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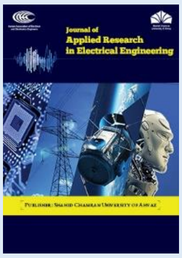

Research Article

Selection and Tuning Propagation Path Loss Model for Hawassa City, Ethiopia at 1800 MHz Frequency

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Abstract: Path loss models estimate the average path loss a signal experiences at a particular distance from a transmitter. However, each type of existing path loss propagation model is designed to predict path loss in a particular environment that may be inaccurate in other different; hence selecting the best path loss model and optimizing it will minimize that inaccuracy. This work presents a comparative analysis of five empirical path loss models, COST- 231, ECC-33, Hata, SUI, and Ericsson model, with respect to the measured data from the 14 selected sites in Hawassa city, Ethiopia at 1800 MHz frequency bands. A drive test methodology was adopted for data collection and Nemo Handy and Nemo Outdoor were used as measuring tools for the test. Error measuring tools such as root mean square error, mean absolute error, standard deviation, and mean absolute percentage error were used to select the terrain type of each site and the path loss model that best fits that site. The results show that not only Hawassa city consists of urban and sub-urban terrains but also ECC-33 and Hata are better estimators for Hawassa urban and sub-urban areas with RMSE of 4.18 and 7.86 respectively. The model tuning using the least square method reduced the RMSE of ECC-33 and Hata to 2.46 and 5.18 respectively. The reduction in RMSE shows that the tuned versions are close to the environment. Hence, using the tuned versions of the selected models will result in good cellular network design and enhance the service quality.

Keywords: Path loss, path loss model, urban, sub-urban, model tuning, least square method.

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1. Introduction

Mainly all wireless communications involve the transmission of data in the form of electromagnetic (EM) waves. The transmitted information experiences a path loss, the reduction in power density (attenuation) of an electromagnetic wave or degradation in its signal strength, as it propagates between transmitter and receiver [1, 2]. Propagation of the radio waves especially in urban areas is quite complex because it consists of reflected, Scattering and diffracted waves produced by multipath propagation.

A propagation model which is a set of mathematical expressions, diagrams, and algorithms is used to represent the radio characteristics of a given environment and related signal strength degradations [3]. Radio propagation models are used to describe the relationship between the signal radiated by a transmitter and the signal received by a receiver as a function of distance and other variables [4].

Generally, propagation models can be put into two categories: empirical propagation and deterministic propagation model [5]. Deterministic path loss models are those that use the laws governing the propagation of electromagnetic waves for the determination of the power of a received signal at a given distance from the transmitter by considering that specific environment; whereas empirical propagation models are mathematical formulations based on data measurement and observation of the given environment. Such propagation models are derived empirically from statistical analysis of large number of field measurements [6].

Direct deployment of the existing empirical models may give rise to high prediction errors due to two main reasons. Firstly, the environment they were initially built for is different from the one where the network is being deployed.

Secondly, some terrains are ambiguous and are difficult to categorize them as open, urban or sub-urban. Thus, this work is aimed at knowing the environment of Hawassa city based on results of the existing path loss models and the actual measured data, select the best path loss models from the existing ones and finally tuning the best models to make it as fit as possible at 1800 MHz frequency band. The fineness of the path loss models and terrain grouping is done based on the results from error measuring tools such as RMSE, MAE, SD and MAPE. The result of this work can be used by any telecom operator to make any decision in Hawassa city and in other cities and towns with approximately similar terrain.

2. Empirical Models

Empirical models are models based on the practical measurement data. They are useful to study the principle behavior of system-level concepts or to enable a rough estimation of the number of required sites in a large area for example in green field planning during a license auction. These models do not require site-specific terrain information. Instead input parameters are e. g. path loss decay exponents, effective antenna heights or average clutter loss factors characterizing the average propagation environment [7]. COST- 231, ECC-33, SUI, Hata, and Ericsson models are the concerns of this work and hence discussed as follows.

2.1. COST-231 Model

The COST-231 Hata model is designed to be used in the frequency band from 500 MHz to 2000 MHz, BS antenna height from 30m to 200m and MS antenna height from 1m to 10m. The basic equation for path loss in dB [8, 9]:

$$PL = 46.3 + 33.9 \log_{10} f - 13.82 \log_{10} h_b - a_{hm} + (44.9 - 6.55 \log_{10} h_b) \log_{10} d + C_m \quad (1)$$

where, f is the frequency in MHz, d is the distance between base station and mobile station antennas in km, and h_b is the base station antenna height above ground level in meters. The parameter C_m is defined as 0 dB for suburban or open environments and 3 dB for urban environments. The parameter a_{hm} is defined for urban environments as:

$$a_{hm} = 3.2\,(\log_{10} 11.75 h_r)^2 - 4.97 \quad \text{for } f > 400 \text{ MHz} \quad (2)$$

And for suburban or rural (flat) environments,

$$a_{hm} = (1.1 \log_{10} f - 0.7) h_r - (1.56 \log_{10} f - 0.8) \quad (3)$$

where, h_r is the mobile station antenna height above ground level.

2.2. ECC-33 Model

The ECC−33 path loss model is developed by the Electronic Communication Committee (ECC). It is extrapolated from original measurements by Okumura and modified its assumptions [10]. The ECC−33 path loss model is empirical model composed from four terms and not to make double discussion it is going to be discussed in Section 7 [11].

2.3. Stanford University Interim (SUI) Model

The SUI model was developed under the Institute of Electrical and Electronics Engineers (IEEE) 802.16 working group for prediction of path loss in urban, suburban and rural environments. This model is defined for the Multipoint Microwave Distribution System (MMDS) frequency band which is from 2.5 GHz to 2.7 GHz. In this model, terrains are grouped into terrain type A, B, and C. Type A is associated with maximum path loss and is appropriate for hilly terrain with moderate to heavy foliage densities. Type C is associated with minimum path loss and applies to flat terrain with light trees densities. Type B is associated characterized with either mostly flat terrains with moderate to heavy three density or hilly terrains with light tree densities [12]. The basic path loss equation with correction factors is presented in [10, 13]:

$$PL = A + 10\gamma \log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + s \text{ for } d > d_o \quad (4)$$

where $A = 20 \log_{10}\left(\frac{4\pi d_o}{\lambda}\right)$, $\gamma = a - b h_b + \frac{c}{h_h}$, and d is the distance between the Access Point (AP) and mobile station in meters, $d_o = 100m$ and s is a log normally distributed factor that is used to account for the shadow fading owning to tree and other cluster and has a valued between 8.2 dB and 10.6dB, and the parameter h_b is the base station height above ground in meters and should be between 10 m and 80 m. The constants used for a, b and c are given in Table 1.

The correction factors for the operating frequency and the mobile station antenna height for the model are:

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

and

$$X_h = -10.8 \log_{10}\left(\frac{h_r}{2000}\right) \quad \text{for terrain type A and B} \quad (6)$$

$$X_h = -20 \log_{10}\left(\frac{h_r}{2000}\right) \quad \text{for terrain type C} \quad (7)$$

where, f is the frequency in MHz and h_r is the mobile station antenna height above ground in meters.

2.4. Hata Model

The Hata model, also known as the Okumura–Hata model, is one of the most commonly used models for a macro cell environment to predict the radio signal attenuation. The model is valid for quasi-smooth terrain in an urban area. To avoid double discussion, the ranges of the used parameters for this model are given and discussed in under and the equations are explained in Section 7.2 [14].

2.5. Ericsson Model

To predict the path loss, the network planning engineers use software provided by Ericsson Company is called Ericsson model. The model also relies on the reformed Okumura-Hata model so that there is a room to change parameters according to the propagation environment. According to Ericsson model we can define the path loss as [10]:

$$L = a_0 + a_1 \log_{10} d + a_2 \log_{10} h_b + a_3 \log_{10}(h_b) \log_{10}(d) - 3.2(\log_{10}(11.75 h_r)^2) + g(f) \quad (8)$$

where: $g(f) = 44.49 \log_{10}(f) - 4.78(\log_{10}(f))^2$, f is the Frequency in (MHz), h_b is the transmission antenna height in (m), h_r is the Receiver antenna height in (m). The default values of these parameters (a_0, a_1, a_2 and a_3) for different terrain are given in Table 2.

Table 1: The parameters of SUI model in different environment [10].

Model parameter	Terrain A	Terrain B	Terrain C
A	4.6	4	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

Table 2: Values of parameters for Ericsson model [10].

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12	0.1
Suburban	43.2*	68.93*	12	0.1
Rural	45.95*	100.6*	12	0.1

3. Error Measurement

Error measurement was done to evaluate the closeness of the predicted path loss to the measured path loss. In this work four types of error measurement techniques were used which are Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Standard Deviation (SD) and Mean Absolute Error (MAE). The values from these measurement tools are used to identify the approximate terrain type of a given cell and select the path loss model that nearly suits the cell.

3.1. RMSE

Root mean square error measures the average dispersion of a set of data predicted by a model from an observed data. It is the most used techniques in most papers that are done on performance comparison. In this paper also RMSE is mainly used to compare the calculated and measured path loss. It is calculated using the following formula [15]:

$$RMSE = \sqrt{\frac{1}{n}(\sum_1^n(PL_m - PL_P)^2} \quad (9)$$

where, PL_m- is the measured path loss, PL_P- is the calculated path loss and n - is the number of measured data

3.2. MAPE

The mean absolute percentage error (MAPE) is a statistical measure of how accurate a prediction model is. It calculates this accuracy as a percentage, and can be calculated as the average absolute percent error for each time period minus measured values divided by measured values.

$$MAPE = \frac{1}{n}\sum_1^n\left|\frac{(PL_m - PL_P}{PL_m}\right| \quad (10)$$

where: PL_m is the actual value and PL_P is the predicted value. MAPE is the most common measure used to predict error, and works best if there are no extremes to the data (and no zeros).

3.3. SD

Standard deviation (SD) measures how much a data is spread out around the mean or average [16]. It is calculated as follows:

$$SD = \sqrt{\frac{\sum_1^n((PL_m - PL_P) - ME)^2}{n-1}} \quad (11)$$

where, ME is mean error.

$$\text{MAE} = \frac{1}{n}\sum_1^n|PL_m - PL_P| \quad (12)$$

3.4. MAE

The Mean Absolute Error (*MAE)* is used to measure the closeness of the predicted values to the actually measured values. It is calculated as follows:

4. Model Optimization Algorithm

The main purpose of the work is to select the best path loss models (among the mentioned ones) for Hawassa city and tune the selected model to make it more fit with the actual environment. From the available tuning algorithms, Linear Least Square method (LLSM) is used to tune the selected models.

LLSM is by far the most widely used modeling method. Not only it is the most widely used method but it is also plays a strong underlying role in many other modeling methods, including: nonlinear least squares regression, weighted least squares regression and LOESS. This method is a form of mathematical regression analysis which is used to determine the line of best fit for a set of data, providing a visual demonstration of the relationship between the data points. LLSM is an arithmetic tuning approach where all environmental influences are considered. The key idea of LLSM is to minimize the difference between the measured and predicted data in a way of mean square error function. Therefore, its simplicity and easy implementation was the main reason to choose LLSM for mode optimization process on this case study. The following equation shows the mathematical representation of LLSM:

$$E\ (a, b, c, \ldots) = \sum_1^n[yi - PR, i(xi, a, b, c)]^2 \quad (13)$$

where, = measured path loss values at distance xi, PR, i = (xi, a, b, c) = model calculated path loss values at distance xi and a, b and c are the model parameters, n represents number of experiment data.

The Path Loss model is considered optimized at the values of a and b where the equation bring minimum value of $E\ (a, b, c, \ldots)$.

5. Methodology

Drive Test is used by many telecom industries as the best possible solution to collect signal strength, mobile network latency, voice call KPIs and optimization, it is also adopted in this work for data collection process. For the Drive test measurement process, measurements tools such as Nemo handy, Nemo outdoor, GPS, mobile phones, laptop, ACTIX software for data analysis and a vehicle have been used. There are a total of 44 sites which are installed and covered Hawassa city. At the beginning, planning was done to decide where the measurements should be taken. A Google earth assisted and physical observation planning was done on the entire city so that the best sites which can represent all the morphology types, open areas, suburban areas and urban areas of Hawassa city, can be selected. Doing so 14 sites which nearly represent all morphology types were selected. In this work, a sector is considered as a site because a sector facing to one side of an area and the other to another side of an area actually represents different area types. The selected sites and their absolute location are depicted in Fig. 1 and Table 3, respectively. A sample drive test displayed on google earth is put by Fig. 2.

Table 3: Selected sites.

No.	Site ID	Specific Location	Latitude	Longitude	Antenna Height
1	222078	Baleweld Church	7.0199	38.47249	29
2	222080	New Market	7.0227	38.5008	27
3	222082	Nigist Fura	7.0275	38.4848	35
4	222089	Liz Sefer	7.03561	38.48378	29
5	222096	Behind St. Gebriel church	7.0452	38.482	27
6	222097	Pay Station	7.045912	38.490708	33
7	222101	Chefe Genet Church	7.05038	38.51297	38
8	222102	Beza Collage	7.04801	38.47805	29
9	222105	Tele Branch	7.052475	38.470555	37
10	222110	Old Market	7.0597	38.4744	34
11	222112	Hawassa University (Techno)	7.05313	38.50423	30
12	222116	Debub Ez Condominium	7.07088	38.47975	34
13	222118	Industry Park	7.07464	38.50618	30
14	222120	Dato	7.08375	38.4898	35

Fig. 1: Selected sites.

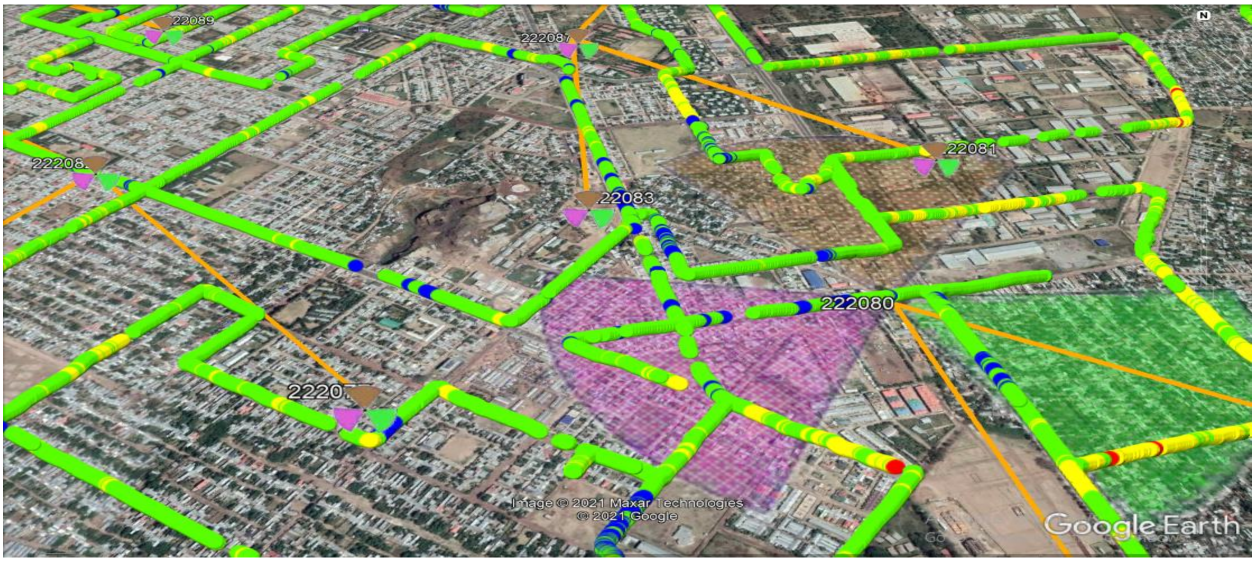

Fig. 2: Sample drive test of 1800 MHz displayed on Google earth.

For all sites, received signal strength was measured at a reference distant of 100m from the BS and at continuous intervals of 100m up to 1000m at every 15^0 interval. For every sector (site) 80 measurement value was taken. In this work, 240 measurement values have been taken for every base station. Based on the data from Ethio-telecom, all sites are configured with a transmission power of 43 dBm and have being used for path loss calculation at 1800 MHz frequency [17]. For 11 sites the measured path loss is depicted below in graph 3.

6. Terrain Categorization

The terrain identification was done based on the values of RMSE, MAPE, MAE and SD of each site which are calculated from the measured path loss and the predicted path loss by each path loss model. The predicted value of each path loss model was calculated assuming every cell to be urban, sub-urban and rural. Doing so, the selected 14 sites nearest terrain is identified and presented in Table 4.

6.1. Path Loss Model Selection

Based on the presented terrain category, the performance of each path loss model was calculated using RMSE and presented in Table 5 and Table 6.

In the selection process, it should be noted that the smallest the error the better the model is. For urban sites, the one with smallest RMSE value is ECC-33 model and hence selected to be the one that fits best for the cells under this terrain category. For sub-urban sites, the one with smallest RMSE value is Hata model and hence selected to be the one that fits best for the cells under this terrain category. Though these models are relatively good, they can be made better fit for the actual Hawassa city terrain by tuning them as they are developed for a different terrain which is discussed in Section 7.

7. Model Tuning

In this section, the relatively best fit path loss models are tuned using LLSM so that they will better fit for Hawassa city at 1800 MHz frequency than their original version. In the model tuning process the average height of 1800 MHz base station antennas in urban areas and Sub Urban areas is rounded to 30m and 28m respectively, and the mobile station height is 1.5m. Once optimized, it will be compared with the original one which is discussed in the upcoming sections.

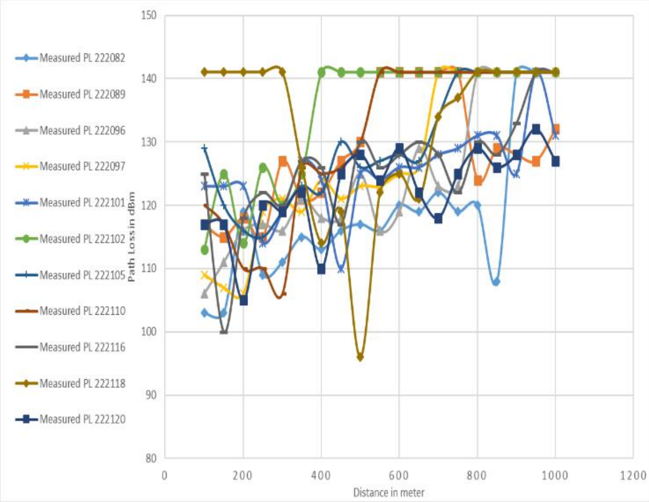

Fig. 3: Measured Path Loss of the eleven Sites at 1800 MHz.

Table 4: Urban area type Average measured path loss performance at 1800 MHz.

RMSE				
Cost-231	SUI	Ericsson	ECC-33	Hata
4.26	25.18	4.45	4.18	4.96

Table 5: Sub-Urban area type Average measured path loss performance at 1800 MHz.

RMSE				
Cost-231	SUI	Ericsson	ECC-33	Hata
7.95	31.75	12.12	24.15	7.86

7.1. Tuning ECC-33 for Urban Area Types

$$PL_{ECC-33} = A_{fs} + A_{bm} - G_b - G_r \quad (14)$$

where,

$$A_{fs} = 92.4 + 20\log_{10} d + 20\log_{10} f$$

$$A_{bm} = 20.41 + 9.83\log_{10} d + 7.894\log_{10} f + 9.56[\log_{10} f]^2$$

$$G_b = \log_{10}\left(\frac{h_b}{200}\right)\{13.958 + 5.8[\log_{10} d]^2\}$$

$$G_r = 0.759h_r - 1.862$$

Table 6: 1800 MHz Sites and the area type they are categorized.

No.	Site ID	Latitude	Longitude	Antenna Height	Best Fit Model	Area Type
1	222082	7.0199	38.47249	35	ECC-33	Urban
2	222089	7.0227	38.5008	29	ECC-33	Urban
3	222096	7.0275	38.4848	27	ECC-33	Urban
4	222097	7.03561	38.48378	33	ECC-33	Urban
5	222101	7.0452	38.482	38	ECC-33	Urban
6	222102	7.045912	38.490708	29	Ericsson	Urban
7	222105	7.05038	38.51297	37	ECC-33	Urban
8	222110	7.04801	38.47805	34	ECC-33	Urban
9	222116	7.052475	38.470555	34	ECC-33	Urban
10	222118	7.0597	38.4744	30	ECC-33	Urban
11	222120	7.05313	38.50423	35	ECC-33	Urban
12	222078	7.07088	38.47975	29	Hata	Sub-Urban
13	222080	7.07464	38.50618	27	Cost-231	Sub-Urban
14	222112	7.08375	38.4898	30	Hata	Sub-Urban

where, f is the frequency in GHz, d is the distance between base station and mobile antenna in km, h_b is the base station antenna height in meters and h_r is the mobile antenna height in meters.

We can rewrite equation (1) as:

$$PL_{ECC-33} = c_1 + c_2 x_i + c_3 (x_i)^2 \quad (15)$$

where

$x_i = \log_{10} d_i$,

$$c_1 = 92.4 + 20\log_{10} f + 20.41 + 7.894\log_{10} f + 9.56[\log_{10} f]^2 - 13.958\log_{10}(\frac{h_b}{200}) - 0.759h_r + 1.862$$

$c_2 = 9.83 + 20$,

$c_3 = -5.8\log_{10}(\frac{h_b}{200})$

For this work Abm is selected for the overall optimization/tuning process.

$$A_{bm} = K_1 + K_2 \log_{10} d + 7.894\log_{10} f + 9.56[\log_{10} f]^2 \quad (16)$$

i.e., we should find $K_1$and K_2 so that the optimized model, equation b fit better than the original one.

$$PL_{Tuned\_ECC-33} = \widetilde{C_1} + \widetilde{C_2} 2x_i + c_3 (x_i)^2 \quad (17)$$

Where

$x_i = \log_{10} d_i$

$\widetilde{C_1} = 94.262 + k1 + 27.894\log_{10} f + 9.56[\log_{10} f]^2 - 13.958\log_{10}(\frac{h_b}{200}) - 0.759h_r$

$\widetilde{C_2} = k2 + 20$

where $k1$ is the tuned offset value of A_{bm} and k_2 is the tuned slope value of the d-term in A_{bm}.

Then, the minimum error can be calculated by setting the following error function's partial derivative with respect to $\widetilde{C_1}$ and $\widetilde{C_2}$ to zero.

$$E\left(\widetilde{C_1}, \widetilde{C_2}\right) = \sum_1^n [y_i - PL_{ECC} i(\widetilde{C_1}, \widetilde{C_2})]^2 \quad (18)$$

This means $\frac{\partial E}{\partial \widetilde{C_1}} = 0$ and $\frac{\partial E}{\partial \widetilde{C_2}} = 0$.

Solving them we get the following equations for $\widetilde{C_1}$ and $\widetilde{C_2}$ and values are given in [10].

$$\widetilde{C_1} = \frac{n\sum_1^n y_i \sum_1^n (x_i)^2 - c3\left(\sum_1^n x_i\right)^2 \sum_1^n (x_i)^2 - n\sum_1^n x_i \sum_1^n y_i x_i + nc3\sum_1^n x_i \sum_1^n (x_i)^3 - nc3\left(\sum_1^n (x_i)^2\right)^2 + c3\sum_1^n (x_i)^2 \left(\sum_1^n x_i\right)^2}{n^2 \sum_1^n (x_i)^2 - n\left(\sum_1^n x_i\right)^2} \quad (19)$$

$$\widetilde{C_2} = \frac{c3\sum_1^n x_i \sum_1^n (x_i)^2 + n\sum_1^n y_i x_i - nc3\sum_1^n (x_i)^3 - \sum_1^n y_i \sum_1^n x_i}{n\sum_1^n (x_i)^2 - (\sum_1^n x_i)^2} \quad (20)$$

Substituting the values into (19) and (20), the tuned coefficients of A_{bm} (k1 and k2) and the calibrated parameters of the tuned ECC-33 model ($\widetilde{C_1}$ and $\widetilde{C_2}$) for urban terrains of hawassa city are found and presented in Table 7.

$$\widetilde{C_1} = 117.469 + 27.894\log_{10} f + 9.56[\log_{10} f]^2 - 13.958\log_{10}(\frac{h_b}{200}) - 0.759h_r \quad (21)$$

Then, the calibrated ECC-33 model equation for urban area types will be:

$$PL_{ECC-33} = A_{fs} + \widetilde{A_{bm}} - G_b - G_r \quad (22)$$

where,

$A_{fs} = 92.4 + 20\log_{10} d + 20\log_{10} f$

$\widetilde{A_{bm}} = 23.207 + 8.187\log_{10} d + 7.894\log_{10} f + 9.56[\log_{10} f]^2$

$G_b = \log_{10}(\frac{h_b}{200})\{13.958 + 5.8[\log_{10} d]^2\}$

$G_r = 0.759h_r - 1.862$

The performance of tuned version of ECC-33 model is presented in through RMSE, MAPE, MAE and SD.

The ECC-33 path loss model tuning reduces the RMSE value from 4.18 to 2.46 dB which is a visible improvement in terrain representation. Fig. 4 shows the measured average path loss, the predicted path loss by ECC-33 model and the predicted path loss by the tuned ECC-33 model. It can be clearly observed that the tuned ECC-33 model better fits measured average path loss.

7.2. *Tuning Hata Model for sub*urban area types

The model is give below based on the assumption that Hawassa city is under medium city, and the terrain type under consideration is sub-urban.

$$PL_{Hata} = 40.9 + 33.9\log_{10} f - 13.82\log_{10} h_b - a_{hm} + (44.9 - 6.55\log_{10} h_b)\log_{10} d - 2\,[\log_{10}(\frac{f}{28})]^2 \quad (23)$$

where,

$$a_{hm} = (1.1\log_{10} f - 0.7)h_m - (1.56\log_{10} f - 0.8)$$

The above equation can be rewritten as:

$$P_{LHata} = E_0 + E_s + B_s \log_{10} d \quad (24)$$

where, $E_0 = 40.9$, $E_s = 33.9\log_{10} f - 13.82\log_{10} h_b - a_{hm} - 2\,[\log_{10}(\frac{f}{28})]^2$, and $B_s = 44.9 - 6.55\,(\log_{10} h_b)$

Table 7: Performance of Tuned ECC-33 after for urban area.

RMSE	MAPE	MAE	SD
2.46	1.54	2.04	1.53

Table 8: Tuned parameters of ECC-33 model for urban areas

$\widetilde{C_1}$	Tuned slope value of A_{bm}, $\widetilde{C_2}$	Tuned offset value of A_{bm}, $K1$	$K2$
Eq. (21)	28.187	23.207	8.187

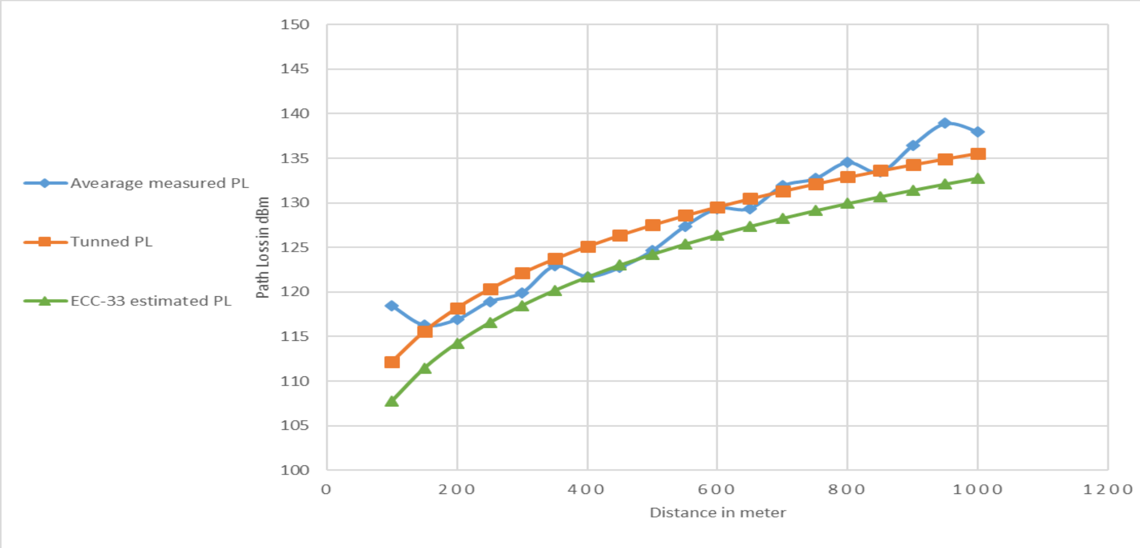

Fig. 4: Urban area Calibrated ECC-33 model Vs measured PL and original ECC-33 (1800).

where, E_0 is Initial offset parameter, E_s is Initial system design parameter, and B_s is the slope of the model curve. We can then write the total Hata path loss as:

$$P_{LHata} = a + bx \tag{25}$$

where $a = E_0 + E_s$, $b = B_s$ and $x = \log_{10} d$, a simplified logarithmic base.

Having that existing model, we need to make it more predictive by tuning the coefficients. That is, we need to have new coefficients $\widetilde{E_o}$ and $\widetilde{B_s}$ for a new path loss equation that will better fit the actual measured data and be better representation of the actual Hawassa city suburban terrains.

$$P_{LTuned\_Hata} = \widetilde{E_o} + E_s + \widetilde{B_s} B_s \log_{10} d \tag{26}$$

The above equation can be written as:

$$P_{LTuned\_Hata} = \hat{a} + \hat{b}x \tag{27}$$

Now let we have the values of $\hat{a}$ and $\hat{b}$ using Linear Least Square method, i.e. the minimum error can be calculated by setting the partial differentials of the following error function to zero.

$$E\left(\hat{a},\hat{b}\right) = \sum_1^n [y_i - PL_{Hata} i(x_i, \hat{a}, \hat{b})]^2 \tag{28}$$

This means $\frac{\partial E}{\partial \hat{a}} = 0$ and $\frac{\partial E}{\partial \hat{b}} = 0$. Doing so we get:

$$\hat{a} = \frac{\sum_1^n (x_i)^2 . \sum_1^n y_i - \sum_1^n y_i x_i . \sum_1^n x_i}{n \sum_1^n (x_i)^2 - \left(\sum_1^n x_i\right)^2} \tag{29}$$

$$\hat{b} = \frac{n \sum_1^n y_i x_i - \sum_1^n y_i . \sum_1^n x_i}{n \sum_1^n (x_i)^2 - \left(\sum_1^n x_i\right)^2} \tag{30}$$

Then we find the tuned Hata path loss model by substituting the tuned parameters $\tilde{a}$ and $\tilde{b}$ into the original Hata pathloss model that we begin the process with

$$\widetilde{E_o} = \hat{a} - E_s \tag{31}$$

$$\widetilde{B_s} = \frac{\hat{b}}{B_s} = \frac{\hat{b}}{44.9 - 6.55 (\log_{10} h_b)} \tag{32}$$

where, a_{hm} is unchanged.

Evaluating equations (29)-(32), the tuned coefficients of A_{bm} ($\hat{a}$ and $\hat{b}$) and the calibrated parameters of the tuned Hata model ($\widetilde{E_o}$ and $\widetilde{B_s}$) for urban terrains of hawassa city are found and presented in Table 9. Finally, we get the tuned Hata path loss equation for the Hawassa city Sub-Urban area types will be:

$$PL_{Hata} = 46.363 + 33.9 \log_{10} f - 13.82 \log_{10} h_b - a_{hm} + (43.06 - 6.28 \log_{10} h_b) \log_{10} d - 2 \left[\log_{10}\left(\frac{f}{28}\right)\right]^2 \tag{33}$$

The performance of tuned version of Hata model is presented in Table 10 using RMSE, MAPE, MAE and SD. The Hata path loss model tuning resulted in reduction of the RMSE value from 7.86 to 5.18 dB which is a visible improvement in terrain representation. Fig. 5 shows the measured average path loss, the predicted path loss by Hata model and the predicted path loss by the tuned Hata model. It can be clearly observed that the tuned Hata model better fits measured average path loss and hence nearly represents the actual Hawassa city sub-urban terrain.

Table 9: Tuned parameters of Hata model for Sub-Urban areas.

Tuned parameter $\hat{a}$	Tuned parameter $\hat{b}$	E_s	B_s
130.135	33.969	83.772	35.421
E_o	$\widetilde{E_o}$	Slope Correction factor, $\widetilde{B_s}$	
40.9	46.363	0.959	

Table 10: Performance of tuned Hata model for Sub-Urban area.

RMSE	MAPE	MAE	SD
5.18	3.63	4.63	2.76

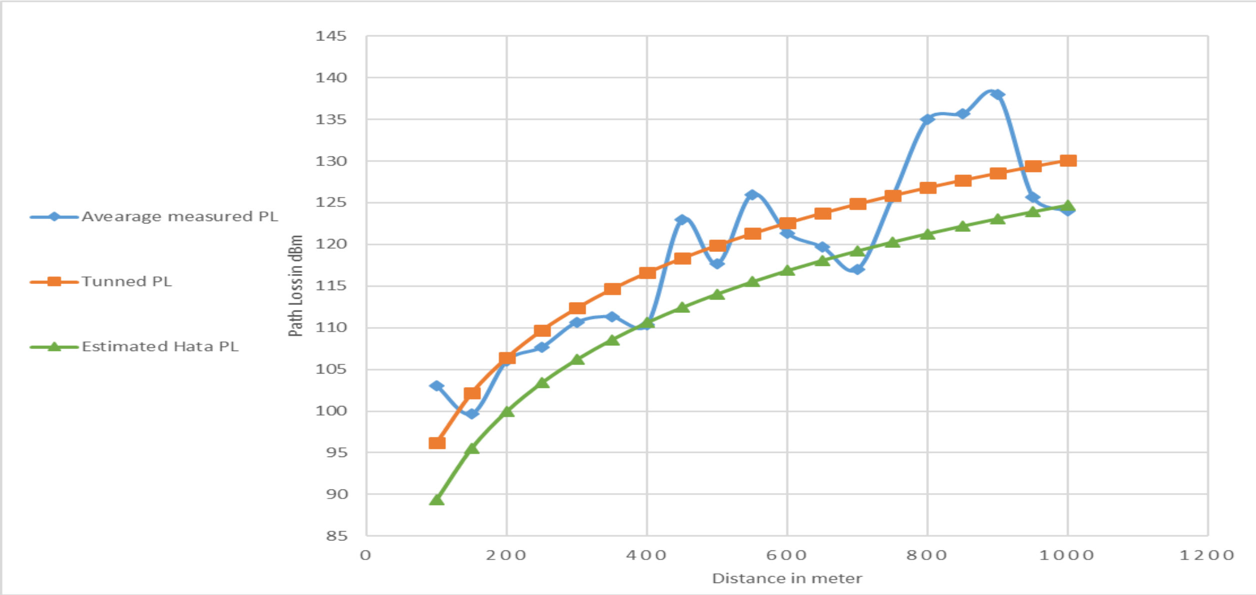

Fig. 5. Sub-Urban area calibrated Hata model vs. measured PL and original Hata (1800).

8. Conclusion

This work categorizes the terrain type of Hawassa city at 1800 MHz, selects the best path loss models among the five models, and optimizes the selected ones using Least Square Algorithm. Among the total 40 sites of Hawassa city, 14 cities that nearly represent the entire city terrain were selected. Among them, 11 sites were found to be urban for which ECC-33 with 4.18dB RMSE was the best. Tuning this model, the RMSE value was reduced to 2.46dB. The rest were suburban for which Hata model outperforms with 7.86dB RMSE. Tuning this model, the RMSE value was reduced to 5.18dB.

CRediT Authorship Contribution Statement

Tamirat Yenealem: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Roles/Writing - original draft, Writing - review & editing. **Robel Getachew:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Roles/Writing - original draft, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues; including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy has been completely observed by the authors.

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