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Performance Analysis of Various Outdoor Propagation Path Loss Models for WiMax Wireless Network in Different Environments

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Abstract

In this paper, an analysis of six different path loss models has been done. The path loss models analyzed consists of the FSPL (Free Space Path Loss) model, COST 231 Hata model, ECC-33 (European Communication Conference) model, SUI (Stanford University Interim) model, Ericsson model and the COST 231 Walfish-Ikegami model. For analysis purpose different receiver antenna heights in urban, suburban and rural environments has been considered. We consider the operating frequency to be 2.5 GHz, suitable for the WiMax environment. After the analysis it was observed that different regions had different propagation models giving the optimum results. No one single model could be used for all the three different environments. The SUI model showed the lowest path loss in the urban environment. On the contrary, ECC-33 model showed the highest path loss and also showed huge fluctuations due to change of the receiver's antenna height. For the suburban environment SUI model was preferred as it showed the lowest path loss. The ECC-33 model showed the same path loss as like as urban environment because of the same parameters are used in the simulation. In flat or rural area, COST 231 Hata model showed the lowest path loss.

Keywords— Path loss models, Propagation models, WiMAX.

I. INTRODUCTION

Wireless mode of communication is basically preferred since it enables two distant people to exchange information without being physically connected. The term is commonly used in the industry of telecommunications. The devices such as transmitters or remote controls involve some form of energy. This energy can be in the form of radio waves or acoustic energy. Information is transferred in this manner over both short and long distances.

In wireless communication systems, the information transmitted between transmitter and receiver antenna involves the electromagnetic waves. The signal strength of this electromagnetic wave weakens during propagation [1]. The difference in the signal strength from transmitter to receiver antenna is termed as path loss. Path loss (PL) at destination is generally determined by the use of different models. These models can be stochastic, deterministic or empirical [2], [3], [4], [5], [6], [7]. The main reasons for the occurrence of path loss are free space, absorption, diffraction and multipath propagation [8], [9], [10], [11]. For different type of environment we have different propagation models. All of them were designed keeping in mind the specifications of a particular environment alone. The different types of environments considered are urban, suburban, and rural. In most of the models only the important parameters such as distance, carrier frequency and antenna heights are considered. The radio propagation models are found to be generally empirical in nature. It involves carrying out large number of calculations and depending upon the result a model is synthesized. By the use of a radio propagation model one can determine the expected behavior of the channel. Some of the basic empirical models give the exact behavior of a channel under a set of conditions. In 1945, Herald T. Friis [12], a Danish-American radio engineer, derived a formula known as the transmission equation. This equation is widely used to predict the power received by a receiving antenna, given the transmitting antenna is some distance away and is transmitting a known amount of power.

Similarly, in 1957 John Egli [13] introduced the Egli model which is a terrain model used for radio propagation. It was used for point-to-point link. This Egli model was formulated based on the real-world data on ultra high frequency (UHF) and very high frequency (VHF) television transmission. Okumura et al. in 1968 came out with prediction curves based on propagation measurement conducted in Kanto, Japan [14]. The Okumura model presents signal strength prediction curves over the distance in a quasi-smooth urban area where the terrain undulation is less than 20m. For other types of area classifications, correction factors are also given. This includes irregularities such as sloped terrain, hilly terrain, mixed land-sea path, and diffraction by ridges and mountains. In order to utilize the Okumura model, the parameters such as base station antenna height, terrain undulation height, slope, etc. must be determined according to [8].

The Hata model[15] developed in 1980 was an improvised version of the Okumura model. It involved computational simplifications. The Okumura-Hata model was developed based on the frequency 150 MHz to 1500 MHz [17]. Cooperate in Science and Technology (COST) 231 group in the early 1990's [10], took some measurements from several European cities. On the basis of the results they formulated several validated models. The COST-231 Hata, an extension to the Hata-Okumura model was widely used for predicting path loss in mobile wireless system. The COST-231 Hata used the frequency band from 1500 MHz to 2000 MHz. In recent developments, Chen and Kobayashi [15] proposed a linear regression approach in 2002 which was used to determine the parameters of wave propagation models for WLANs based on the measured signal strengths at test points. The regression model was then used to estimate signal strengths for unknown points. Apart from this, George Mason University (GMU) developed their own indoor-outdoor model in their campus in 2007. It was done to describe the 802.11 b/g path losses between an outdoor receiver and indoor transmitter. Several measurements were taken with indoor transmitters and outdoor receivers and path losses obtained from their measurements [16].

II. DESCRIPTION OF SELECTED MODELS

In a mobile communications system transmission often takes place over irregular terrain. The terrain profile of a particular area needs to be taken into account in order to estimate the path loss. The presence of objects such as trees, buildings, and other obstacle also must be taken into account. For this a number of propagation models are present that can be used for the estimation of the path loss. The models analyzed in this paper are mentioned in the following section.

FREE SPACE MODEL:-

The free-space propagation model is basically used when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. This helps to estimate the path loss in that environment. The simplest example of a free space propagation is satellite communication. Microwave line of sight radio links can also be categorized under free space propagation. The surface area of a sphere of radius d is $4\pi d^2$. Therefore, the power density w at distance d from a transmitter with power P_t and antenna gain G_t is given by:-

$$\mathbf{W = P_t G_t / (4\pi d)^2}$$

Similarly, the available power P_r at a receiver antenna with gain G_r is given by the Friis free space equations

$$\mathbf{W = P_t G_t G_r \lambda^2 / (4\pi d)^2}$$

where λ is the wavelength of operation and A is the effective area or `aperture' of the antenna, with $Gr = 4\pi A / \lambda^2$. The product P_tG_t is called the effectively radiated power (ERP) of the transmitter. In terms of the reference point d_o it can be expressed as

$$\mathbf{P_r(d)= P_r(d_o)[d_o/d]^2}$$

For indoor d_o=1m, Outdoor d_0= 100m to 1km
In order to compare the results of this model with the others we go for the logarithmic form of it that allows an easy analysis of the model. In the logarithmic form the path loss equation takes the below form

$$\mathbf{FSPL\ (dB) = 20\ log10\ (d) + 20\ log10\ (f) + 32.44}$$

Where, d is the distance of the receiver from the transmitter (km) and f is the signal frequency (MHz).

OKUMURA MODEL:-

The radio propagation model was proposed by Okumura in the city of Tokyo, Japan. The model was meant to be used in cities with many urban structures. The model however doesn't suit well for very tall structures.The model could be used for urban, suburban and open areas. Okumura's model is one of the simplest and best in terms of accuracy in prediction of the path loss. The model for the urban areas serves as the base for the other terrains such as the suburban and the rural areas. The Okumura model is considered to have a disadvantage and that is the inability to respond to rapid changes in the terrain. The model is therefore not preferred for rural areas. It gives decent results for the path loss in urban and suburban areas. Variation of about 10dB to 14dB is observed in the measured value as compared to the expected value of the path loss.
The coverage frequency of the Okumura model is from 150Mhz-1920Mhz. The mathematical formula of the model can be expressed as:

$$\mathbf{L= L_{FSL} + A_{MU} - H_{MG} - H_{BG} - \Sigma\ K_{correction}}$$

where,
L = The median path loss. Unit: Decibel (dB)
L_{FSL} = The Free Space Loss. Unit: Decibel (dB)
A_{MU}= Median attenuation. Unit: Decibel (dB)
H_{MG} = Mobile station antenna height gain factor.
H_{BG} = Base station antenna height gain factor.
$K_{correction}$= Correction factor gain (such as type of environment, water surfaces, isolated obstacle etc.)

HATA MODEL:-

The Hata model (Hat 90) was the improvised version of the Okumura model. It was a more empirical approach providing computational simplifications. The Hata model works for the loss equation for the urban area is taken as the reference and correction factor are introduced for the suburban and the rural areas. The standard formula for median path loss in urban areas is given by the following equation

$$\mathbf{L_{50}(dB) = 69.55 + 26.16log_{10}(f_c) - 13.82log_{10}(h_b) - a(h_{re}) + [44.9 - 66.5log_{10}(h_b)]log_{10}d + c_m}$$

Where, f_c is the frequency (in MHz) ranging from 150 MHz to 1500MHz and h_b is taken to be the effective transmitter (base station) antenna height (in meters) ranging from 30m to 200 m. Similarly, h_{re} is the effective receiver (mobile) antenna height (in meters) ranging from 1m to 10m, d is the T-R separation distance (in km), and c_m is the correction factor for effective mobile antenna height. The factor c_m is a function of the size of the coverage area. The correction factor for a small to medium sized city, is given by the following equation:-

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

Path loss for suburban clutter is:

$$\mathbf{L_{50}\ (suburban) = L_{50}\ (urban) - 2\{log_{10}\ (f_c / 28)\}^2 - 5.4}$$

Path loss for the open country is :

$$\mathbf{L_{50}(Open\ Country) = L_{50}\ (urban) - 4.78\{log\ (f_c)\}^2 + 18.33log\ (\ ) - 40.94}$$

The expressions provided by Hata has sufficient practical value although it might be missing out on path specific correction unlike the Okumura model. The results obtained from the Hata's model are very similar to the ones obtained from the Okumura's as long as the distance is greater than 1 km.

STANFORD UNIVERSITY INTERIM MODEL (SUI):-

The third model that has been used for comparison is the Stanford University Model. This model is based on the Comparative Study of Path Loss Models of WiMAX at 2.5GHz Frequency Band by Md. Didarul Alam and Md. Rezaul Huque Khan. It works well for the Multipoint Microwave Distribution System (MMDS) frequency band from 2.5GHz to 2.7GHz. The SUI model covers three common types of terrains. These terrains are categorized as terrain A, B and C. These are further classified as urban, suburban and rural areas. Terrain A basically gives the maximum path loss and is appropriate for hilly areas where the foliage densities ranges from moderate to heavy. Terrain B, is for mostly flat terrains with moderate to heavy tree densities or hilly terrains with light tree densities. The last category, Terrain C is basically for rural environment where the path loss is minimum. The foliage density in such terrain is also very less. The below expressions are taken into considerations:

$$\mathbf{L_p = A + 10\,\gamma\,\log_{10}(d/do) + X_f + X_h + s}$$

where, *s* is the log distributed factor having value between 8.2dB to 10.6dB. It considers the shadow fading due to trees and other obstacles. And A is given by,

$$\mathbf{A = 20\log_{10}(4\pi d_0/\lambda)}$$

where λ was obtained through the equation of (*c/f*) where *c* is the speed of light.

$$\mathbf{\gamma = a - bh_b + (c/h_b)}$$

where a is 3.6, b is 0.005 m-1 and c is 20 m. The correction factor for the frequency and the receiver antenna's height respectively can be expressed as X_f and X_h:

$$X_f = 6.0\log_{10}(f/2000)$$

$$\mathbf{X_h = -20.0\log_{10}(h_r/2000)} \text{ for terrain type C.}$$

ECC-33 MODEL:-

Like the Hata model, the ECC 33 path loss model, developed by Electronic Communication Committee (ECC), is an extrapolation of the data obtained from Okumura's model. It basically represents a fixed wireless access(FWA) system. This model works well for a frequency greater than 3GHz.. In this model path loss is given by

$$PL = A_{fs} + A_{bm} - G_b - G$$

where, A_{fs} is the Free space attenuation [dB] and A_{bm} is the basic median path loss [dB]. The gain factors for the transmitting and the receiving antenna respectively are G_b and G_r. The individual expressions for these factors can be given as:

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

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 20\log_{10}(f) + 9.56[\log_{10}(f)]^2$$

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

COST-231 WALFISCH IKEGAMI MODEL:-

This model is most suitable for flat suburban and urban areas with the height of the building being uniform. This model is a combination of two models proposed by J. Walfish and F. Ikegami. The equation of the proposed model can be given as:
For LOS the required condition is

$$PL_{LOS} = 42.6 + 26\log10(d) + 20\log10(f)$$

And for NLOS the required condition is

$$PL_{LOS} = L_{FSL} + L_{rst} + L_{msd} \text{ for urban and suburban } if\ L_{rst} + L_{msd} > 0 \text{ and } PL_{LOS} = L_{FSL} \text{ if } L_{rst} + L_{msd} < 0$$

Where,
L_{FSL}= Free space loss, L_{rst}= Roof top to street diffraction, L_{msd}= Multi-screen diffraction loss.
Free space loss will be given by

$$L_{FSL} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f)$$

Roof top to street diffraction can be given by the following expression

$$L_{rst} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f) + 20\log(H_{mobile})$$

Where d is the distance between transmitter and receiver antenna [m], f is the Frequency [GHz], w is the Street width [m] and is the Street orientation angel with respect to direct radio path in degrees.

$$L_{ori} = -10+0.354\varphi \text{ for } 0\leq \varphi\leq 35$$

$$2.5+0.075(\varphi-35) \text{ for } 35\leq\varphi\leq 55$$

$$4-0.114(\varphi-55) \text{ for } 55\leq\varphi\leq 90$$

The height distribution factor for the mobile and the base station can be given as

$$\Delta h_{mobile}=h_{roof}-h_{base}$$

$$\Delta h_{base}=h_{base}-h_{roof}$$

Environment	a_0	a_1	a_2	a_3
Urban	36.20	30.20	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.60	12.0	0.1

III. SIMULATION & RESULTS

In order to analyze the performance of various empirical propagation models such as the ECC-33 model, Hata Okumura extended Model, COST 231 Hata model, Stanford University Interim (SUI) Model and the Ericsson model, the MATLAB software has been used. Figs. 1 to 3 gives the results for different propagation models at frequencies 2300 MHz, 2600 MHz and 3500 MHz for different terrains. On analysis, it was observed that as the frequency increased, the path loss values decreased proportionally. For distances beyond 500 m, the path loss was confined between 110-160 dB.

Analysis of simulation results in urban area:-

For analysis purpose we have used 2 different antenna heights (i.e. 3 m and 10 m) for receiver. The distance between the transmitter and the receiver has been varied from 250 m to 5 km and transmitter antenna height is 40 m. The numerical results in urban area for different receiver antenna heights are shown in the **Fig. 1** and **Fig. 2**.

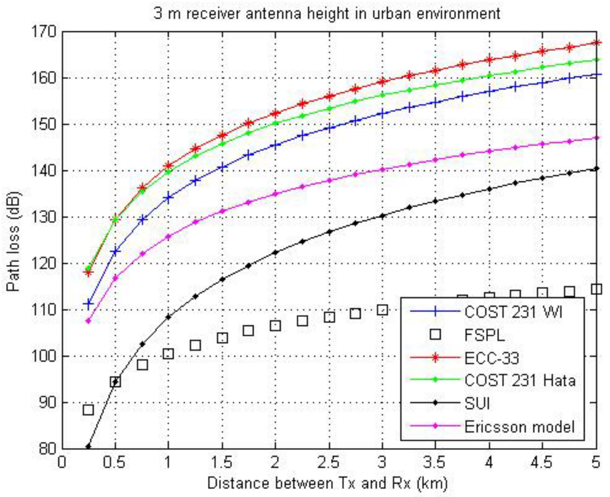

Fig 1. Path loss in urban environment at 3 m receiver antenna height.

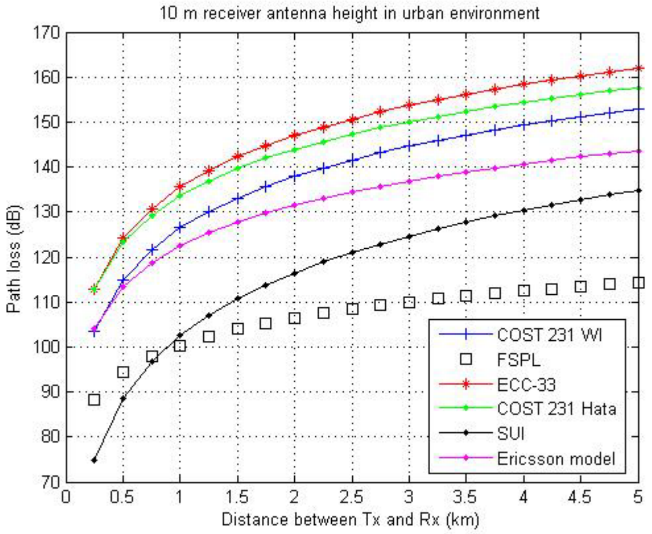

Fig 2. Path loss in urban environment at 10 m receiver antenna height.

From the results it can be seen that the SUI model showed the lowest prediction (126 dB to 120 dB) in urban environment. The fluctuations for the SUI model was the least as compared to other models when the receiver antenna height was changed. On the contrary, the ECC-33 model showed the heights path loss (158 dB) and also showed the highest fluctuations because of the change in receiver's antenna height. In this model, path loss is found to decrease when the receiver's antenna height increases. On the basis of this, increasing the receiver antenna heights will provide a high probability to find a better quality signal. The ECC-33 model showed the highest path loss at 10 m receiver antenna height.

Analysis of simulation results in suburban area:-

For the suburban area, we have used 2 different antenna heights (i.e. 3 m and 10 m) for receiver. The distance between the transmitter and the receiver is varied from 250 m to 5 km and the transmitter antenna height is 30 m. The numerical results for different models in the suburban area for different receiver antenna heights are shown in the **Fig. 3** and **Fig. 4**. These depict the effectiveness of the SUI model which gives the lowest path loss (120 dB to 115 dB) in this terrain with small fluctuations due to the variation in the receiving antenna's heights. Ericsson model showed the heights path loss (160 dB and 158 dB) prediction especially at 6 m and 10 m receiver antenna height. The COST-Walfisch Ikegami model gave moderate path loss with remarkable fluctuations of path loss with-respect-to antenna heights changes. This can be attributed to the fact that same parameters for simulation was used for suburban and the urban environment.

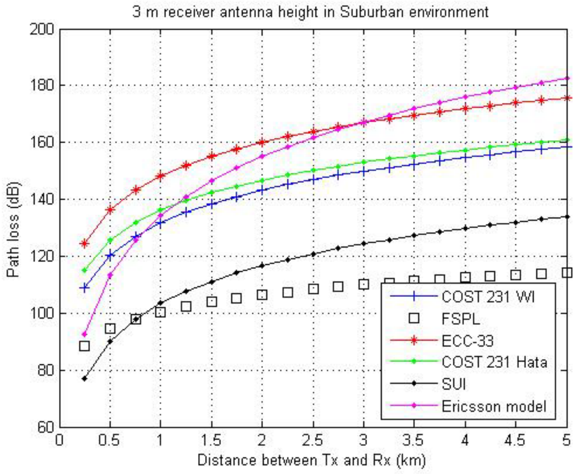

Fig 3. Path loss in suburban environment at 5 m receiver antenna height.

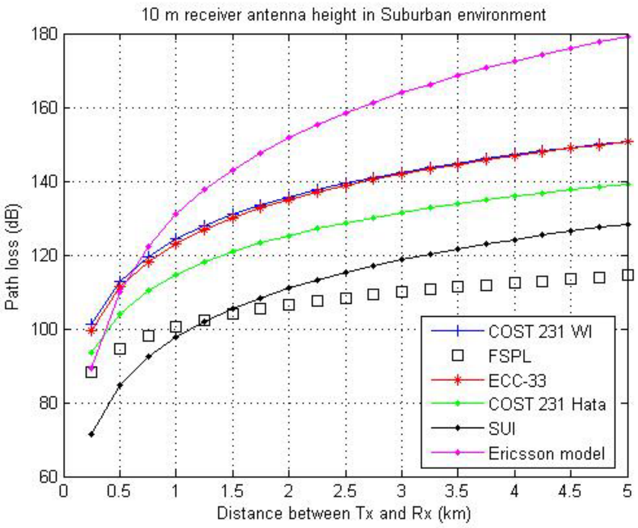

Fig 4. Path loss in suburban environment at 10 m receiver antenna height.

Analysis of simulation results in flat area:-

Same heights for the receiving antenna are used93m and 10m). The distance between the transmitter and the receiver varies from 250 m to 5 km and transmitter antenna height is 20 m. Since COST 231 W-I model has no particular parameters for the rural area, therefore we have considered a LOS equation. The results for varying antenna heights has been shown in **fig 5** and **fig 6**.

For the rural area the lowest path loss was obtained from the COST 231 Hata model. The result was even better as the receiving antenna height was increased to 10m from 3m. The COST 231 W-I model did not show much variation despite the change in the receiving antenna's height. In our simulation, we considered LOS equation for this environment. In a rural area the foliage density is very less. Thus, we may get a line of sight signal. Whereas, the Ericsson model showed the heights path loss, varying from (156 dB to 150 dB) as it can be seen from the graph

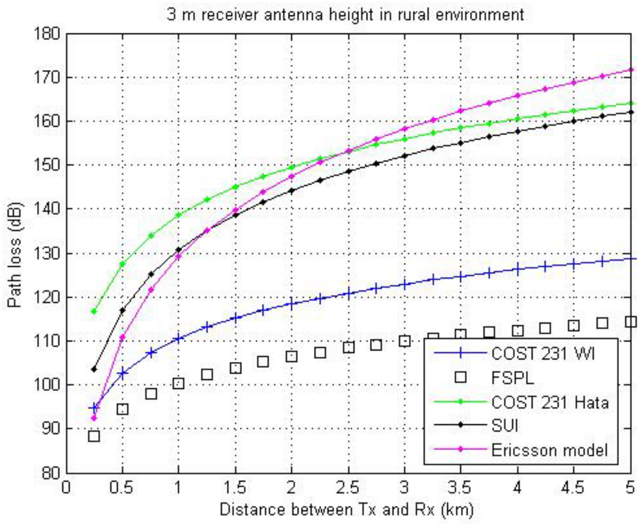

Fig 5. Path loss in rural environment at 3 m receiver antenna height.

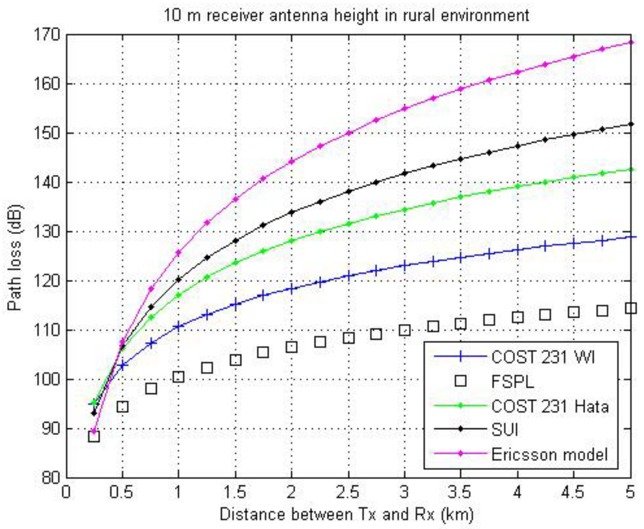

Fig 6. Path loss in rural environment at 10 m receiver antenna height.

IV. CONCLUSION

On a detailed analysis of the results for different propagation models it was observed that the SUI model experienced the lowest path loss. The other models experienced quite high path loss values due to the multipath propagation of the signal in a NLOS environment. However, SUI model experienced high path loss in an open area as compared to the urban and the suburban areas. The COST-Hata model was found to be more effective by providing low values of path loss at 10 m receiver antenna height. Since different environments have different properties, therefore no single model could be used for all the three types of environments undertaken for the research. However, there is a trade-off to be considered. If we increase the power of the transmitting antenna we may be able to increase the cell size and the coverage area may increase. But, it might also lead to an increment in the adjacent channel interference with the neighbouring cells. Similarly, if we try to reduce the path loss by reducing the transmission power then we might not be able to provide signal to all the users in the cell. The efficiency of the system will decrease. Users that are situated at the edges of the cell may not get proper signal or any signal at all.

Therefore, the challenge in front of us remains to minimize the path loss in an environment for a strong connection at the same time ensuring maximum coverage area and accommodating more users with a good quality of service.

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