Comparison of Empirical Propagation Path Loss Models for Mobile Communication

Michael S. Mollel* Dr. Michael Kisangiri
School of Computational and Communication Science and Engineering, Nelson Mandela African Institution of Science and Technology,PO box 447, Arusha, Tanzania
E-mail: mollelm@nm-aist.ac.tz; kisangiri.michael@nm-aist.ac.tz

Abstract
Empirical propagation models have found favor in both research and industrial communities owing to their speed of execution and their limited reliance on detailed knowledge of the terrain. In mobile communication the accuracy prediction of path losses is a crucial element during network planning and optimization. However, the existence of multiple propagation models means that there is no propagation model which is precisely and accurate in prediction of path loss fit for every environs other than in which they were designed. This paper presents few empirical models suitable for path loss prediction in mobile communication. Experimental measurements of received power for the 900 MHz GSM system are made in urban, suburban, and rural areas of Dar es Salaam, Tanzania. Measured data are compared with those obtained by five prediction models: Stanford University Interim (SUI) models [1], the COST-231 Hata model [2], the ECC-33 model [3], the ERICSSON model [4], and the HATA-OKUMURA model [5]. The results show that in general the SUI, COST-231, ERICSSON, and Hata-Okumura under-predict the path loss in all environments, while the ECC-33 model shows the best results, especially in suburban and over-predict pathloss in urban area.

Keywords: Propagation pathloss, empirical models, radio coverage, mobile communications.

1. INTRODUCTION

Propagation models are used extensively in network planning, particularly for conducting feasibility studies and during initial deployment. They are also very useful for performing interference studies as the deployment proceeds. The generalization of these models, to any environment, is suitable for either particular areas (urban, suburbs and rural), or specific cell radius (macrocell, microcell, picocell) depending on the diversity of environment where mobile communications occur. In general, there is a relationship between these models and types of environments for which they are suitable.

These models can be broadly categorized into three types; empirical, deterministic and stochastic. Empirical models are those based on observations and measurements alone. These models are mainly used to predict the path loss, but models that predict rain-fade and multipath have also been proposed [6]. The deterministic models make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. Deterministic models often require a complete 3-D map of the propagation environment. Stochastic models, on the other hand, model the environment as a series of random variables. These models are the least accurate but require the least information about the environment and use much less processing power to generate predictions[6].

Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive [7]. The former type is designed to provide information relating to the time dispersive characteristics of the channel i.e., the multipath delay spread of the channel. An example of this type are the Stanford University Interim (SUI) channel models developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 working group [1]. Examples of non-time dispersive empirical models are ITU-R [8], Hata [5] and the COST-231 Hata model [2]. All these models predict mean path loss as a function of various parameters, for example distance, antenna heights etc. In this paper, the validity of various empirical models for the mobile communication scenario will be determined by comparing their predictions with measurements taken at 900 MHz in Dar es salaam, Tanzania May 2014.

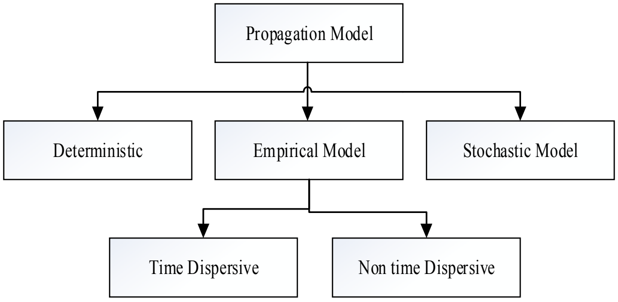


Figure 1: Categorize of propagation models

2. PROPAGATION MODELS

2.1 FREE SPACE MODEL

Path loss in Free Space L defines how much strength of signal is lost during propagation from transmitter to receiver. Free Space Model is diverse on frequency and distance. It is calculated as:

$$L = 32.45 + 20log(d) + 20log(f) \qquad (1)$$

Where, f is the Frequency in (MHz) and d is the distance in (Km)

2.2 ERICSSON MODEL

To predict the path loss, the network planning engineers are used a software provided by Ericsson company is called Ericsson model [4]. This model also stands on the modified Okumura-Hata model to allow room for changing in parameters according to the propagation environment. Path loss according to this model is given by [4].

$$L = a_0 + a_1 log(d) + a_2 log(h_b) + a_3 log(h_b) log(d) - 3.2(log(11.75 h_r)^2) + g(f) \qquad (2)$$

where g(f)is defined by [4].

$$g(f) = 44.49 log(f) - 4.78(log(f))^2 \qquad (3)$$

and parameters 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 1.

Table 1: Values of parameters for Ericsson model [4, 9]

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

*The value of parameter a_0 and a_1 in suburban and rural area are based on the Least Square (LS) method in [9].

2.3 HATA-OKUMURA MODEL

In an attempt to make the Okumura's model easier for computer implementation Hata's model delivered from Okumura and has fit Okumura's curves with analytical expressions. This makes the computer implementation of the model straightforward. It is an empirical formulation [5] of the graphical path-loss data provided by Okumura's model. Hata's formulation is limited to some values of input parameters .The formula for the median path loss in urban areas is given by [5].

$$L(urban) = 69.55 + 26.16 log f - 13.82 log h_{te} - ah_{re} + (44.9 - 6.55 log h_{te}) log d \qquad (4)$$

where f is the frequency (in MHz), which varies from 150 -1500 (MHz), h_{te} and h_{re} are the effective heights of the base station and the mobile antennas (meters) respectively, d is the distance from the base station to the mobile antenna and $a(h_{re})$ is the correction factor for the effective antenna height of the mobile unit, which is a function of the size of the area of coverage. For small to medium-sized cities, the mobile-antenna correction factor is given by [5].

$$a(h_{re}) = (1.1 log f - 0.7) h_{re} - (1.56 log f - 0.8) \qquad (5)$$

For a large city, it is given by

$$a(h_{re}) = \begin{cases} 8.29(log(1.54 h_{re}))^2 - 1.1 & , f < 300MHz \\ 3.2(log(11.75 h_{re}))^2 - 4.97 & , f \geq 300MHz \end{cases} \qquad (6)$$

To obtain the path loss in a suburban area, the standard Hata formula is modified as follows [5].

$$L = L_{50}(urban) - 2[log(f/28)]^2 - 5.4 \qquad (7)$$

The path loss in open rural areas is expressed through [5].

$$L = L(urban) - 4.78(log f)^2 - 18.33 log(f) - 40.98 \qquad (8)$$

2.4 COST-231 HATA MODEL

A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model [2]. It was devised as an extension to the Hata-Okumura model [5, 10]. The COST-231 Hata model is designed to be used in the frequency band from 500 MHz to 2000 MHz It also contains corrections for urban, suburban and rural (flat) environments. Although its frequency range is outside that of the measurements, its simplicity and the availability of correction factors has seen it widely used for path loss prediction at this frequency band. The basic equation for path loss in dB is [2].

$$L = 46.3 + 33.9 \log f - 13.82 \log h_b + c_m - ah_m + (44.9 - 6.55 \log h_b) \log d \tag{9}$$

where, f is the frequency (MHz), d is the distance from the base station to the mobile antenna 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 3dB for urban environments. The parameter ah_m is defined for urban environments as [7].

$$ah_m = 3.2(\log(11.75 h_r))^2 - 4.97 \quad , f > 400 Mhz \tag{10}$$

and for suburban or rural (flat) environments [7].

$$ah_m = (1.1 \log f - 0.7) h_r - (1.56 \log f - 0.8) \tag{11}$$

where, h_r is the mobile antenna height above ground level. This model is quite suitable for large-cell mobile systems, but model requires that the base station antenna to be higher than all adjacent rooftop.

2.5 STANFORD UNIVERSITY INTERIM (SUI) MODEL

IEEE 802.16 Broadband Wireless Access working group proposed the standards for the frequency band below 11 GHz containing the channel model developed by Stanford University, namely the SUI models [4, 6]. This prediction model come from the extension of Hata model with frequency larger than 1900 MHz the correction parameters are allowed to extend this model up to 3.5 GHz band. In the USA, this model is defined for the Multipoint Microwave Distribution System (MMDS) for the frequency band from 2.5 GHz to 2.7 GHz [6].

The base station antenna height of SUI model can be used from 10 m to 80 m. Receiver antenna height is from 2 m to 10 m. The cell radius is from 0.1 km to 8 km [4]. The SUI model describes three types of terrain, they are terrain A, terrain B and terrain C. There is no declaration about any particular environment. Terrain A can be used for hilly areas with moderate or very dense vegetation. This terrain presents the highest path loss. In our paper, we consider terrain A as a dense populated urban area. Terrain B is characterized for the hilly terrains with rare vegetation, or flat terrains with moderate or heavy tree densities. This is the intermediate path loss scheme. We consider this model for suburban environment. Terrain C is suitable for flat terrains or rural with light vegetation, here path loss is minimum.

The basic path loss expression of The SUI model with correction factors is presented as [6].

$$L = A + 10\gamma \log(\frac{d}{d_o}) + X_f + X_h + s \quad for\ d > d_o \tag{12}$$

where, d is the distance between base station and mobile antenna in(meters) , d_0 =100m , λ is the wavelength in (meters), X_f is the correction for frequency above 2GHz in (MHz), X_h is the correction for receiving antenna height ,S is the correction for shadowing in dB and γ is the path loss exponent.

The random variables are taken through a statistical procedure as the path loss exponent γ and the weak fading standard deviation S is defined. The log normally distributed factor S, for shadow fading because of trees and other clutter on a propagations path and its value is between 8.2 dB and 10.6 db. The parameter A is defined as [4, 6].

$$A = 20 \log(\frac{4\pi d_0}{\lambda}) \tag{13}$$

and the path loss exponent γ is given by [6]:

$$\gamma = a - bh_b + (\frac{c}{h_b}) \tag{14}$$

where, the parameter h_b is the base station antenna height in meters. This is between 10 m and 80 m. The constants a, b, and c depend upon the types of terrain, that are given in

Table 2. The value of parameter γ = 2 for free space propagation in an urban area, 3 < γ < 5 for urban NLOS environment, and γ > 5 for indoor propagation [4].The frequency correction factor X_f and the correction for receiver antenna height X_h for the model are expressed in [6]:

$$X_f = 6.0 \log(\frac{f}{2000}) \tag{15}$$

$$X_h = \begin{cases} -10.8\,log(\frac{h_r}{2000}) & \text{for terrain type A and B} \\ -20.0\,log(\frac{h_r}{2000}) & \text{for terrain type C} \end{cases} \qquad (16)$$

where, f is the operating frequency in MHz, and h_r is the receiver antenna height in meters. For the above correction factors this model is extensively used for the path loss prediction of all three types of terrain in rural, urban and suburban environments.

Table 2: The parameter values of different terrain for SUI model

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

2.6 ECC-33 MODEL

The original Okumura experimental data were gathered in the suburbs of Tokyo[10] . The authors refer to urban areas subdivided into 'large city' and 'medium city' categories. They also give correction factors for 'suburban' and 'open' areas. Since the characteristics of a highly built-up area such as Tokyo are quite different to those found in typical European suburban areas, use of the 'medium city' model is recommended for European cities[11, 12]. Although the Hata- Okumura model [8] is widely used for UHF bands its accuracy is questionable for higher frequencies. The COST-231 model extended its use up to 2 GHz but it was proposed for mobile systems having omnidirectional receiver antennas sited less than 3 m above ground level. A different approach was taken in [3], which extrapolated the original measurements by Okumura and modified its assumptions so that it more closely represents a wireless system. The path loss model presented in [3], is referred to here as the ECC-33 model. The path loss is defined as.

$$L = A_{fs} + A_{bm} - G_b - G_r \qquad (17)$$

where, A_{fs}, A_{bm}, G_b and G_r are the free space attenuation, the basic median path loss, the Base station height gain factor and the receiver height gain factor. They are individually defined as [3].

$$A_{fs} = 92.4 + 20\,log\,d + 20\,log\,f \qquad (18)$$

$$A_{bm} = 20.41 + 9.83\,log\,d + 7.89\,log\,f + 9.56\left[log\,f\right]^2 \qquad (19)$$

$$G_b = log\left(\frac{h_b}{200}\right)\left(13.958 + 5.8\,log\left(d\right)\right)^2 \qquad (20)$$

for medium city environments[3].

$$G_r = \left[42.57 + 13.7\,log\,f\right]\left[log\left(h_r\right) - 0.585\right] \qquad (21)$$

and for the large city[3].

$$G_r = 0.759h_r - 1.862 \qquad (22)$$

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. The medium city model is more appropriate for European cities whereas the large city environment should only be used for cities having tall buildings. It is interesting to note that the predictions produced by the ECC-33 model do not lie on straight lines when plotted against distance having a log scale.

3.MEASUREMENT CONFIGURATION

3.1 Terrestrial description of Dar es Salaam

Dar es Salaam is the largest city in Tanzania. With a population increase of 5.6% per year from 2002 to 2012, the city has become the third fastest growing in Africa (ninth fastest in the world), after Bamako and Lagos, respectively. The city is at 6°48' South, 39°17' East (−6.8000, 39.2833). The region is divided into three terrain profile in mobile communication per se urban, suburban, and rural areas. Urban environment include all area with congested people and establishment such as Kariakoo and Posta, suburban areas are those that are just adjacent to the city, or surround the city and have less congested people compared to urban areas like Manzese, Mbagala, Kimara and Tegeta , while rural areas includes remotes area such as Kigamboni and Bunju. At the center of the city cast narrow streets and high building, the buildings height vary between 20 to 45m within the urban areas ,while in suburban areas buildings heights vary between 6 to 15m .Most of the buildings are mass of concrete and bricks. Extensive experimental tests were performed in the geographic area of Dar es Salaam for both environs.

3.2 Experimental Details

A drive test tools used for collecting data include a laptop equipped with drive test Ericsson software, Map info software (professional version 10.0), a communication Network Analyzer software (ACTIX analyzer 4.05), Garmin GPS 12XL receiver, Two W995 Sony Ericsson TEMS phone for idle and dedicated mode, an inverter and extension board . A schematic diagram of the Field measurement set-up is shown in Figure 2. The test was carried out on three different locations in Dar es Salaam: Posta (NIC house - DAR022), with coordinate (6°49'0.48"S 39°17'30.48"E) is selected to present urban area, Mbagala Kizuiani-DAR169, with coordinate (6°54'17.25"S 39°15'57.60"E) selected to present sub-urban area, and Kimbiji (Kigamboni-DAR095) coordinates (6°59'24.31"S 39°31'32.44"E) selected to present rural area. That means that these sites were selected to represent the most common propagation characteristics of Dar es Salaam

The two Sony Ericsson UEs (M1 and M2), GPS receiver and the Dongle probe were coupled to a laptop placed in a car. The laptop was powered on to launch TEMS investigation software. The sectors were identified before setting out for the drive test. All the equipment were connected and detected on TEMS interface. After the necessary configuration of the TEMS equipment, the drive test readings started by clicking record in the start command window. The car was driven around through a predefined route in the direction of the Active Sector (AS) of the directional antenna away from the site until it got to the coverage border. The measurements were performed in a car and speed limit kept as constant (around 40Km/h) as possible to avoid traffic issues and errors. Two modes of configurations for the handsets were used for the monitored software during the drive test.

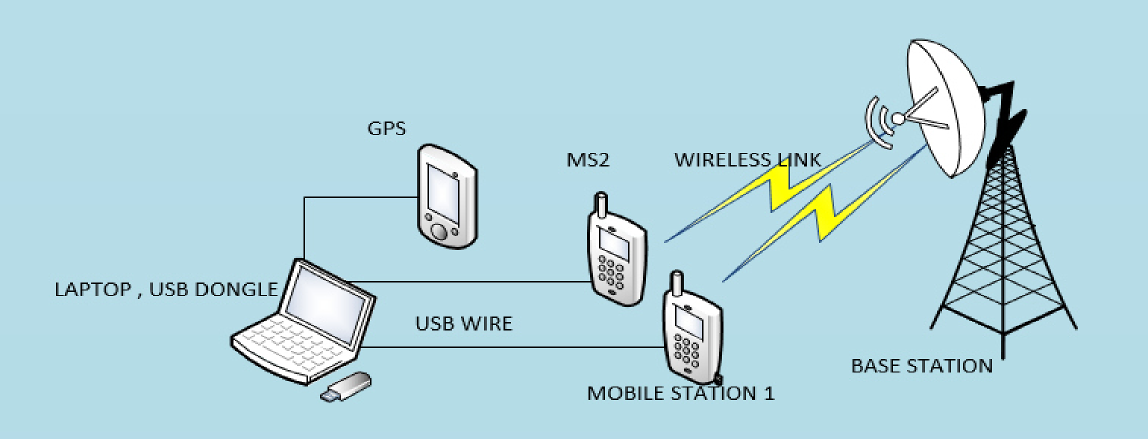


Figure 2: A SET-UP FIELD-TEST MEASUREMENT

These were the idle and dedicated modes. M1 was set at idle mode and M2 was set at dedicated mode. M2 was present automatically to make a continuous call to a fixed destination number. The received signal power is measured using Ericsson handset and transferred to the TEMS log file in the laptop. The GPS receiver gave the location and distance from the sectors/Node B synchronously with the received power level reading and was recorded on the laptop. The experimental data were taken at distances ranging from 30 meters to 1.3 Km and the experiment were done several times in each base station to improve accuracy of this experiment, then mean pathloss from each station were obtained and are shown in Tables 3. Due to the huge number of measured samples for each base station and in order to remove the effects of fast fading, the measured data were averaged over every 100 m of the path between the base station and the receiver. The specifications of the tested base stations are illustrated in Table 3.

Table 3: BASE STATION PARAMETERS

Parameters		**Values**
Antenna type		Kathrein739686
Operating frequency		900/1800
Base Station Transmitting power		47dBm
Base station height	Kimbiji-DAR095(Rural)	42m
	Kizuiani- DAR169(Suburban)	35m
	Posta - DAR022(Urban)	33m
Mobile Station height		1 m
Base Station antenna gain		17.2dBi
Mobile Station antenna gain		0
Connector loss		2dB
Cable loss		1.5dB
Duplexer loss		1.5dB

TEMS and Google earth software simulates the drive test in real time, that is, it shows the path taken as well as the different Received levels (Rx) with different color codes. The green color is the best case signal reception (Rx < -75), red being the worst case (-105 < Rx < -150), that is, almost no signal, and intermediate colors (for example, orange) are regions of call drops or bad quality signal Fig. 3-5.

4.RESULTS AND DISCUSSION

The location Map of Investigated Areas for base stations (rural, suburban, and urban) under study in Dar es Salaam are shown in Fig. 3-5.

Figure 3: Drive test simulation in urban area Dar es Salaam

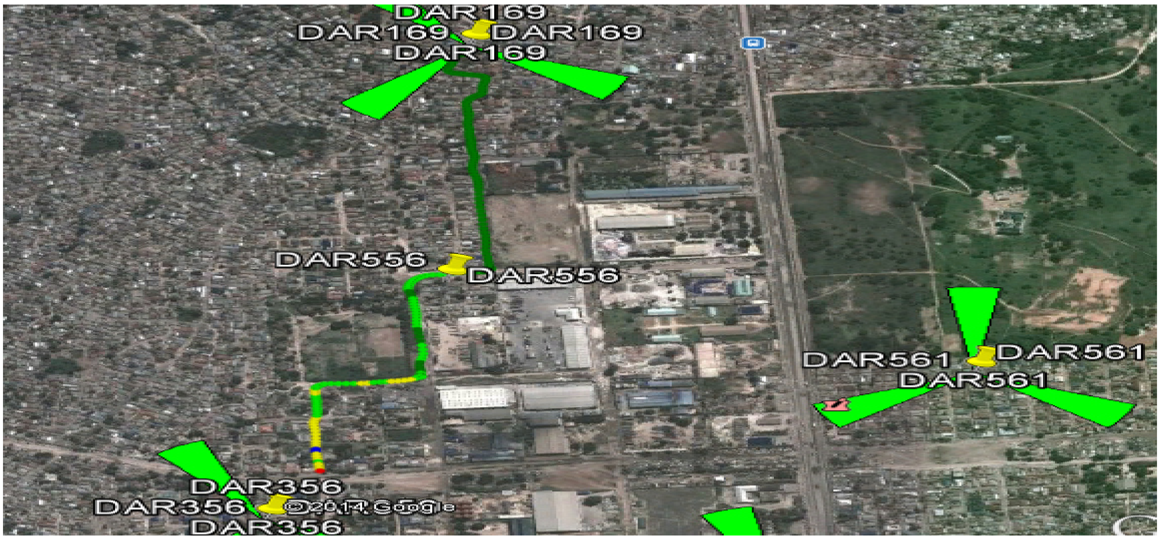


Figure 4: Drive test simulation in suburban area Dar es Salaam

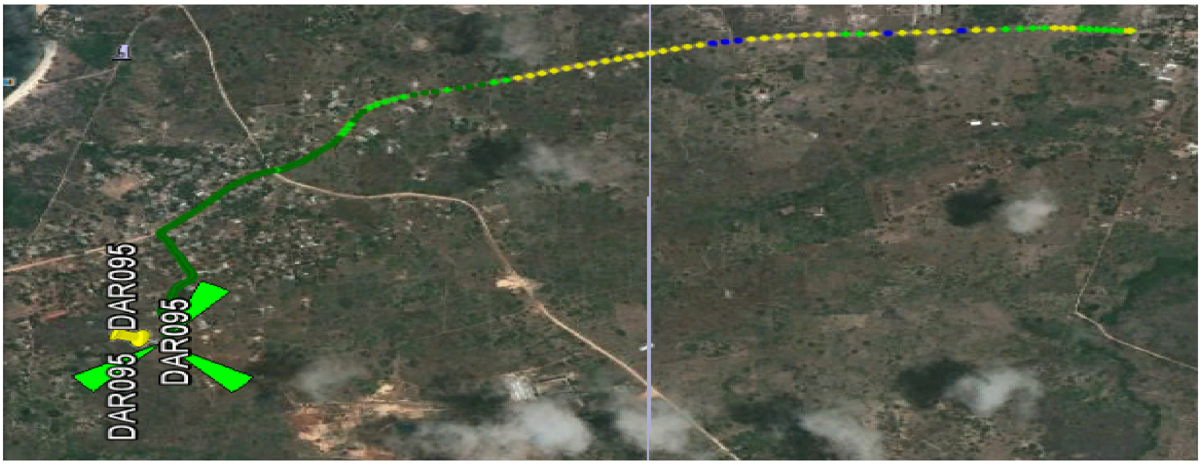


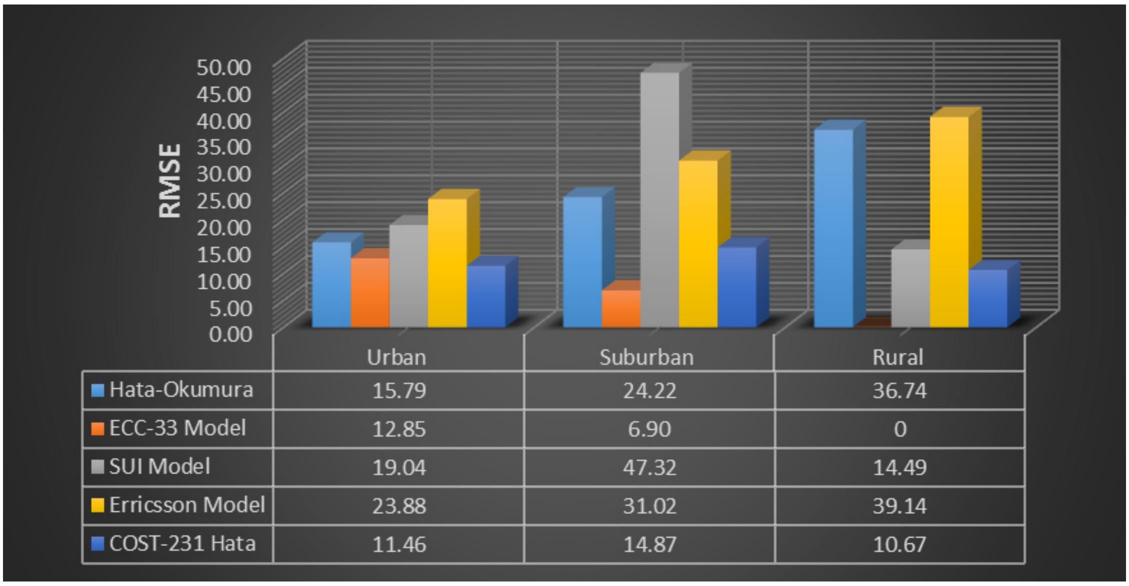
Figure 5: Drive test simulation in rural area Dar es Salaam

The actual path loss measurements can be analyzed relative to the five models discussed in section 2 to see whether these propagation models are accurate used for path loss prediction for 900MHz GSM in different terrain for Dar es Salaam region. It is necessary to know that ECC-33 model is not applicable to rural environment. The accuracy of the path loss models are calculated in terms of the root mean square error (RMSE) [13-16].

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (\mathrm{PL}_{mi} - PL_i)^2}{N}} \qquad (23)$$

where, PLmi is the measured path loss at position i in dB, PLi is the calculated path loss at position i in dB, and N is the number of measured path loss samples.

Table 4: ROOT MEAN SQUARE ERROR



	Urban	Suburban	Rural
■ Hata-Okumura	15.79	24.22	36.74
■ ECC-33 Model	12.85	6.90	0
■ SUI Model	19.04	47.32	14.49
■ Erricsson Model	23.88	31.02	39.14
■ COST-231 Hata	11.46	14.87	10.67

Discussed empirical propagation models are plotted together with experimental results to see which one estimates the path loss more accurately.

Figure 6 shows the path loss from Posta (urban), the following observations are made:

1. The ECC-33 Model overestimates the path loss while the other models underestimates the pathloss.
2. The ECC-33 and the COST231-Hata model show small deviation from measurement.
3. The variation in the experimental values (non-straight line graph) can be attributed to the Posta environment having many obstructions in the path, like many high buildings in close proximity.

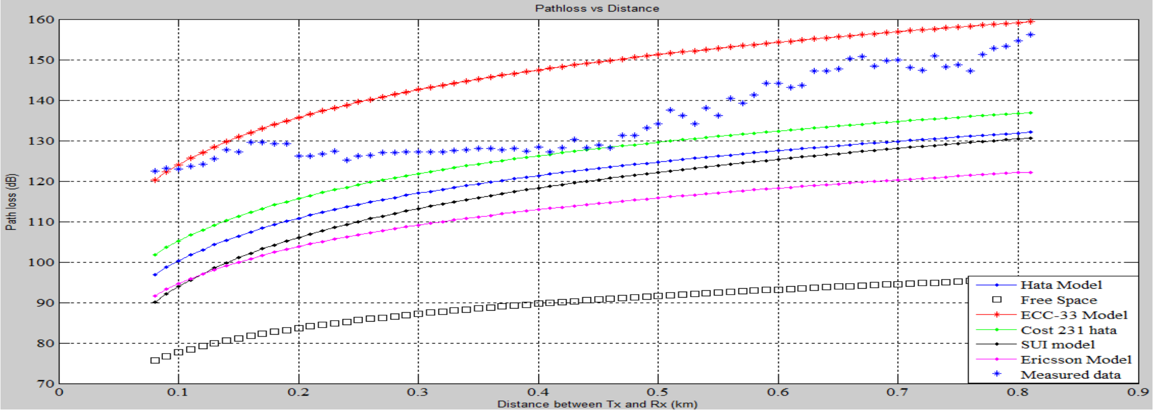


Figure 6: COMPARISON OF PATH LOSS MODELS WITH THE MEASUREMENT FROM URBAN AREA:

Figure 7 shows the path loss from Kizuiani (Suburban) the following observations are made:

1. The ECC-33 Model shows the best prediction results while the other models underestimates the pathloss.
2. The ECC-33 model shows small deviation from measurement with RMSE of 6.9 if we can assume the deviation from the acceptable range (maximum rmse 6dB)[17] is happened by chance hence it can be suitable to use this model for prediction of pathloss.
3. The sudden peak of pathloss can be attributed to a sharp turn around a building at that particular location. Moreover, the other deviations (ups and downs) are normally the cause of shadowing, reflection, diffraction or scattering, most probably due to the presence of trees.

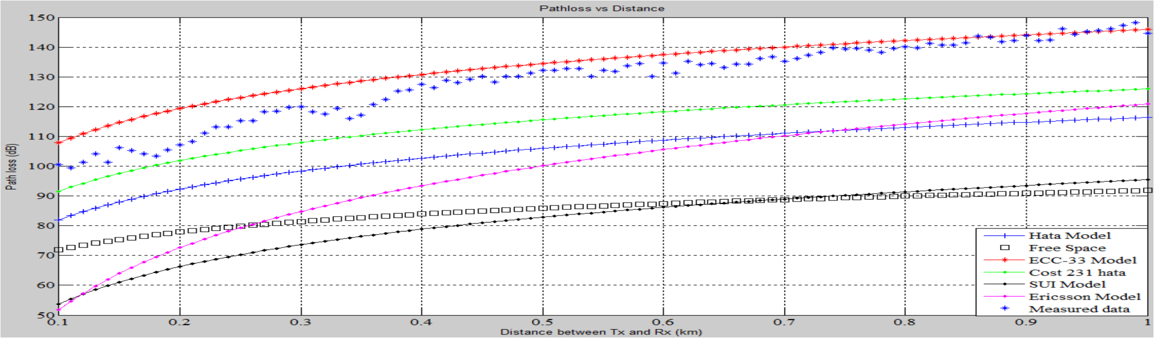


Figure 7: COMPARISON OF PATH LOSS MODELS WITH MEASUREMENT FROM SUBURBAN AREA

Figure 8 shows the path loss from Kimbiji (Rural) the following observations are made:

1. The Hata-Okumura, the COST-231 Hata, the SUI, and the Ericsson model underestimates the pathloss.
2. The SUI, and the COST-231 Hata show small deviation from measurement values.
3. For Kimbiji, the presence of hills and crests is the main reason for the variations in the path loss.

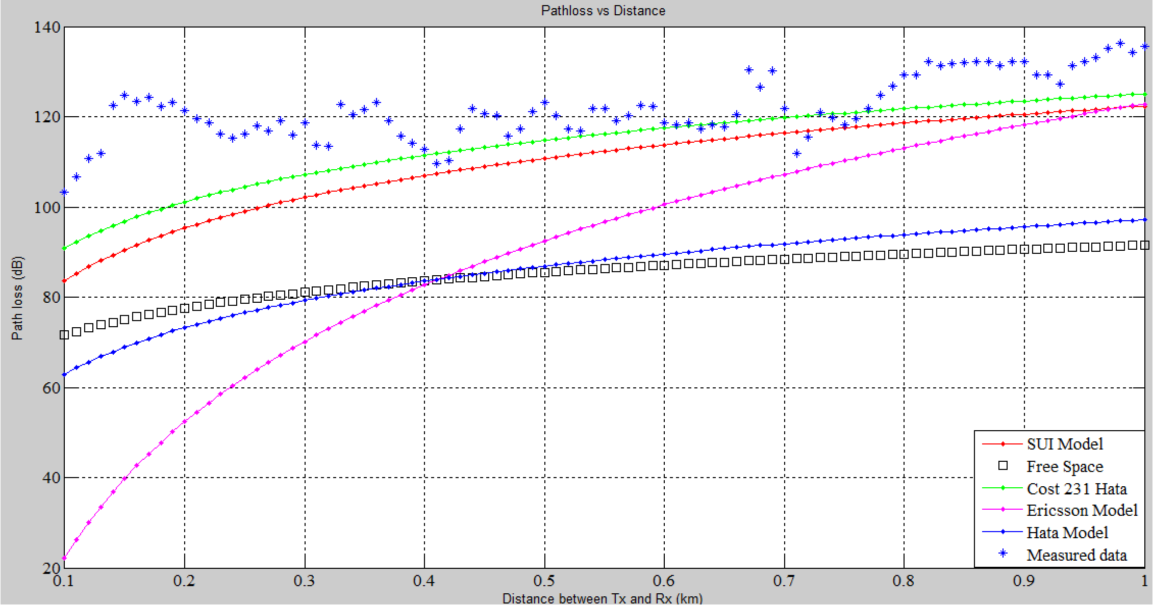


Figure 8: COMPARISON OF PATH LOSS MODELS WITH MEASUREMENTS FROM RURAL AREA

4.CONCLUSION

The path loss has been estimated using five models, namely the Stanford University Interim (SUI) models, the COST-231 Hata model, the ECC-33 model, the Ericsson model, and the Hata-Okumura model and the result have be compared with the measured data from the field . The comparison results show that the ECC-33 model gives in general a better prediction for suburban environment, whereas the other model underestimate the pathloss in all three terrain .From the results obtained, it is recommended that for accurate prediction of radio signal characteristics for mobile communication, one of existing models needs to be adjusted to fit for the environment if the cost for the field measurement is too high.

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