2014

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Mollel, Michael

Pan African International Conference on Information Science, Computing and Telecommunications

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Conference Paper · July 2014

DOI: 10.1109/SCAT.2014.7055150

1 author:

Michael Samwel Mollel
The Nelson Mandela African Institute of Science and Technology

An Overview of Various Propagation Model for Mobile Communication

Michael S. Mollel, Dr. Michael Kisangiri
Nelson Mandela African Institution of Science and Technology (NM-AIST), School of Computational and Communication Science and Engineering
Arusha, Tanzania
mollelm@nm-aist.ac.tz , kisangiri.michael@nm-aist.ac.tz

***Abstract*—System's propagation characteristics through a medium is one of the important task to be done before planning and optimization of any network in order to estimate the signal parameter accurately for mobile system. Propagation analysis provides a good initial estimate of the signal characteristics .The ability to accurately predict radio-propagation behaviour for wireless personal communication system, such as cellular mobile radio, is becoming crucial to system design. This paper aim to address various propagation model used in planning and optimization of the network and much emphasize on empirical (statistical) models it address models limitation and its applicability. To validate the models, field measurements were carried out at different locations within Dar es Salaam and its environs. The measurements system consist of live radio base stations transmitting at 900/ 1800/2100 MHz Downlink signal strength level data were collected using drive test exercise. The respective path loss values were estimated and compared with existing model for rural, suburban and urban areas. The result indicated an appreciable inconsistency with the empirical models for all terrain areas.**

***Index Terms*— radio propagation, communication channels, path loss, drive test.**

1. INTRODUCTION

The commercial success of cellular communication, since its initial implementation in early 1980s, has led to an intense interest among wireless engineers in understanding and predicting radio-propagation characteristics in various urban and suburban areas, and even within buildings. As the explosive growth of mobile communication continues ,it us very valuable to have the capability of determining optimum base-station locations ,obtaining suitable data rates and estimating their coverage ,without conducting a series of propagation measurement ,which are very expensive and time consuming .It is therefore important to develop effective propagation models for mobile communication ,in order to provide design guidelines for mobile system[1].

2. PATH LOSS

The path loss between a pair of antennas is the ratio of the transmitted power to the received power, usually expressed in decibels. It includes all of the possible elements of loss associated with interactions between the propagating wave and any objects between transmit and the receive antennas. In the case of channels with large amounts of fast fading, such as mobile channels, the path loss applies to the power averaged over several fading cycles (the local median path loss). This path loss is hard to measure directly, since various losses and gains in the radio system also have to be considered. These are best accounted for by constructing a link budget, which is usually the first step in the analysis of a wireless communication system. In order to define the path loss properly, the losses and gains in the system must be considered. The elements of a simple wireless link are shown in Fig. 1 [2].

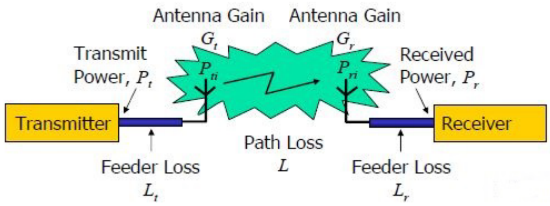

Figure 1: Elements of a wireless communication system

The power appearing at the receiver input terminals, P_R can then be expressed as [2].

$$P_R = \frac{P_T G_T G_R}{L_T L L_R} \tag{1}$$

Where the parameters are defined in Fig. 1, with all gains G and losses L expressed as power ratios and powers expressed in watts. The antenna gains are expressed with reference to an isotropic antenna, which radiates the power delivered to it equally in all directions. The values used are those corresponding to the direction of the other antenna and may not necessarily be the maximum values. The effective isotropic radiated power (EIRP) is then given by [2]

$$EIRP = \frac{P_T G_T}{L_T} \tag{2}$$

Where P_{TI} is the effective isotropic transmit power, similarly, the effective isotropic received power is P_{RI} , where

$$P_{RI} = \frac{P_R L_R}{G_R} \tag{3}$$

The advantage of expressing the powers in terms of EIRP is that the path loss, L, can then be expressed independently of system parameters by defining it as the ratio between the transmitted and the received EIRP, or the loss that would be experienced in an idealized system where the feeder losses were zero and the antennas were isotropic radiators($G_{T,R}=1$, $L_{T,R}=1$)[2, 3].

$$\text{Pathloss}, L=\frac{P_{TI}}{P_{RI}}=\frac{P_T G_T G_R}{P_R L_T L_R} \tag{4}$$

The main goal of propagation modelling is to predict L as accurately as possible, allowing the range of a radio system to be determined before installation. The maximum range of the system occurs when the received power drops below a level which provides just acceptable communication quality. This level is often known as the receiver sensitivity. The value of L for which this power level is received is the maximum acceptable path loss. It is usual to express the path loss in decibels, so that [2].

$$L_{dB}=10\log\left(\frac{P_{TI}}{P_{RI}}\right) \tag{5}$$

3. PROPAGATION MODELS

In this paper, we studied a number of path loss models for predicting the propagation loss for mobile. Path loss models play a major role in planning of wireless cellular systems. They represent a set of mathematical equations and algorithms that are used for radio signal propagation prophecy in definite areas. There are three kind of models [4]:

1. Empirical Model
2. Stochastic Model
3. Deterministic Model

In this paper we worked on the Empirical Models as these models are based on data used to predict, not explain a system and are based upon observation and measurement alone. Empirical Model further split into two parts time dispersive and non-time dispersive .SUI model is one example of time dispersive Model and Cost 231 Hata model is example of non-time dispersive model [4].

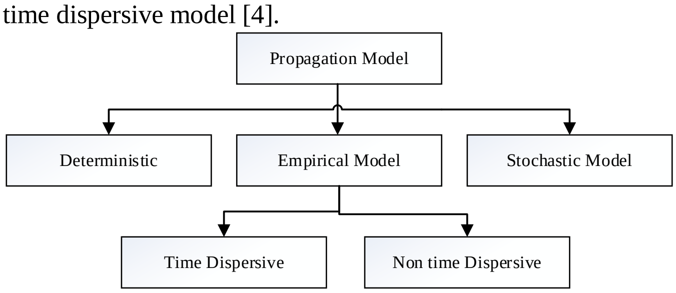

Figure 2: Categorize of Propagation Models

3.1 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:

$$L = 32.45+20\log(d)+20\log(f) \tag{6}$$

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

3.2 ERICSSON MODEL

To predict the path loss, the network planning engineers are used a software provided by Ericsson company is called Ericsson model [5]. 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 [5].

$$\begin{aligned} L = a_0 + a_1\log(d) + a_2\log(h_b) + a_3\log(h_b)\log(d) \\ -3.2(\log(11.75\,h_r)^2) + g(f) \end{aligned} \tag{7}$$

where g(f)is defined by [5].

$$g(f) = 44.49\log(f) - 4.78(\log(f))^2 \tag{8}$$

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 [5, 6]

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 [6].

3.3 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 [7] 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 [7].

$$\begin{aligned} L(\text{urban}) = 69.55 + 26.16\log f - 13.82\log h_{te} \\ -ah_{re} + (44.9 - 6.55\log h_{te})\log d \end{aligned} \tag{9}$$

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 [7].

$$a(h_{re}) = (1.1\log f - 0.7)h_{re} - (1.56\log f - 0.8) \tag{10}$$

For a large city, it is given by

$$a(h_{re}) = \begin{cases} 8.29(\log(1.54\,h_{re}))^2 - 1.1 & , f < 300\text{MHz} \\ 3.2(\log(11.75\,h_{re}))^2 - 4.97 & , f \geq 300\text{MHz} \end{cases} \tag{11}$$

To obtain the path loss in a suburban area, the standard Hata formula is modified as follows [7].

$$L_{50}(dB) = L_{50}(\text{urban}) - 2\left[\log(f/28)\right]^2 - 5.4 \tag{12}$$

The path loss in open rural areas is expressed through [7].

$$L_{50}(dB) = L_{50}(urban) - 4.78(\log f)^2 - 18.33\log f - 40.98 \quad (13)$$

Hata implementation of the Okumura's model can be found in almost every RF propagation tool in use today. However, there are some aspects of its application that a user has to be aware of:

- This model is quite suitable for large-cell mobile systems, but not for personal communications systems that cover a circular area of approximately 1 km in radius
- The Hata model was derived as a numerical fit to the propagation curves published by Okumura. As such, the model is somewhat specific to Japan's propagation environment. In addition, terms like "small city", "large city", "suburban area" are not clearly defined and can be interpreted differently by people with different backgrounds. Therefore, in practice, the area adjustment factor should be obtained from the measurement data in the process of propagation model optimization.
- In the Okumura's original model, the effective antenna height of the transmitter is calculated as the height of the TX antenna above the average terrain. Measurements have shown several disadvantages to that approach for effective antenna calculation. In particular, Hata's model tends to average over extreme variations of the signal level due to sudden changes in terrain elevation. To circumvent the problem, some prediction tools examine alternative methods for calculation of the effective antenna height

3.4 COST-231 HATA MODEL

A model that is widely used for predicting path loss in mobile wireless system is the COST-231 Hata model [8]. It was devised as an extension to the Hata-Okumura model [7, 9]. 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 [8].

$$L_{50}(dB) = 46.3 + 33.9\log f - 13.82\log h_b + c_m - ah_m + (44.9 - 6.55\log h_b)\log d \quad (14)$$

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 metres. The parameter c_m is defined as 0dB for suburban or open environments and 3dB for urban environments. The parameter ah_m is defined for urban environments as [10].

$$ah_m = 3.2(\log(11.75 h_r))^2 - 4.97 \quad , f > 400\text{Mhz} \quad (15)$$

and for suburban or rural (flat) environments [10].

$$ah_m = (1.1\log f - 0.7) h_r - (1.56\log f - 0.8) \quad (16)$$

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.

3.5 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 [5, 11]. 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 [11].

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 [5]. 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 [11].

$$L = A + 10\gamma\log\left(\frac{d}{d_o}\right) + X_f + X_h + s \qquad \text{for } d > d_o \quad (17)$$

Where, d is the distance between base station and mobile antenna in(metres) , d_0=100m , λ is the wavelength in (metres), 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 [5, 11].

$$A = 20\log\left(\frac{4\pi d_0}{\lambda}\right) \quad (18)$$

and the path loss exponent γ is given by [11]:

$$\gamma = a - bh_b + \left(\frac{c}{h_b}\right) \quad (19)$$

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 $\gamma = 2$ for free space propagation in an urban area, $3 < \gamma < 5$ for urban NLOS environment, and $\gamma > 5$ for indoor propagation [5].

The frequency correction factor X_f and the correction for receiver antenna height X_h for the model are expressed in [11]:

$$X_f = 6.0\log(\frac{f}{2000}) \quad (20)$$

$$X_h = \begin{cases} -10.8\log(\frac{h_r}{2000}) & \text{for terrain type A and B} \\ -20.0\log(\frac{h_r}{2000}) & \text{for terrain type C} \end{cases} \quad (21)$$

where, f is the operating frequency in MHz, and h_r is the receiver antenna height in metres. 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

3.6 ECC-33 MODEL

The original Okumura experimental data were gathered in the suburbs of Tokyo[9] . 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[12, 13]. 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 [14], 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 [14], is referred to here as the ECC-33 model. The path loss is defined as.

$$L = A_{fs} + A_{bm} - G_b - G_r \quad (22)$$

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 [14].

$$A_{fs} = 92.4 + 20\log d + 20\log f \quad (23)$$

$$A_{bm} = 20.41 + 9.83\log d + 7.89\log f + 9.56\left[\log f\right]^2 \quad (24)$$

$$G_b = \log\left(\frac{h_b}{200}\right)\left(13.958 + 5.8\log(d)\right)^2 \quad (25)$$

for medium city environments[14].

$$G_r = \left[42.57 + 13.7\log f\right]\left[\log(h_r) - 0.585\right] \quad (26)$$

and for the large city[14].

$$G_r = 0.759h_r - 1.862 \quad (27)$$

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 metres and h_r is the mobile antenna height in metres. 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.

4. DATA COLLECTION METHOD AND PROCEDURE

In order to verify the accuracy of models the comparison between the measured and calculated from theory were required.

To predict path loss model for cellular transmission, practical data from the field measurement are required. Downlink data were collected at various distances on live radio from Tigo sites at transmits frequency of 900/1800/2100 MHz. 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 Analyser software (ACTIX analyser 4.05), Garmin GPS 12XL receiver, Two W995 Sony Ericsson TEMS phone for idle and dedicated mode, an inverter and extension board. The test was carried out on three different locations in Dar es Salaam: Posta (NIC house), with coordinate (6°49'0.48"S 39°17'30.48"E) is selected as urban area, Mbagala Kizuiani, with coordinate (6°54'17.25"S 39°15'57.60"E) selected as sub-urban area, and Kimbiji (Kigamboni) coordinates (6°59'24.31"S 39°31'32.44"E) selected as rural area.

The two Sony Ericsson UEs, GPS receiver and the Dongle probe were coupled to a laptop placed in a car. The laptop was powered on in order to launch TEMS investigation software. All the equipment were connected and detected on TEMS interface. The sectors were identified before setting out for the drive test. 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 car was driven at an average speed of 40Km/h. Two modes of configurations for the handsets were used for the monitored software during this drive–test. These were the idle and dedicated modes. M_1 was set at idle mode and M_2 was set at dedicated mode. M_2 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 1-1.3 Km. Measurements were carried out May, 2014.

TABLE 3: SIMULATION PARAMETERS.

Parameters		**Values**	
Antenna type		Kathrein739686	Kathrein742215
Operating frequency		900/1800	2100
Base Station Transmitting power		47dBm	45dBm
Base station height	Kimbiji	42m	42m
	Kizuiani	35m	35m
	NIC	33m	33m
Mobile Station height		0.5m	0.5m
Base Station antenna gain		17.2dBi	18dBi
Mobile Station antenna gain		0	0
Connector loss		2dB	2dB
Cable loss		1.5dB	1.5dB
Duplexer loss		1.5dB	1.5dB
Body loss		3dB	3dB

5. RESULTS AND DISCUSSIONS

Experimental measurements of radio propagation characteristics are made in urban, suburban and rural areas for a 2G/3G system working at 900/1800/2100 MHz, measurements were carried out in the Dar es Salaam for three different environment, Posta (NIC) were selected to represent urban, Kizuiani present suburban part and Kimbiji present rural .Dar es Salaam is a mega city in Tanzania, with a high percent of residential areas. Simulation parameters were presented in Table 3. The mean value of measurements at each location is compared with results obtained with four statistical models: SUI, COST 231 Hata, Ericsson Model, ECC-33, and Hata-Okumura Model.

Prediction error standard deviations for urban, suburban and rural are given in Table 4.Results of measurements as well as predictions of the Pathloss obtained by models are given in Fig. 3 for urban, Fig. 4 for suburban and Fig.5 for rural. In our experiment for the three environment urban, suburban and rural neither of the models used has been suitable for prediction of Pathloss in Dar es Salaam environs since the acceptable limit for good signal propagation is up to [11]. Experiment shows the minimum error standard deviation of 12.98 from COST 231 Model in urban, 14.5 from ECC in suburban and 10.99 from SUI in rural. COST 231 Hata model has the least average error standard deviation for the three environments.

TABLE 4: ERROR STANDARD DEVIATION

Error Standard Deviation	**HATA**	**ECC**	**SUI**	**ERICSSON**	**COST-231**
Urban	17.68	25.98	15.92	25.84	12.98
Sub Urban	28.47	14.50	37.67	31.91	18.88
Rural	37.89	N/A	10.99	43.94	11.22

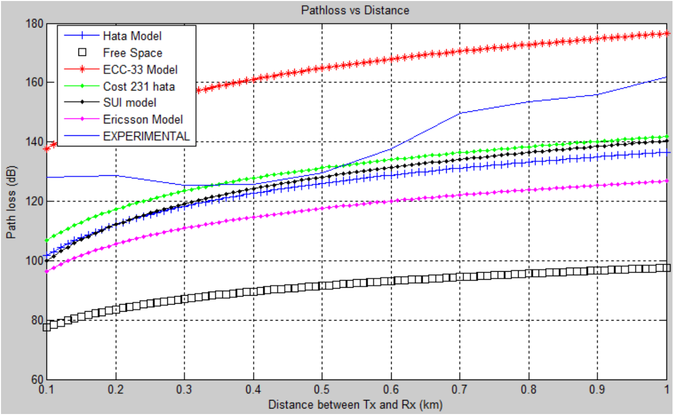

Figure 3: Comparison of path loss models with the measurement from urban area.

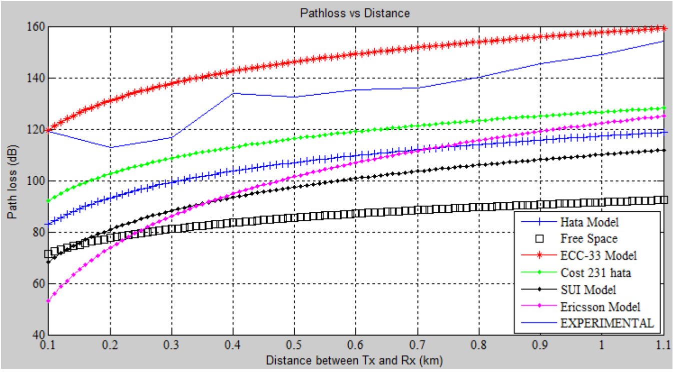

Figure 4: Comparison of path loss models with measurement from suburban area

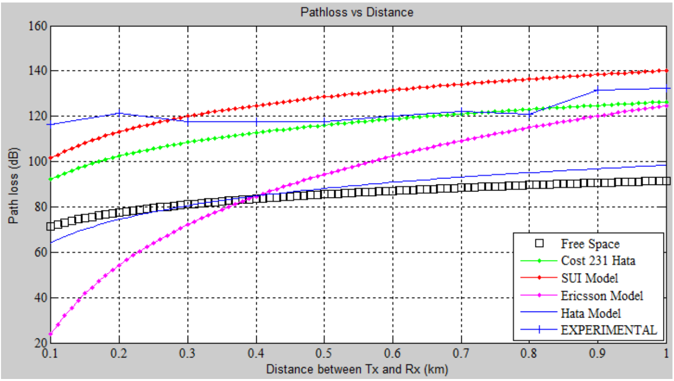

Figure 5: Comparison of path loss models with measurements from rural area

From the results of this paper, it is thereby recommended that: It is better to go for field measurement rather than relying on the existing empirical propagation models during equipment design and radio waves path profile estimation.

6. CONCLUSION

Several propagation model has been described in this paper. All aims to predict the propagation Pathloss in a specific point. All of these methods have been available for many years and have stood the test possibly with modification and updating. They differ widely in approach, complexity and accuracy. But sometimes, when it comes to accuracy, no one method outperforms all others in all conditions. Statistical methods are based on measured and average losses along typical classes of radio links. Each of these models has advantages and disadvantages associated with each of them. Specifically, some baseline assumption are used with any propagation model and need to be understood prior to utilizing them. Most cellular operators use a version of Hata model for conducting propagation characterization. Neither of the prediction models used has been suitable for both urban, suburban and rural propagation in our experiment that means neither of models were accuracy enough for prediction of path loss in Dar es Salaam environs. From the results obtained, it is recommended that for accurate prediction of radio signal characteristics for cellular transmission, one of existing models needs to be adjusted if the cost for the field measurement is too high.

ACKNOWLEDGMENT

The authors would like to express their thanks to Clement Gasper, Mrs Anna Kisangiri, Roger, MIC Tanzania LTD for their valuable contribution to perform this work.

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