AN ANALYTICAL STUDY FOR THE PERFORMANCE ANALYSIS OF PROPAGATION MODELS IN WiMAX

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Abstract: In this paper, we compare and analyze six different path loss models (i.e. FSPL model, COST 231 Hata model, ECC-33 model, SUI model, Ericsson model and COST 231 Walfish-Ikegami model) in different receiver antenna heights in urban, suburban and rural environments in NLOS condition for WiMAX. We consider Bangladesh as three regions such: Urban, Suburban, flat area and use operating frequency 2.5 GHz. Our observation shows that none of a single propagation model is well suited for all environments. SUI model showed the lowest prediction in urban environment. ECC-33 model showed the heights path loss and also showed huge fluctuations due to change of receiver antenna height. COST-Hata model showed the moderate result and 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, COST 231 Hata model showed the lowest path loss.

Keywords: MATLAB, Path loss models, Propagation models, WiMAX.

1. Introduction

One of the technologies that can lay the foundation for the next generation (*fourth generation* [4G]) of mobile broadband networks is popularly known as "WiMAX." WiMAX, *Worldwide Interoperability for Microwave Access,* is designed to deliver wireless broadband bitrates, with *Quality of Service* (QoS) guarantees for different traffic classes, robust security, and mobility. The term "Mobile WiMAX" is used to describe wireless systems based on the IEEE Standard 802.16e-2005, which is an amendment to the IEEE standard 802.16-2004 and is the best solution to provide BWA at same data rates offered by DSL etc. Broadband Wireless Access (BWA) systems have potential operation benefits in Line-of-sight (LOS) and Non-line-of-sight (NLOS) conditions, operating below 11 GHz frequency. During the initial phase of network planning, propagation models are extensively used for conducting feasibility studies. Propagation models are used for calculation of electromagnetic field strength for the purpose of wireless network planning during preliminary deployment. It describes the signal attenuation from transmitter to receiver antenna as a function of distance, carrier frequency, antenna heights and other significant parameters like terrain profile. There are numerous propagation models available to predict the path loss but they are inclined to be limited to the lower frequency bands (up to 2 GHz). The contribution to this paper undergoes the comparison and analysis of five path loss models which have been proposed for frequency at 2.5 GHz in urban and suburban and rural environments in different receiver antenna heights.

1.1 Related Studies

Models such as the Harald.T. Friis free space model is used to predict the signal power at the receiver end when transmitter and receiver have line-of-sight condition. The classical Okumura model is used in urban, suburban and rural areas for the frequency range 200 MHz to 1920 MHz for initial coverage deployment. A developed version of Okumura model is Hata-Okumura model known as Hata model which is also extensively used for the frequency range 150 MHz to 2000 MHz in a build up area. Several performance evaluation and analysis have been presented in the literature. Comparison of path loss models for 3.5 GHz has been investigated by many researchers in many respects. In Cambridge, UK from September to December 2003, the FWA network researchers investigated some empirical propagation models [1] in different terrains as function of antenna height parameters. Another measurement was taken by considering LOS and NLOS conditions at Osijek in Croatia during spring 2007 [2]. Coverage and throughput prediction were considered to correspond to modulation techniques in Belgium [3]. September 1981, M. Hata, investigate some empirical formula for propagation loss in land mobile radio services [4] in Sweden. The Path loss models [5] have also been used for a comparison between these models. In this paper, different receiver antennas have been used during the measurement campaign and the results have been compared. We also describe various accurate path loss prediction methods [6] used both in rural and urban environments. The Walfisch-Bertoni and Hata models, which are both used for UHF propagation in urban areas, were chosen for a detailed comparison. The comparison shows that the Walfisch-Bertoni model, which involves more parameters, agrees with the Hata model for the overall path loss. In Malaysia, May 2007, this paper deals with the performance of WiMAX networks in an Outdoor environment using the SUI channel models [7].

1.2 Aims and Objectives

Today the challenge is how to predict the path loss at the cellular frequency of 2.5 GHz. There are several empirical propagation models which can precisely calculate up to 2 GHz. But beyond 2 GHz,
there are few reliable models which can be referred for the WiMAX context. There are few proposed models [1]-[4], which focus on frequency range at 2.5 GHz out of which we base our analysis. In this paper, we compare and analyze path loss behavior for some proposed models at 2.5 GHz frequency band. Our research goal is to identify a suitable model in different environments by applying suitable transmitter and receiver antenna heights. Thus, a network engineer may consume his/her time by using our referred model for deploying the initial planning in different terrains.

2. Models for propagation under consideration

In our thesis, we analyze six different models and also consider free space path loss model which is most commonly used idealistic model. We take it as our reference model; so that it can be realized how much path loss occurred by the others proposed models.

2.1 Free Space Path Loss Model (FSPL)

In telecommunication, free-space path loss (FSPL) is the loss in signal strength of an electromagnetic wave that would result from a line-of-sight path through free space, with no obstacles nearby to cause reflection or diffraction. Free-space path loss is proportion to the square of the distance between the transmitter and receiver, and also proportional to the square of the frequency of the radio signal. The equation for FSPL is

$$\mathrm{FSPL} = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi df}{c}\right)^2 \qquad (1)$$

Where:

λ is the signal wavelength (in meters), f is the signal frequency (in hertz), d is the distance from the transmitter (in meters), c is the speed of light in a vacuum, 2.99792458×10^8 meters per second.

This equation is only accurate in the far field; it does not hold close to the transmitter. If the separation d is continually decreased, eventually the received power appears greater than the transmitted power which is [obviously] impossible in reality, since free space is not an amplifier.

Free-space path loss in decibels a convenient way to express FSPL is in terms of dB:

$$\mathrm{FSPL(dB)} = 10\log_{10}\left(\left(\frac{4\pi}{c}df\right)^2\right)$$
$$= 20\log_{10}(d) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) \qquad (2)$$

where the units are same as before.

For typical radio applications, it is common to find f measured in units of MHz and d in km, in which case the FSPL equation becomes

$$\mathrm{FSPL\ (dB)} = 20\log_{10}(d) + 20\log_{10}(f) + 32.45 \qquad (3)$$

For d in statute miles, the constant becomes 36.58.

2.2 cost 231 hata model

The Hata model is introduced as a mathematical expression to mitigate the best fit of the graphical data provided by the classical Okumura model to predict the path loss in the frequency range 1500 MHz to 2000 MHz. COST 231 Hata model is initiated as an extension of Hata model. The basic path loss equation for this COST-231 Hata Model can be expressed as:

$$\mathrm{PL} = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_b) - ah_m + (44.9 - 6.55\log_{10}(h_b))\log_{10} d + c_m \qquad (4)$$

Where

d: Distance between transmitter and receiver antenna [km], f: Frequency [MHz], h_b: Transmitter antenna height [m].

The parameter c_m has different values for different environments like 0 dB for suburban and 3 dB for urban areas and the remaining parameter ah_m is defined in urban areas as:

$$ah_m = 3.20(\log_{10}(11.75h_r))^2 - 4.79, \quad \text{for } f > 400\ \text{MHz} \qquad (5)$$

The value for ah_m in suburban and rural (flat) areas is given as:

$$ah_m = (1.11\log_{10} f - 0.7)h_r - (1.5\log_{10} f - 0.8) \qquad (6)$$

Where the h_r is the receiver antenna height in meter.

2.3 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 model. 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. The basic path loss expression of the SUI model with correction factors is presented as:

$$\mathrm{PL} = \mathrm{A} + 10\gamma \log_{10}\left(\frac{\mathrm{d}}{\mathrm{d_o}}\right) + \mathrm{X_f} + \mathrm{X_h} + \mathrm{S}$$

$$\text{For } \mathrm{d} > \mathrm{d_o} \tag{7}$$

Where the parameters are

d: Distance between BS and receiving antenna [m], λ: Wavelength [m], d_o: 100 [m], d_o: 100 [m], X_f : Correction for frequency above 2 GHz [MHz], X_h : Correction for receiving antenna height [m], S: Correction for shadowing [dB], γ: Path loss exponent.

The parameter A is defined as

$$A = 20\log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \tag{8}$$

And the path loss exponent γ is given by

$$\gamma = a - bh_b + \left(\frac{c}{h_b}\right) \tag{9}$$

Where, the parameter h_b is the base station antenna height in meters. This is between 10 m and 80 m. 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.

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

$$X_f = 6.0\log_{10}\left(\frac{f}{2000}\right) \tag{10}$$

$$X_h = \begin{cases} -10.8\log_{10}\left(\frac{h_r}{2000}\right), \text{for terrain type A and B} \\ -20\log_{10}\left(\frac{h_r}{2000}\right), \text{for terrain type C} \end{cases} \tag{11}$$

Where, f is the operating frequency in MHz, and h_r is the receiver antenna height in meter. 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.

2.4 Hata-Okumura extended model or ECC-33 Model

An extrapolated method is applied to predict the model for higher frequency greater than 3 GHz. In this model path loss is given by

$$PL = A_{fs} + A_{bm} - G_b - G_r \tag{12}$$

A_{fs}: Free space attenuation [dB], A_{bm}: Basic median path loss [dB], G_b: Transmitter antenna height gain factor, G_r: Receiver antenna height gain factor.

These factors can be separately described and given by as

$$A_{fs} = 92.4 + 20\log_{10}(d) + 20\log_{10}(f) \tag{13}$$

$$A_{bm} = 20.41 + 9.83\log_{10}(d) + 20\log_{10}(f) + 9.56[\log_{10}(f)]^2 \tag{14}$$

$$G_b = \log_{10}\left(\frac{h_b}{200}\right)\{13.958 + 5.8[\log_{10}(d)]^2\} \tag{15}$$

When dealing with gain for medium cities, the G_r will be expressed in

$$G_r = [42.57 + 13.7\log_{10}(f)][\log_{10}(h_r) - 0.585] \tag{16}$$

For large city

$$G_r = 0.759h_r - 1.862 \tag{17}$$

Where

d: Distance between transmitter and receiver antenna [km], f: Frequency [GHz], h_b: Transmitter antenna height [m], h_r: Receiver antenna height [m].

This model is the hierarchy of Okumura-Hata model.

2.5 COST 231 Walfish-Ikegami (W-I) Model

This model is a combination of J. Walfish and F. Ikegami model. This model is most suitable for flat suburban and urban areas that have uniform building height. The equation of the proposed model is expressed in:

For LOS condition

$$PL_{LOS} = 42.6 + 26\log_{10}(d) + 20\log_{10}(f) \quad (18)$$

And for NLOS condition

$$PL_{LOS} = \begin{cases} L_{FSL} + L_{rst} + L_{msd} & \text{for urban and suburban} \\ L_{fs} & if\ L_{rst} + L_{msd} > 0 \end{cases} \quad (19)$$

Where

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

Free space loss

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

Roof top to street diffraction

$$L_{rst} = \begin{cases} -16.9 - 10\log(w) + 10\log(f) + 20\log(H_{mobile}) + L_{ori} \\ 0 \end{cases} \quad H_{roof > H_{mobile}} \quad (21)$$

where

$$L_{ori} = \begin{cases} -10 + 0.354\varphi & \text{for } 0 \le \varphi \le 35 \\ 2.5 + 0.075(\varphi - 35) & \text{for } 35 \le \varphi \le 55 \\ 4 - 0.114(\varphi - 55) & \text{for } 55 \le \varphi \le 90 \end{cases} \quad (22)$$

Note that

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

where

d: Distance between transmitter and receiver antenna [m], f: Frequency [GHz], w: Street width [m], φ: Street orientation angel w.r.t. direct radio path [degree].

In our simulation, we use the following data, i.e. building to building distance 50 m, street width 25 m, street orientation angel 30 degree in urban area and 40 degree in suburban area and average building height 15 m, base station height 30 m.

2.6 Ericsson Model

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

$$PL = a_0 + a_1.\log_{10}(d) + a_2\,.\log_{10}(h_b) + a_3.\log_{10}(h_b)\,.\log_{10}(d) - 3.2(\log_{10}(11.75h_r)^2) + g(f) \quad (23)$$

Where $g(f)$ is defined by

$$g(f) = 44.49\log_{10}(f) - 4.78(\log_{10}(f))^2 \quad (24)$$

And parameters

f: Frequency [MHz], h_b: Transmission antenna height [m], h_r: Receiver antenna height [m].

3. SIMULATION ENVIRONMENT & DESIGN

For analyzing the performance of propagation models for WiMAX, we have used MATLAB software package. For evaluating and analyzing the performance of WiMAX propagation models I have used MATLAB simulation. A typical simulation model is shown in **Fig. 1**.

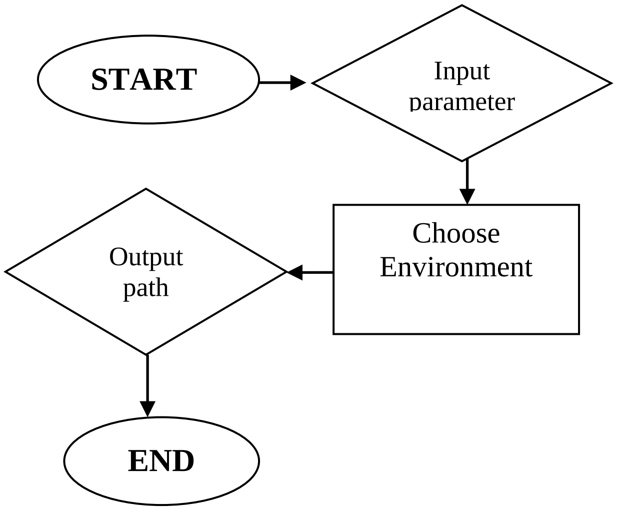

Fig. 1: Simulation process flow chart for three different environments.

Simulation Parameters: The following **Table 1** presents the parameters we applied in our simulation.

Table 1: Simulation parameters

Parameters	Values
Transmitter antenna height	40 m in urban and 30 m in suburban and 20 m in rural area
Receiver antenna height	3 m, 6 m and 10 m
Operating frequency	2.5 GHz
Distance between Tx-Rx	5 km
Building to building distance	50 m
Average building height	15 m
Street width	25 m
Street orientation angle	30^0 in urban and 40^0 in suburban
Correction for shadowing	8.2 dB in suburban and rural and 10.6 dB in urban area

4. Performance analysis & discussion

4.1 Analysis of simulation results in urban area

In our calculation, we set 2 different antenna heights (i.e. 3 m and 10 m) for receiver, distance varies from 250 m to 5 km and transmitter antenna height is 40 m. The numerical results for different models in urban area for different receiver antenna heights are shown in the **Fig. 2** and **Fig. 3**.

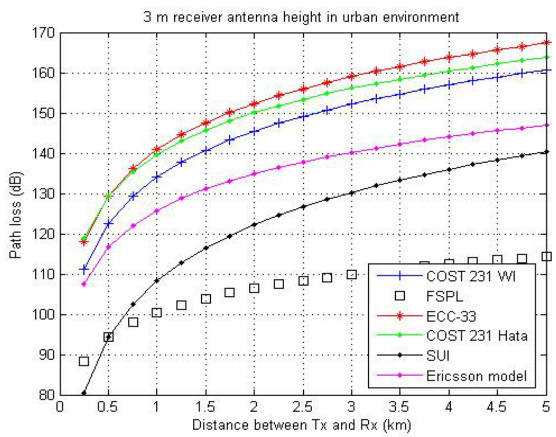

Fig. 2: Path loss in urban environment at 3 m receiver antenna height.

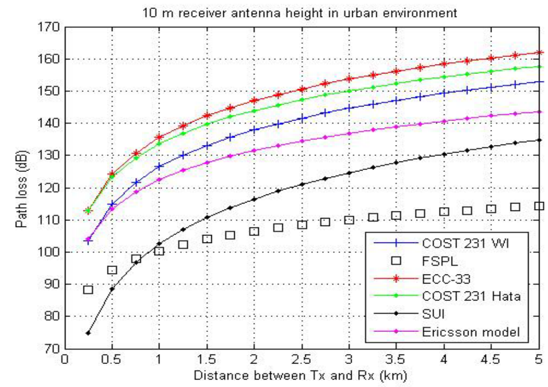

Fig. 3: Path loss in urban environment at 10 m receiver antenna height.

Our simulation result exhibits that SUI model showed the lowest prediction (128 dB to 121 dB) in urban environment. It also showed the lowest fluctuations compare to other models when we changed the receiver antenna heights. In that case, the ECC-33 model showed the heights path loss (156 dB) and also showed huge fluctuations due to change of receiver antenna height. In this model, path loss is decreased when increased the receiver antenna height. Increase the receiver antenna heights will provide the more probability to find the better quality signal from the transmitter. ECC-33 model showed the biggest path loss at 10 m receiver antenna height.

4.2 Analysis of simulation results in suburban area

In our calculation, we set 3 different antenna heights (i.e. 3 m and 10 m) for receiver, distance varies from 250 m to 5 km and transmitter antenna height is 30 m. The numerical results for different models in urban area for different receiver antenna heights are shown in the **Fig. 4** and **Fig. 5**.These represent us that the SUI model predict the lowest path loss (121 dB to 116 dB) in this terrain with little bit flections at changes of receiver antenna 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-WI model showed the moderate result with remarkable fluctuations of path loss with-respect-to antenna heights changes. The ECC-33 model showed the same path loss as like as urban environment because of same parameters are used in the simulation.

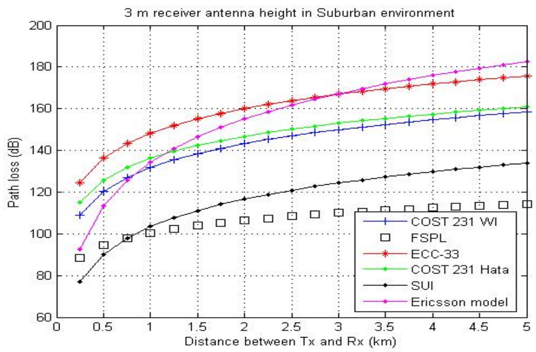

Fig. 4: Path loss in suburban environment at 3 m receiver antenna height.

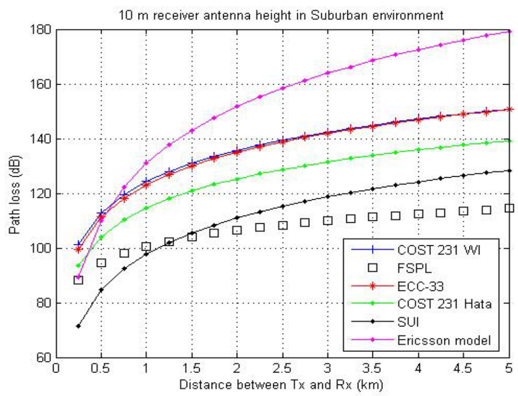

Fig. 5: Path loss in suburban environment at 10 m receiver antenna height.

4.3 Analysis of simulation results in flat area

we set 3 different antenna heights (i.e. 3 m and 10 m) for receiver, distance varies from 250 m to 5 km and transmitter antenna height is 20 m. COST 231 W-I model has no specific parameters for rural area, we consider LOS equation provided by this model The numerical results for different models in urban area for different receiver antenna heights are shown in the **Fig. 6** and **Fig. 7**.

In this environment COST 231 Hata model showed the lowest path loss (132 dB) prediction especially in 10 m receiver antenna height. COST 231 W-I model showed the flat results in all changes of receiver antenna heights. There are no specific parameters for rural area. In our simulation, we considered LOS equation for this environment (the reason is we can expect line of sight signal if the area is flat enough with less vegetation). Ericsson model showed the heights path loss (154 dB to 150 dB).

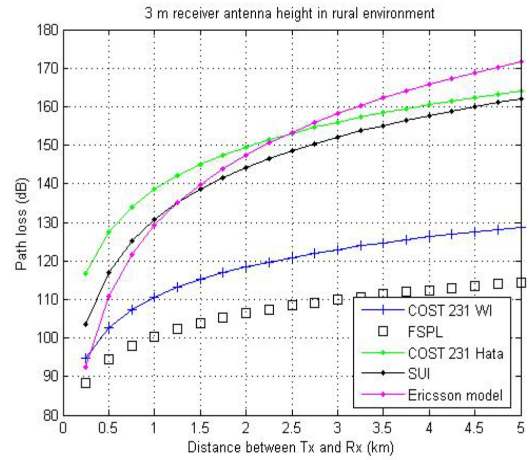

Fig. 6: Path loss in rural environment at 3 m receiver antenna height.

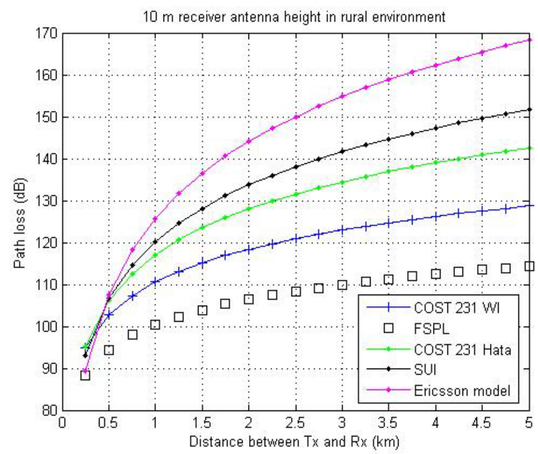

Fig. 7: Path loss in rural environment at 10 m receiver antenna height.

5. Conclusion

Our comparative analysis indicate that due to multipath and NLOS environment in urban and suburban area, SUI models experiences lowest path losses compare to flat area. In flat area COST-Hata model provide lowest path loss than SUI model at 10 m receiver antenna height. Moreover, we did not find any single model that can be recommended for all environments.

If we consider the worst case scenario for deploying a coverage area, we can serve the maximum coverage by using more transmission power, but it will increase the probability of interference with the adjacent area with the same frequency blocks. On the other hand, if we consider less path loss model for deploying a cellular region, it may be inadequate to serve the whole coverage area. Some users may be out of signal in the operating cell especially during mobile condition. So, we have to trade-off between transmission power and adjacent frequency blocks interference while choosing a path loss model for initial deployment.

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