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Optimization of Empirical Pathloss Models of WiMax at 4.5 GHz Frequency Band

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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 optimize depending on various parameters like frequency, height of receiver antenna, distance between transmitter and receiver etc. For optimization purpose we are using COST 231 Hata model, COST 231 Walfisch-Ikegami 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 4.5 GHz frequency band.*
Key words: *Cost231-extensiion to Hata model, Cost 231 W-I Model, ECC-33 model, Path loss, WiMax.*

I. 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. 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. 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.

In this paper, a few path loss models have been studied in next Section. 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 optimization.

II. Material and Methods

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 optimize in this paper.

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 (1):
The calculation is done by using the following equation:

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

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

2 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. 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 (2):

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

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:

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

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.

III. 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 and above. 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 (3):

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

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 $\quad G_r=0.759h_r-1.892$

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 India.

IV. 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:

For line-of-sight (LOS) Condition, (4):

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

And for Non-line-of-sight (NLOS) condition, (5):

$$PL_{NLOS}=L_{FSL}+L_{rts}+L_{msd} \qquad \text{for urban and suburban}$$

$$PL_{NLOS}=LFSL \qquad \text{if } Lrts+Lmsd>0$$

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:

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

Roof top to street diffraction:

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

$\quad = 0 \quad$ for hroof>hmobile

L_{ori}	$= -10+0.345\,\Phi$	for	**$0<\Phi<35$**
	$= 2.5+0.075\,(\Phi-35)$	for	**$35<\Phi<55$**
	$= 4-0.114\,(\Phi-55)$	for	**$55<\Phi<90$**

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 $h_{bas}e<h_{roof}$

$k_f= -4+0.7((f/925)-1)$ 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.

V. Result and Discussion

Now in this research we are using frequency which are also used for WiMax consideration that is at 4.5 GHz, I choose to predict path loss of WiMax signal at this frequency band. The desired WiMax transmitter to receiver distance is varied up to 5 Km and the carrier frequency is set to 4.5 GHz. Here, three different receiver antenna heights (3 m, 6 m, 10 m) have been considered. I selected three different areas, *e.g.*, Palasia (A.B Road), Aerodrome, and Bypass Road as urban, suburban and rural environments respectively to collect certain parameters because these areas meet the requirements to be urban, suburban and rural areas. Palasia (A.B Road) is an area having closely spaced buildings that range up to 8 stories in height, street grids, billboards and other obstacles. Aerodrome is an area associated with moderately spaced one-to-four story buildings, trees *etc.* while Bypass Road is a rural area with few buildings separated by significant distance, wheat-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. The following table presents the parameters applied in simulation for three different environments.

Table1. 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	4.5 GHz	4.5 GHz	4.5 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, 18m	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

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.

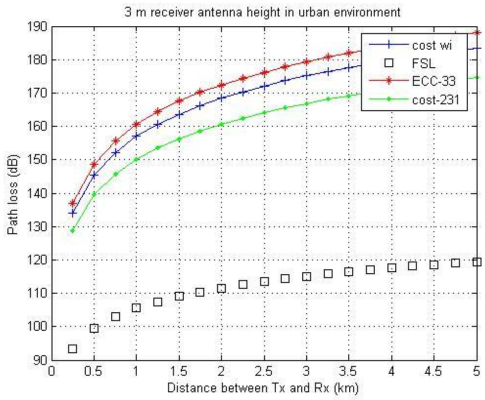

Fig 1. Path Loss in Urban Environment at 3 m Receiver Antenna Height

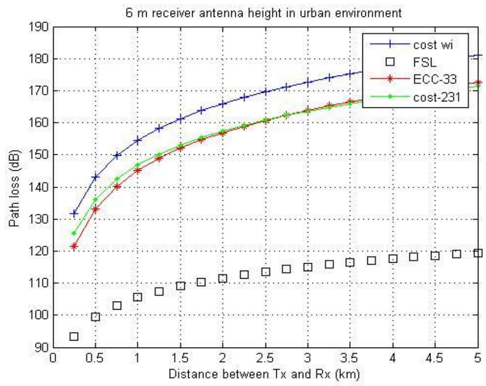

Fig 2. Path Loss in Urban Environment at 6 m Receiver Antenna Height

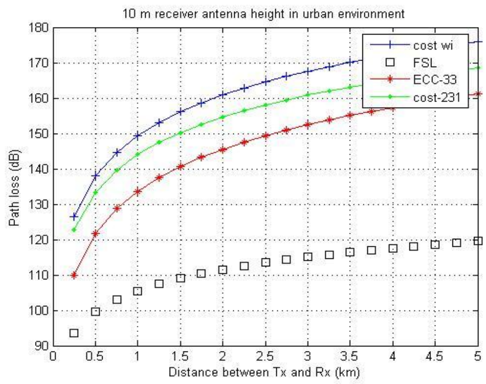

Fig 3. Path Loss in Urban Environment at 10m Receiver Antenna Height

The bar chart in Figure 4 illustrates the simulation result in urban area for three different receiver antenna heights. Based on the optimization among the propagation models, the lowest path loss is predicted by COST-231 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, ECC-33 model shows highest path loss at 3 m receiver antenna height while COST-WI model forecasts the highest at 3 m receiver antenna heights and in addition, the ECC-33 model shows 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.

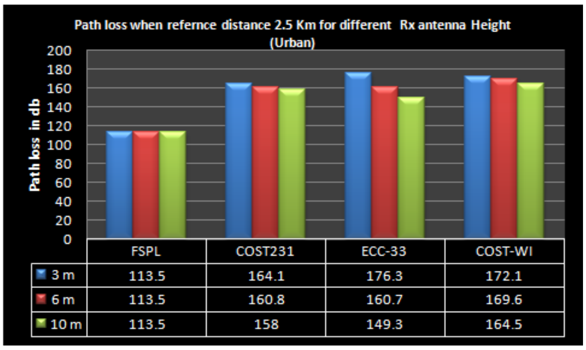

Fig4. Analysis of Simulation Results in Urban Environment at a Reference Distance of 2.5 km for Different Receiver Antenna Heights

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.

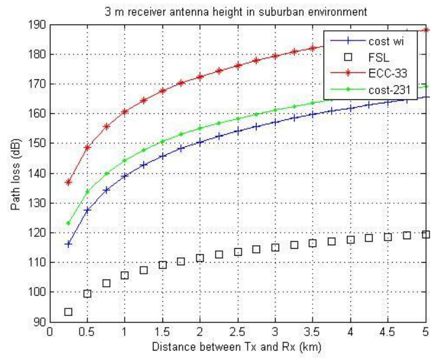

Fig5. Path loss in Suburban Environment at 3 m Receiver Antenna Height

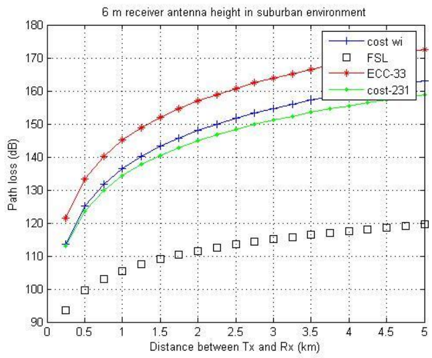

Fig6. Path Loss in Suburban Environment at 6 m Receiver antenna height

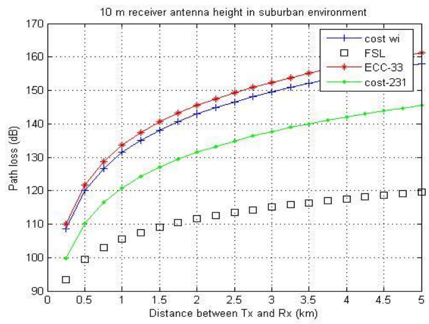

Fig7. Path Loss in Suburban Environment at 10m Receiver Antenna Height

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 COST-231 model with a 10 m receiver antenna height. The COST W-I model show small fluctuations in 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 path losses remain the same for the three different receiver antenna heights because of the LOS condition.

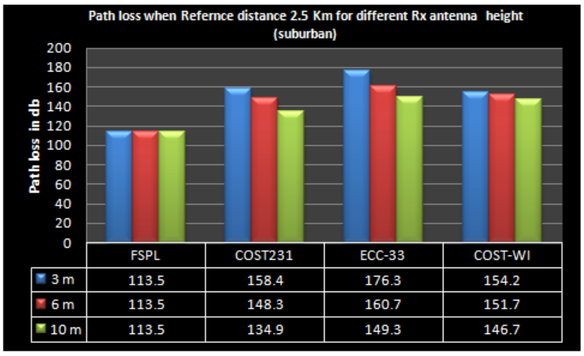

Fig8. Analysis of Simulation Results in Suburban Environment at a Reference Distance of 2 km for Different Receiver Antenna Heights

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.

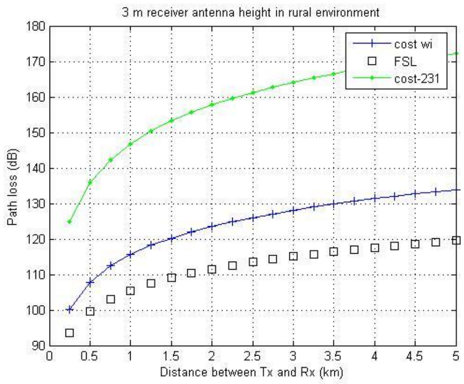

Fig9. Path Loss in Rural Environment at 3m Receiver Antenna Height

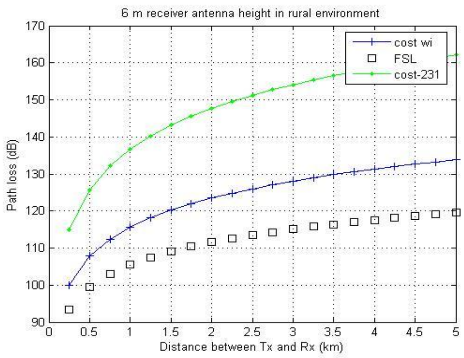

Fig10. Path Loss in Rural Environment at 6m Receiver Antenna Height

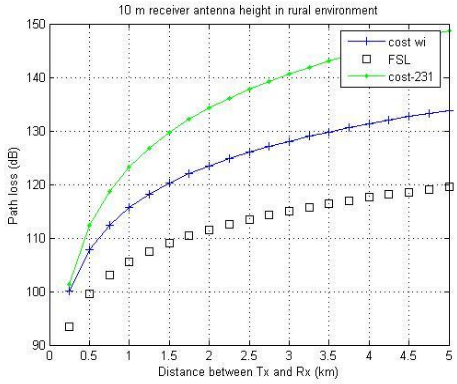

Figure11. Path Loss in Rural Environment at 10m Receiver Antenna Height

The optimize 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 231 model with moderate path loss. 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 WI model shows less path loss compared to another model especially at 10 m receiver antenna height. But considering all receiver antenna heights.

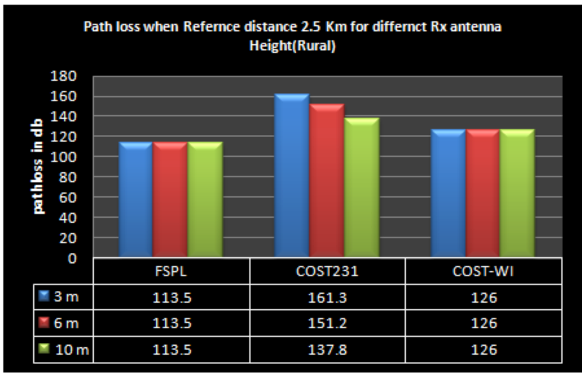

Fig12. Analysis of Simulation Results in Rural Environment at a Reference Distance of 2.5 km for Different Receiver Antenna Heights

VI. Conclusion

In this 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, Cost 231WI 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. 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. 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.

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