Comparative Study of Path Loss Models of WiMAX at 2.5 GHz Frequency Band

Md. Didarul Alam[1] and Md. Rezaul Huque Khan[2]

Department of Applied Physics, Electronics and Communication Engineering
University of Chittagong, Chittagong-4331, Bangladesh
didar.apece@cu.ac.bd, rhkcu@yahoo.com

Abstract

Correct prediction of path loss is a pivotal step of WiMAX network planning to estimate external interference level and cell radius accurately. In this paper, different path loss models are compared depending on various parameters like frequency, height of receiver antenna, distance between transmitter and receiver etc. For comparative analysis, COST 231 Hata model, COST 231 Walfisch-Ikegami model, Stanford University Interim (SUI) model, Ericsson model, ECC-33 model and Free Space Path Loss models are used in three different environments (Urban, Suburban and Rural environments). After analyzing the results, it is found that no single model is suited or recommended for all types of propagation environments at 2.5 GHz frequency band.

Keywords: *WiMAX, Path loss, Stanford University Interim (SUI) model, ECC-33 model, Ericsson model, Hata model*

1. Introduction

In wireless communication, loss that occurs in between transmitter and receiver is known as propagation path loss. We measure this path loss in different areas like rural, urban, and suburban with the help of propagation path loss models. These models can be broadly categorized into three types; empirical, deterministic and stochastic. Empirical models are 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 [1]. 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 complete 3-D map of the propagation environment. An example of a deterministic model is ray tracing model [2]. Stochastic models, on the other hand, model the environment as a series of random variables. These models are least accurate but require least information about the environment and use much less processing power to generate predictions. Empirical models can be split into two subcategories namely, time dispersive and non-time dispersive [3, 4].

In this paper, a few path loss models have been studied in Section 2. Then path loss is estimated for three types of environments using MATLab. Some parameters like frequency, distance between transmitter and receiver antenna, base station height, height of buildings, building separation, width of roads, road orientation angle *etc.*, are used for comparison.

2. Path Loss Models

In WiMAX system, transfer of information between the transmitting antenna and the receiving antenna is achieved by means of electromagnetic waves. The interaction between the electromagnetic waves and the environment reduces the strength of the signal sent from transmitter to receiver that causes path loss. There are different models to calculate path loss. Some of them are described and compared in this paper [5].

2.1 Free Space Path Loss (FSPL) Model

Path loss in free space PL_{FSPL} defines how much strength of the signal is lost during propagation from transmitter to receiver. FSPL model is diverse on frequency and distance. The calculation is done by using the following equation [6]:

$$PL_{FSPL} = 32.45 + 20\log_{10}(d) + 20\log_{10}(f)$$

Where, f is frequency in MHz, d is the distance between transmitter and receiver in meter.

2.2 COST 231 Hata Model

The Hata model [7] is introduced as a mathematical expression to mitigate the best fit of the graphical data provided by the classical Okumura model. Hata model is used for the frequency range of 150 MHz to 2000 MHz to predict the median path loss. 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 path loss equation for this COST-231 Hata Model can be expressed as [8]:

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

Where, h_b is transmitter antenna height in meter.

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 [8]:

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

The value of ah_m in suburban and rural (flat) areas is given by:

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

Where, h_r is the receiver antenna height in meter.

2.3 ECC-33 Model

Recently, through the ITU-R Recommendation P.529, the International Telecommunication Union (ITU) encouraged Hata-Okumura model for further extension up to 3.5 GHz [9]. The tentatively proposed propagation model of Hata-Okumura model with report is referred to as ECC-33 model or Electronic Communication Committee model. In this model path loss is given by [8]:

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

Where, A_{fs} is free space attenuation in dB, A_{bm} is basic median path loss in dB, G_b is transmitter antenna height gain factor and G_r is receiver antenna height gain factor.

These factors can be separately described and given by as:

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

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

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

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]

For large city

G_r= 0.759h_r-1.892

Where, d is the distance between transmitter and receiver antenna in Km, f is frequency in GHz, h_b is transmitter antenna height in meter and h_r is receiver antenna height in meter.

This model is the hierarchy of Okumura-Hata model. So the urban area is also subdivided into “large city” and “medium city”, as the model was formed in the Tokyo city having crowded and tallest buildings. In my analysis, I considered the medium city model is appropriate for the cities of Bangladesh.

2.4 COST 231 Walfisch-Ikegami Model

This model is a combination of J. Walfisch and F. Ikegami model. The COST 231 project further developed this model. Now it is known as COST 231 Walfisch-Ikegami model. It distinguishes different terrain with different proposed parameters. The equation of the proposed model is expressed in [6]:

For line-of-sight (LOS) condition,

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

And for nonline-of-sight (NLOS) condition,

PL_{NLOS}=L_{FSL}+L_{rts}+L_{msd} for urban and suburban

PL_{NLOS}=L_{FSL} if L_{rts+} L_{msd}>0

Where, L_{FSL} is free space loss, L_{rts} is roof top to street diffraction and L_{msd} is multi-screen diffraction loss.

Free space loss:

L_{FSL}=32.45+20log (d) +20log (f)

roof top to street diffraction :

L_{rts}= -16.9-10$\log_{10}$ (w) +10$\log_{10}$ (f) +20$\log_{10}$ (Hmobile) +L_{ori}

= 0 for h_{roof}> h_{mobile}

L_{ori}= -10+0.345 Φ for 0< Φ<35

= 2.5+0.075 (Φ-35) for 35< Φ<55

= 4-0.114 (Φ-55) for 55< Φ<90

Note that

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

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

The multi-screen diffraction loss is:

$L_{msd} = L_{bsh} + k_a + k_d \log_{10}(d) + k_f \log_{10}(f) - 9\log_{10}(f) - 9\log_{10}(B)$ for $L_{msd} > 0$

$= 0$ for $L_{msd} < 0$

Where,

$L_{bsh} = -18\log_{10}(1 + \Delta h_{base})$ for $h_{base} > h_{roof}$

$= 0$ for $h_{base} < h_{roof}$

$k_a = 54$ for $h_{base} > h_{roof}$

$= 54 - 0.8\,\Delta h_{base}$ for $d > 0.5$ Km and $h_{base} < h_{roof}$

$= 54 - 0.8\Delta h_{base}(d/0.5)$ for $d < 0.5$ Km and $h_{base} < h_{roof}$

$k_d = 18$ for $h_{base} > h_{roof}$

$= 18 - 15(h_{base}/h_{roof})$ for $h_{base} < h_{roof}$

$k_f = -4 + 0.7((f/925) - 1)$ for suburban or medium size cities with moderate tree density

$= -4 + 1.5((f/925) - 1)$ for metropolitan or urban area

Where, d is the distance between transmitter and receiver antenna in meter, f is frequency in GHz, B is building to building distance in meter, w is street width in meter, Φ is street orientation angel w.r.t. direct radio path in degree.

2.5 Stanford University Interim (SUI) Model

The frequency bands below 11 GHz use the channel model which is proposed by Stanford University Interim (SUI) model. This model is derived for the Multipoint Microwave Distribution System (MMDS) frequency band from 2.5 GHz to 2.7 GHz. The model covers three most common terrain categories. This model is recommended by IEEE 802.16 Broadband Wireless Access Working Group [11]. The basic path loss formula with correction factors is given as: [6, 10]

$PL = A + 10\,\gamma \log_{10}(d/d_0) + X_f + X_h + s$ for $d > d_0$

Where, d is the distance between Access Point (AP) antenna and customer premises equipment antenna in meter, d_0=100m and s is a log distributed factor that is used to account the effect for the shadow fading owing to trees and other obstacles having value between 8.2 dB and 10.6 dB.

The parameter A is defined as:

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

and the path loss exponent γ is given by:

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

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 1. The value of parameter γ is 2 for free space propagation in an urban area, $3 < \gamma < 5$ for urban NLOS environment, and $\gamma > 5$ for indoor propagation [12].

Table 1. The Parameter Values of Different Terrains for SUI Model [8]

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

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

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

$X_h = -10.8 \log_{10}(h_r/2000)$ for terrain type A and B

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

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

2.6 Ericsson Model

To predict path loss, network planning engineers used software provided by Ericsson Company based on a model called Ericsson model. This model also stands on the modified Hata-Okumura model to allow room for changing in parameters according to the propagation environments. Path loss according to this model is given by [12]:

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

Where, g(f) is defined by:

$g(f) = 44.49 \log10(f) - 4.78(\log(f))^2$

Where, f is the frequency in GHz, h_b is transmitter antenna height and h_r is receiver antenna height in meter.

The default values of these parameters (a_0, a_1, a_2 and a_3) for different terrains are given in Table 2.

Table 2. Values of Parameters for Ericsson Model [11]

Environment	a_0	a_1	a_2	a_3
Urban	36.2	30.2	12.0	0.1
Suburban	43.20	68.93	12.0	0.1
Rural	45.95	100.6	12.0	0.1

The values of parameters a_0 and a_1 in suburban and rural areas are based on the Least Square (LS) method [13].

3. Results and Discussion

In Bangladesh, as the WiMAX service providers are operating at 2.5 GHz frequency band, I choose to predict path loss of WiMAX signal at this frequency band. The desired WiMAX transmitter to receiver distance is varied upto 5 Km and the carrier frequency is set to 2.5 GHz. Here, three different receiver antenna heights (3 m, 6 m, 10 m) have been considered. I selected three different areas, *e.g.*, Chawkbazar, Mohra (Fultola), and patiya (Uzirpur) as urban, suburban and rural environments respectively to collect certain parameters because these areas meet the requirements to be urban, suburban and rural areas. Chawkbazar is an area having closely spaced buildings that range up to 8 stories in height, street grids, hills, billboards and other obstacles. Fultola, Mohra is an area associated with moderately spaced one-to-four story buildings, trees *etc.* while Uzirpur is a rural area of Patiya with few buildings separated by significant distance, rice-fields, farm-lands, trees and mostly open space. As the structural layouts of these areas are not uniform, I utilized cross-check method to evaluate these areas in terms of parameters. The models that I worked with provided two different conditions, *i.e.*, LOS and NLOS. I used FSPL model as a reference model in this paper. Some parameters used in these models like frequency, transmitter antenna height, receiver antenna height *etc.*, are collected from Banglalion Communications Ltd., [14]. The following table presents the parameters applied in simulation for three different environments.

Table 3. Simulation Parameters

Parameters	Urban	Suburban	Rural
Transmitter antenna height	30 m	30 m	20 m
Receiver antenna height	3 m,6 m, 10 m	3 m,6 m, 10 m	3 m,6 m, 10 m
Operating frequency	2.5 GHz	2.5 GHz	2.5 GHz
Distance between transmitter and receiver	5 Km	5 Km	5 Km
Average building height	15 m	12 m	6 m
Street width	10 m, 12 m, 18 m	10 m, 12 m	10 m
Building to building separation	1.5 m	4.5 m	Not applicable
Street orientation angle	30 degree	40 degree	Not applicable
Correction for shadowing	10.6 dB	8.2 dB	Not applicable

3.1 Performance Analysis of Simulation Results in Urban Environment

Three different receiver antenna heights are used for calculation of path loss, with a varying distance between transmitter and receiver. The numerical results for different models in urban area for different receiver antenna heights are illustrated in Figures 1, 2 and 3.

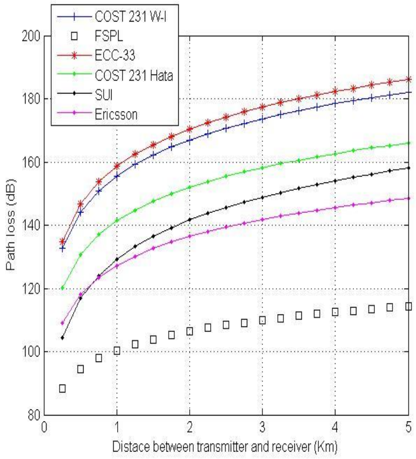


Figure 1. Path Loss in Urban Environment at 3 m Receiver Antenna Height

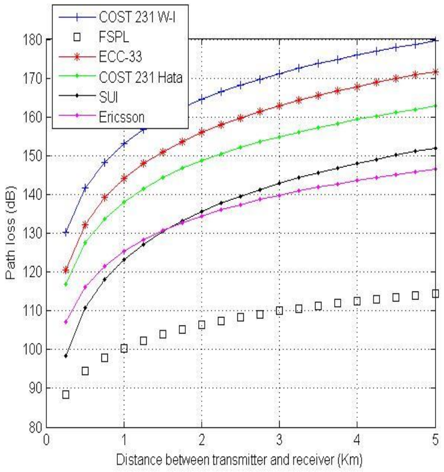


Figure 2. Path Loss in Urban Environment at 6 m Receiver Antenna Height

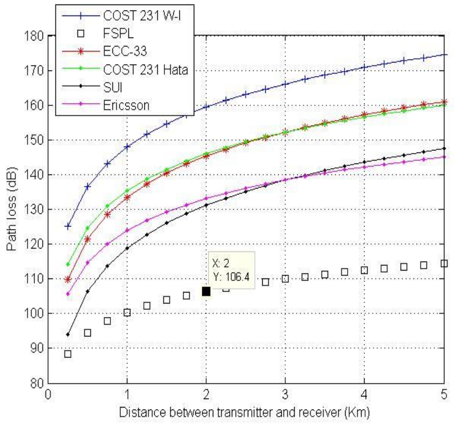
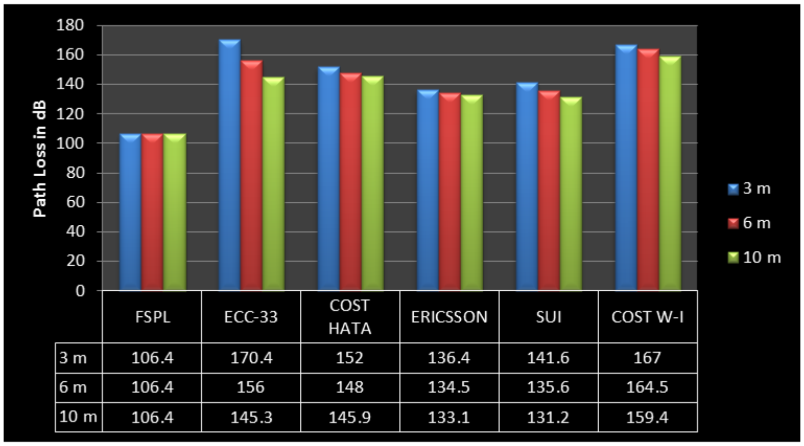


Figure 3. Path Loss in Urban Environment at 10m Receiver Antenna Height

The bar chart in Figure 4 illustrates the simulation result in urban area for three different receiver antenna heights. Based on the comparison among the propagation models, the lowest path loss is predicted by Ericsson model for the same set of parameters. The fluctuation of path loss with respect to receiver antenna heights is also the lowest for this model. In contrary, COST W-I model shows highest path loss at 3 m and 6 m receiver antenna heights while ECC-33 model forecasts the highest at 10 m receiver antenna heights and in addition, the highest fluctuation of path loss compared to other models. As increased receiver antenna height provides higher probability to find out LOS condition of signal from transmitter to receiver, path loss decreases with increasing receiver antenna height for all the models.



	FSPL	ECC-33	COST HATA	ERICSSON	SUI	COST W-I
3 m	106.4	170.4	152	136.4	141.6	167
6 m	106.4	156	148	134.5	135.6	164.5
10 m	106.4	145.3	145.9	133.1	131.2	159.4

Figure 4. Analysis of Simulation Results in Urban Environment at a Reference Distance of 2 km for Different Receiver Antenna Heights

3.2 Performance Analysis of Simulation Results in Suburban Environment

The numerical results for different models in suburban area for different receiver antenna heights are shown in Figures 5, 6 and 7; where the receiver antenna heights are kept the same as in urban environment.

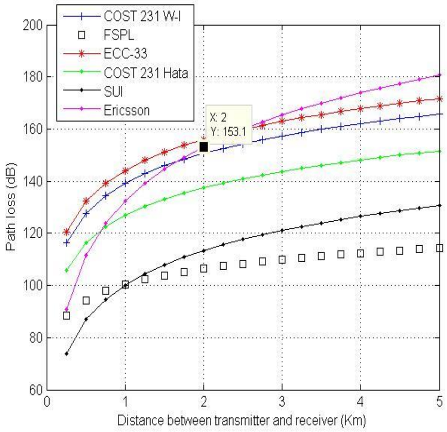


Figure 5. Path loss in Suburban Environment at 3 m Receiver Antenna Height

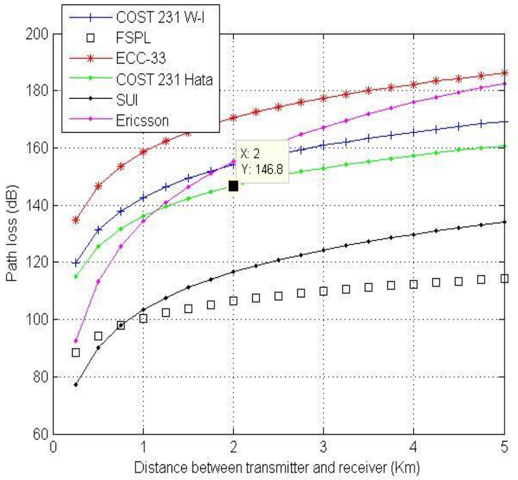


Figure 6. Path Loss in Suburban Environment at 6 m Receiver antenna height

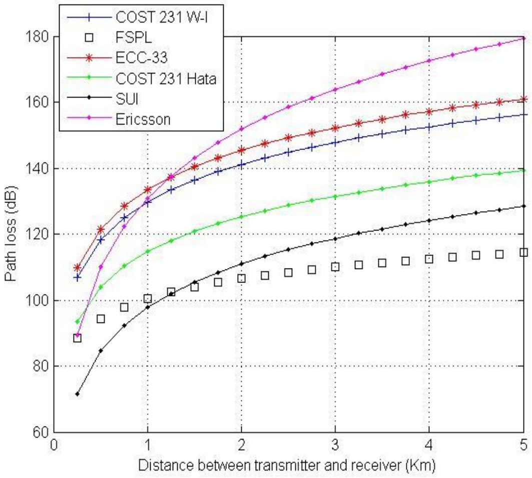
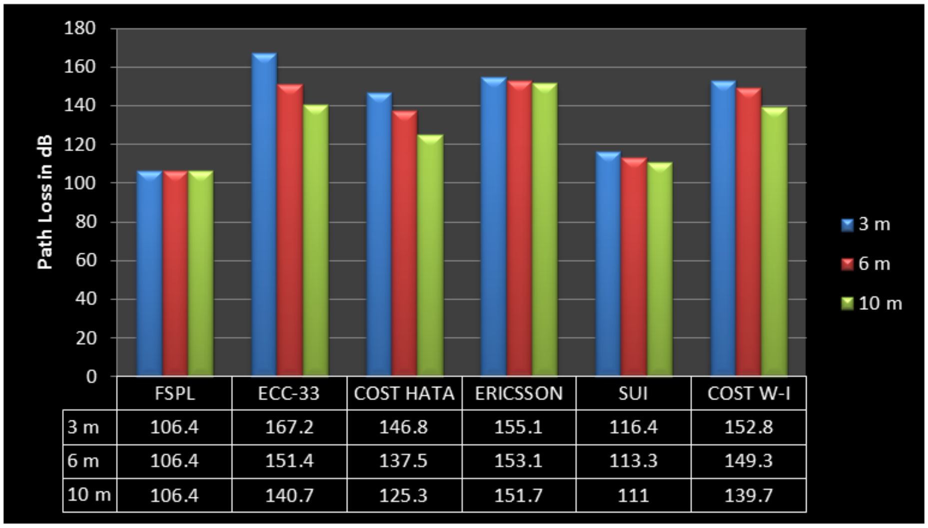


Figure 7. Path Loss in Suburban Environment at 10m Receiver Antenna Height

Figure 8 illustrates the simulation result for suburban environment in terms of different receiver antenna heights. Among the colligated models, ECC-33 model predicts highest path loss for three different antenna heights in this terrain with a remarkable fluctuation of path loss. On the other hand, prediction of path loss is lowest in the case of SUI model with a small path loss fluctuation for the same set of parameters. The COST W-I and Ericsson model show moderate result with little wavering of path loss relating to receiver antenna height change. The COST 231 HATA model also shows remarkable fluctuations of path loss with respect to receiver antenna height change. In the case of FSPL model, the path losses remain the same for the three different receiver antenna heights because of the LOS condition.



	FSPL	ECC-33	COST HATA	ERICSSON	SUI	COST W-I
3 m	106.4	167.2	146.8	155.1	116.4	152.8
6 m	106.4	151.4	137.5	153.1	113.3	149.3
10 m	106.4	140.7	125.3	151.7	111	139.7

Figure 8. Analysis of Simulation Results in Suburban Environment at a Reference Distance of 2 km for Different Receiver Antenna Heights

3.3 Performance Analysis of Simulation Results in Rural Environment

Three different receiver antenna heights (3 m, 6 m and 10 m) are used for the calculation of path loss, with a varying distance between transmitter and receiver (up to 5 Km). Transmitter antenna height of 20 m is considered in this case and in addition, the ECC-33 model is not applicable in rural area and the COST 231 W-I model has no specific parameters for rural area. The numerical results for different models in rural area for different receiver antenna heights are illustrated in Figures 9, 10 and 11.

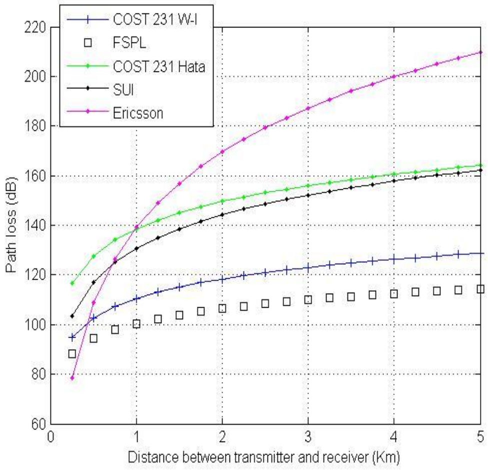


Figure 9. Path Loss in Rural Environment at 3m Receiver Antenna Height

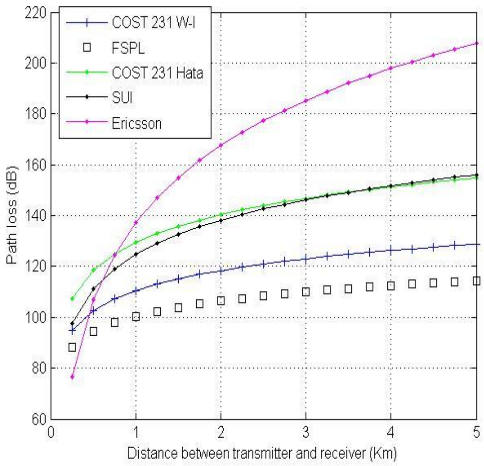


Figure 10. Path Loss in Rural Environment at 6m Receiver Antenna Height

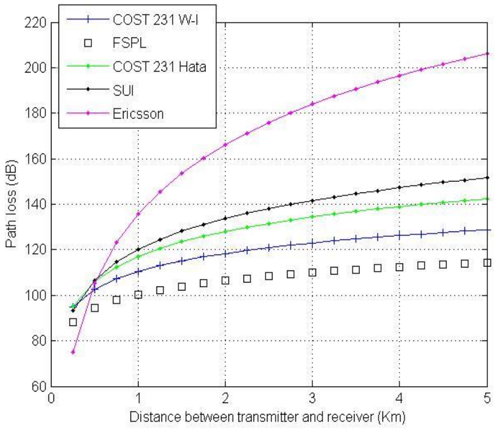


Figure 11. Path Loss in Rural Environment at 10m Receiver Antenna Height

A comparative picture of simulation results in rural environment is shown in Figure 12. From the overall focus, FSPL and COST W-I models show substantially low result in terms of path loss due to LOS condition. Significant fluctuation of path loss is exhibited by COST Hata and SUI models with moderate path loss. Ericson model depicts highest path loss (169.4 dB to 166.1) with low variation for dissimilar receiver antenna heights. For this type of environment, different models can be chosen for different perspectives. If the area is flat enough with less vegetation, where the probability of getting LOS condition for signal is high, in that case, I may consider FSPL model for path loss calculation. Alternatively, if the probability of finding LOS condition is low, in that situation, COST Hata model shows less path loss compared to SUI and Ericsson models especially at 10 m receiver antenna height. But considering all receiver antenna heights, SUI model shows low path loss (144.2 dB at 3 m and 138.2 dB at 6 m) in comparison to other models.

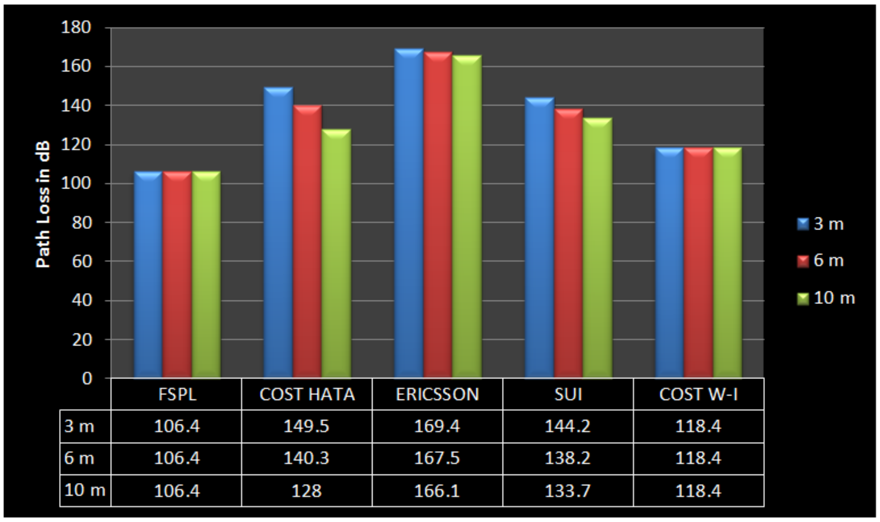


Figure 12. Analysis of Simulation Results in Rural Environment at a Reference Distance of 2 km for Different Receiver Antenna Heights

4. Conclusion

In this comparative analysis, no single model is found to be suited or recommended for the three types of environments. Finally, FSPL model can be referred as the appropriate model to calculate path loss in all three different propagation environments, if there is a LOS condition. On the other hand, in the case of NLOS condition, SUI model shows lowest path loss in different environments for all the three receiver antenna heights while ECC-33 model shows highest path loss as compared to other models.

Table 4. Observation of Path Loss in Three Different Environments

Type of environment	**Model showing lowest path loss (NLOS)**	**Model showing lowest path loss (LOS)**	**Model showing highest path loss (LOS & NLOS)**
Urban	Ericsson	FSPL	ECC-33
Suburban	SUI	FSPL	ECC-33
Rural	SUI	FSPL	Ericsson

The results can be assumed in the preliminary design of WiMAX cellular system. The path losses for suburban areas are lower than the path loss values of urban areas because suburban areas are composed of residential and garden areas, while urban areas are cities with tall buildings and their complete facilities. Similarly, path loss values of rural areas are lower than those values of suburban areas because rural areas are composed of open land with small buildings, farms and free spaces.

Moreover, the simulation results of this paper correspond to the simulation results of path loss prediction conducted in other areas of the world due to the similarities in terrain profiles [4, 15, 16].

For initial deployment of WiMAX network, a trade-off between transmission power and adjacent frequency block interference must be taken into consideration to avoid the probability of interference with adjacent area using the same frequency block while ensuring maximum coverage area.

References

[1] R. K. Crane, “Prediction of Attenuation by Rain”, IEEE Transactions on Communication, vol. COM-28, **(1980)** September, pp. 1727-1732.

[2] E. Athanasiadou, A. R. Nix and L. P. MeGeehan, “A Microcellular Ray Tracing Propagation Model and Evaluation of its Narrowband and Wideband Predictions”, IEEE Journal on Selected Areas in Communication, vol. 18, **(2000)** March, pp. 322-355.

[3] H. R. Anderson, “Fixed Broadband Wireless System Design: The Creation of Global Mobile Communications”, John Wiley & Sons, Inc., New York, NY, **(2003)**.

[4] P. K. Sharma and R. K. Singh, “Comparative Analysis of Propagation Path Loss Models with Field Measured Data”, IJEST, vol. 2, no. 6, **(2010)**, pp. 2008-2013.

[5] www.Comlab.hut.fi/opetus/333/2004-2005/Path Loss Models.pdf.

[6] V. Erceg, K. V. S. Hari, M. S. Smith, D. S. Baum, K. P. Sheikh, C. Tappenden, J. M. Costa, C. Bushue, A. Sarajedini, R. Schwartz, D. Branlund, T. Kaitz and D. Trinkwon, “Channel Models for Fixed Wireless Applications”, IEEE 802.16 Broadband Wireless Access Working Group, **(2001)** July.

[7] M. Hata, “Empirical Formula for Propagation Loss in Land Mobile Radio Services”, IEEE Transactions on Vehicular Technology, vol. VT-29, no. 3, **(1981)** September, pp. 317-325.

[8] V. S. Abhayawardhana, I. J. Wassell, D. Crosby, M. P. Sellers and M. G. Brown, “Comparison of Empirical Propagation Path Loss Models for Fixed Wireless Access Systems”, 61th IEEE Technology Conference, Stockholm, **(2005)**, pp. 73-77.

[9] Electronic Communication Committee (ECC) within the European Conference of Postal and Telecommunications Administration (CEPT), "The Analysis of the Coexistence of FWA Cells in the 3.4-3.8 GHz Band", Tech. Rep., ECC Report 33, **(2003)** May

[10] V. Erceg, L. J. Greenstein, S. Y. Tjandra, S. R. Parkoff, A. Gupta, B. Kulic, A. A. Julias and R. Bianchi, “An Empirically Based Path Loss Model for Wireless Channel in Suburban Environments”, IEEE Journal on Selected Areas in Communication, vol. 17, no. 7, **(1999)** July, pp. 1205-1211.

[11] IEEE Standard 802.16-2004, IEEE Standard for Local and Metropolitan Area Networks, "Part 16: Air Interface for Fixed Broadband Wireless Access Systems", **(2004)**.

[12] J. Milanovic, S. Rimac-Drlje and K. Bejuk, “Comparison of Propagation Model Accuracy for WiMAX on 3.5GHz”, 14th IEEE International Conference on Electronic Circuits and Systems, Morocco, **(2007)**, pp. 111-114.

[13] S. I. lgor, I. Stanic and B. Zrnic, “Minimax LS Algorithm for Automatic Propagation Model Tuning”, Proceeding of the 9th Telecommunications Forum (TELFOR 2001), Belgrade, **(2001)** November.

[14] Banglalion Communications Ltd., http://en.wikipedia.org/wiki/Bangla Lion.

[15] M. Kumari, T. Yadav, P. Yadav, P. K. Sharma and D. Sharma, “Comparative Study of Path Loss Models in Different Environments”, IJEST, vol. 3, no. 4, **(2011)** April, pp. 4683-4690.

[16] V. Kamboj, D. K. Gupta and N. Birla, “Comparison of Path Loss Models for WiMAX in Rural Environment at 3.5 GHz”, IJEST, vol. 3, no. 2, **(2011)** February, pp. 1432-1437.

Authors

Md. Didarul Alam is working as a lecturer in the Department of Applied Physics, Electronics and Communication Engineering, University of Chittagong, Chittagong-4331, Bangladesh. His research interest includes antenna design and wireless communications.

Dr. Md. Rezaul Huque Khan is working as a professor in the Department of Applied Physics, Electronics and Communication Engineering, University of Chittagong, Chittagong-4331, Bangladesh.