a(h_m)$  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
- $150 \text{ MHz} \leq f \leq 1000\text{MHz}$
- $30\text{m} \leq h_b \leq 200\text{m}$
- $1\text{m} \leq h_m \leq 10 \text{ m}$
- $1 \text{ km} \leq d \leq 20\text{km}$

## 2.3. The Terrain Roughness-Based Pathloss Model Tuning Approaches

The elevation data of any terrain is used to quantify the terrain roughness. Particularly, variation in the terrain elevation profile indicates how rough or smooth the terrain is. Most often, the standard deviation of the terrain elevation profile is used to denote the terrain roughness index. In this paper, two terrain parameters are used, namely, the mean elevation and the standard deviation of the elevation. Each of the two terrain parameters are used to optimize the pathloss prediction of Hata model. Let the mean elevation be denoted as  $\bar{M}$  and the mean elevation-based terrain roughness correction factor be denoted as  $C_{\bar{M}}$  where,

$$C_{\bar{M}} = K_{\bar{M}}(\bar{M}) \quad (13)$$

$K_{\bar{M}}$  is the tuning coefficient for the mean elevation-based terrain roughness correction factor. The optimization of the Hata model for urban area is given as follows;

$$LP_{\text{HATA}(\text{urban})} = A + B * \log_{10}(d) + C_{\bar{M}} \quad (14)$$

Let the standard deviation of elevation be denoted as  $\check{S}$  and the standard deviation of elevation-based terrain roughness correction factor be denoted as  $C_{\check{S}}$  where,

$$C_{\check{S}} = K_{\check{S}}(\check{S}) \quad (15)$$

$K_{\xi}$  is the tuning coefficient for the standard deviation of elevation-based terrain roughness correction factor. The optimization of the Hata model for urban area is given as follows;

$$LP_{HATA(urban)} = A + B * \log_{10}(d) + C_{\xi} \quad (16)$$

**2.4. Prediction Performance Analysis of the Model**

In order to evaluate the prediction performance of the model, the root mean square error (RMSE) and prediction accuracy (PA) are used.

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

$$MSE = \sqrt{\frac{1}{n} \left[ \sum_{i=1}^n |PL_{(measured)(i)} - PL_{(predicted)(i)}|^2 \right]} \quad (17)$$

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

$$PA = \left\{ 1 - \frac{1}{n} \left( \sum_{i=1}^n \left| \frac{PL_{(measured)(i)} - PL_{(predicted)(i)}}{PL_{(measured)(i)}} \right| \right) \right\} * 100\% \quad (18)$$

**3. Results and Discussions**

The field measured distance, elevation, received signal strength (RSSI) and pathloss (PLm) are given in Table 1. The measured pathloss (PLm) is obtained by using the link budget equation;

$PL_{m(dB)} = 53.5 \text{ (dBm)} - \text{RSS (dBm)}$ . The distance is obtained by applying the longitude and latitude of each of the measurement points in the Haversine equation with the longitude 1 and latitude 1 being that of the GSM base station while longitude 2 and latitude 2 is for each of the measurement points.

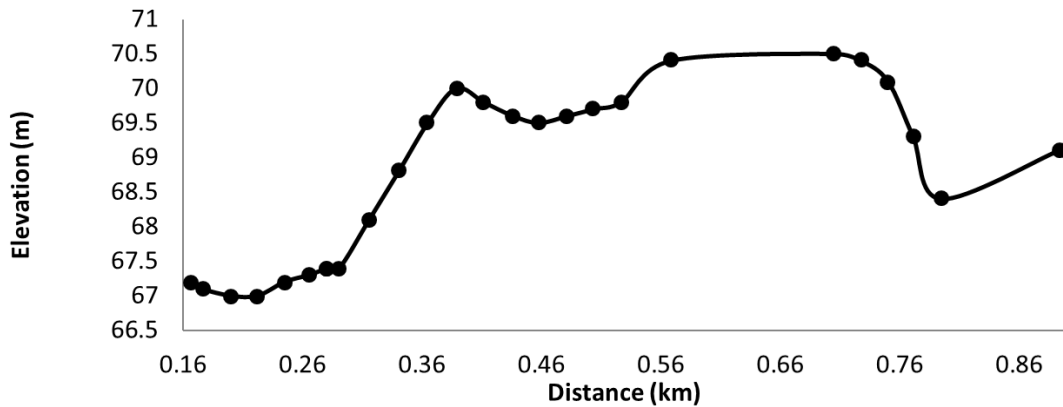


Figure 1. The Elevation Profile of the terrain.

Table 1. The Field Measured Distance, Elevation, Received Signal Strength (RSS) and Pathloss (PLm).

S/N	Distance (Km)	Elevation (m)	RSS (dB)	PLm (dB)	S/N	Distance (Km)	Elevation (m)	RSS (dB)	PLm (dB)
1	0.1664	67.2	-65	118.5	14	0.412	69.8	-73	126.5
2	0.1764	67.1	-69	122.5	15	0.4365	69.6	-71	124.5
3	0.2002	67	-71	124.5	16	0.4581	69.5	-75	128.5
4	0.2224	67	-75	128.5	17	0.4818	69.6	-76.3	129.8
5	0.2449	67.2	-76.3	129.8	18	0.5043	69.7	-73.7	127.2
6	0.2653	67.3	-73.7	127.2	19	0.527	69.8	-73	126.5
7	0.2809	67.4	-67	120.5	20	0.5687	70.4	-77	130.5
8	0.281	67.4	-69	122.5	21	0.7053	70.5	-74.3	127.8
9	0.291	67.4	-71	124.5	22	0.7276	70.4	-77	130.5
10	0.316	68.1	-73	126.5	23	0.7503	70.1	-77	130.5
11	0.3408	68.8	-73	126.5	24	0.7713	69.3	-75	128.5
12	0.365	69.5	-74.3	127.8	25	0.7949	68.4	-74.3	127.8
13	0.3888	70	-73	126.5	26	0.8934	69.1	-73	126.5
14	0.412	69.8	-73	126.5	27	0.8994	69.1	-73	126.5

**Table 2.** The Elevation, The Mean Elevation and The Standard Deviation Of The Elevation.

S/N	Elevation (m)	S/N	Elevation (m)	S/N	altitude (m)	
1	67.2	10	68.1	19	69.8	Mean Elevation ( $\bar{E}$ ) 68.76667
2	67.1	11	68.8	20	70.4	
3	67	12	69.5	21	70.5	
4	67	13	70	22	70.4	Standard Deviation ( $\sigma$ ) 1.215334
5	67.2	14	69.8	23	70.1	
6	67.3	15	69.6	24	69.3	
7	67.4	16	69.5	25	68.4	
8	67.4	17	69.6	26	69.1	
9	67.4	18	69.7	27	69.1	

Table 2 shows the elevation, the mean elevation and the standard deviation of the elevation of the measurement points. The Hata model will be optimised using the mean elevation and then using the standard deviation of the elevation of the measurement points.

Microsoft Excel solver is used to determine the value of  $K_{\bar{M}}$  and also the value of  $K_{\check{S}}$  that minimizes the sum of square error. The results obtained from the Microsoft Excel solver are  $K_{\bar{M}} = 0.641859$  and  $K_{\check{S}} = 36.31799$ . Therefore, with mean elevation ( $\bar{M}$ ) = 68.76667,  $K_{\bar{M}} = 0.641859$ , hence;

$$C_{\bar{M}} = K_{\bar{M}}(\bar{M}) = 44.13848.$$

Also, with standard deviation of elevation ( $\check{S}$ ) = 1.215334,  $K_{\check{S}} = 36.31799$ , hence;

$$C_{\check{S}} = K_{\check{S}}(\check{S}) = 44.13848$$

Table 3 shows the field measure pathloss and the pathloss predicted by the untuned Hata model, the pathloss predicted by the mean elevation tuned Hata model and the pathloss predicted by the standard deviation of elevation tuned Hata model. Also, the table shows that the untuned Hata model has a RMSE of 44.58 dB and prediction accuracy of 65.07%. On the other hand, both the pathloss predicted by the mean elevation tuned Hata model and the pathloss predicted by the standard deviation of elevation tuned Hata model have the same RME of of 6.23 dB and prediction accuracy of 96.06%. The correction factors are the same value (that is,  $C_{\check{S}} = C_{\bar{M}} = 44.13848$ ). Finally, with the RMSE about 6 dB, it can be concluded that the terrain parameter-based tuning approach can effectively be used to minimize the prediction error of the Hata model within the acceptable value which is about 7dB to 10 dB for urban and rural areas.

**Table 3.** The field measure pathloss and the pathloss predicted by the untuned and the tuned Hata model.

S/N	Field Measured Path Loss (dBm)	Untuned Hata Suburban	$C_{\bar{M}}$ Tuned Hata Suburban	$C_{\check{S}}$ Tuned Hata Suburban
1	118.45	68.93	113.06	113.06
2	122.45	69.80	113.94	113.94
3	124.45	71.69	115.83	115.83
4	128.45	73.26	117.40	117.40
5	129.75	74.70	118.84	118.84
6	127.15	75.90	120.03	120.03
7	120.45	76.75	120.89	120.89
8	122.45	76.76	120.89	120.89
9	124.45	77.28	121.42	121.42
10	126.45	78.51	122.65	122.65
11	126.45	79.64	123.78	123.78
12	127.75	80.66	124.80	124.80
13	126.45	81.61	125.75	125.75
14	126.45	82.47	126.61	126.61
15	124.45	83.34	127.47	127.47
16	128.45	84.06	128.20	128.20
17	129.75	84.81	128.95	128.95
18	127.15	85.49	129.63	129.63
19	126.45	86.15	130.29	130.29
20	130.45	87.29	131.43	131.43
21	127.75	90.51	134.64	134.64
22	130.45	90.97	135.11	135.11
23	130.45	91.43	135.57	135.57
24	128.45	91.84	135.98	135.98
25	127.75	92.29	136.43	136.43
26	126.45	94.04	138.18	138.18
27	126.45	94.14	138.28	138.28
	RMSE	44.58	6.23	6.23
	PA (%)	65.07	96.06	96.06

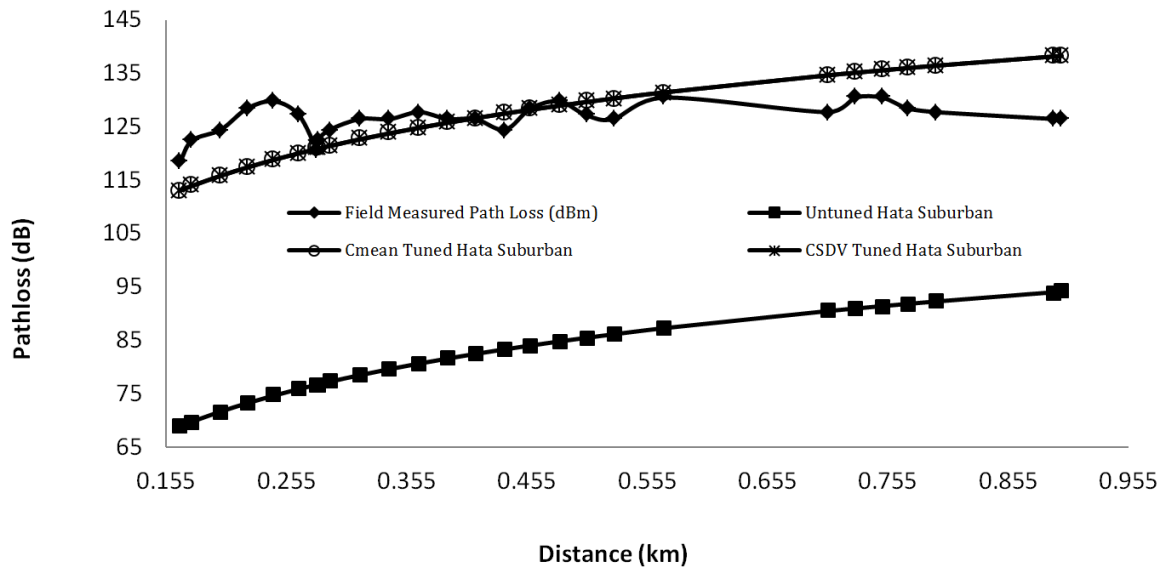


Figure 2. The field measure pathloss and the pathloss predicted by the untuned and the tuned Hata models.

## 4. Conclusion

In this paper, terrain roughness parameter-based tuning approach is presented for Hata model. The study is based on empirical field measurement in a suburban area for a GSM network in the 800 MHz frequency band. In most published works, the standard deviation of the elevation is used to characterize the terrain roughness. However, the mean elevation and the standard deviation of elevation are used separately in this paper to minimize the error using least square method. The results show that the two approach gave the same correction factor for Hata propagation model and hence, the same RMSE and prediction accuracy. Also, both approach reduced the Hata model prediction error within the acceptable 7 dB for suburban and rural areas.

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