Performance of Path Loss Model in 4G Wimax Wireless Communication System in 2390 MHz

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Abstract. In 4G WiMAX wireless communication system, the signals like all RF wave, are susceptible to path loss. Path loss represents the attenuation suffered by an RF signal as it propagates from the transmitter to the receiver through various terrains and is considered an important element in designing a radio link. This paper outlines how an optimised model for the prediction of path loss for WiIMAX signals up to 2390MHz band is developed based on measured field strengths in Cyberjaya, Malaysia. The data is collected at 50m radial increments within 1km from the base station using a directional CPE. The existing path loss models used in this study are the Stanford University Interim (SUI), COST-231 Hata and Egli models. After analysis of the measured path loss, the model that best predicted the actual path loss, the COST-231 Hata model, is optimised. The optimisation is done by determining the difference between the measured and predicted path loss. The optimised model is validated using standard deviation error and relative error analysis, and the results indicate that the new optimised model predicts path loss with improved accuracy of about 25-40%. The optimised models show relative errors of between 7.24% -17.6% in the suburban environment and 4.34% - 11.91% in the open urban environment, which are superior to the high relative errors shown by the COST-231 Hata model.

Keywords: WIMAX; path loss modeling; model optimisation

1. Introduction

In wireless communication system, Non Line of Sight (NLOS) between the transmitter and the receiver in a wireless link will introduce multipath, which decreases the signal strength and introduces a subsequent increase in the receiver Bit Error Rate (BER) [1]. Path loss represents the signal attenuation suffered by a Radio Frequency (RF) signal as it propagates from the transmitter to the receiver. To increase the robustness of the transmitted information, engineers need to estimate the path loss introduced by a terrain to sufficiently compensate for the power lost during signal propagation. The prediction of the path loss exponent of an environment is a significant step in determining the extent of path loss in an environment [2]. Existing path loss models may be used to estimate path loss, but it is ideal to develop an optimised model to use over a certain terrain in a particular band, as the propagation characteristics of the signal is somewhat dependant on the frequency [3]. To date, the existing empirical path loss models do not predict the path loss suffered by WiMAX signals in the 2360-2390MHz band.

2. Path Loss Measurement

In this work, the measurement was conducted at Cyberjaya as it has a mostly suburban terrain profile [4]. The MMU BS selected is situated at 02 55 555 N 101 38 500 E, 23m above ground level. This site has four WiMAX Base Stations (WBSs) which transmit in vertical polarization. All four WBS serve a mixed environment of open urban and suburban environments. Fig. 1 shows the estimated coverage area of the MMU BS and the environments that each WBS serves.

Fig.1: MMU BS coverage area.

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Fig. 2 shows the experimental setup. The Customer Premise Equipment (CPE) is a vertically polarized directional antenna with a 50º beam width. The CPE was mounted on an adjustable makeshift mast, and was manually held during the field test. At each measurement location, a GPS was used to establish the location of the CPE. A compass was used to confirm that the antenna was facing towards the LOS path of the selected WBS correctly. The Received Signal Strength (RSS) was observed using a spectrum analyzer at CPE heights of 2m and 4m for the duration of 1 minute and was recorded at every 10s interval. The RSS measurements were conducted along a radial increment of 50m within a 1km radius from the site. However, as the measurements were taken along the Line of Sight (LOS) of each WBS, the maximum radius attainable at 270º was 500m due to the limitations by the geography of the measurement area. The measurement at 100m from each WBS was used as the reference distance. The path loss exponent is determined using Eq. (1) [5],[6],[7] where d is the distance from the transmitter.

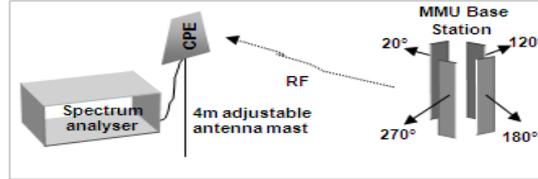$$PL\ (dB) = 10nlog_{10}d \qquad (1)$$

Fig. 2: Experimental Setup

The performance of the optimised models will be validated based on relative errors Eq. (2) [8],[9] and standard deviation of errors Eq. (3) [6]

$$\delta_{error} = \frac{\left|PL_{measured} - PL_{model}\right|}{PL_{measured}}100\% \qquad (2)$$

$$\delta_{error} = PL_{measured} - PL_{model} \qquad (3)$$

where $PL_{measured}$ is the measured Path Loss (dB), PL_{model} is the model estimated Path Loss (dB), δ_{error} is the relative error in % and σ_{error} is the standard deviation of error.

3. Path Loss Models

The three models were selected which are COST-231 Hata model [10]-[12] as in Eq.(4), SUI model[13] in Eq.(7), and Egli model in Eq. (8) [14] were respectively selected based on their applicability in wireless communications. The COST-231 Hata model as below.

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

In this model, f is the frequency in MHz, d is the distance between base station and CPE antennas in km and h_b is the base station antenna height above ground level in meters. The correction parameter ah_m is defined by Eq. (5) and Eq. (6) for urban and suburban environments respectively [7]. The correction parameter, c_m is given as $c_{m(urban)} = 3dB$ and $c_{m(suburban)} = 0dB$ [2], where H_r is the height of the CPE antenna in meters.

$$ah_m = 3.2\left(log_{10}(11.75H_r)\right)^2 - 4.97 \qquad (5)$$

$$ah_m = (1.1log_{10}f - 0.7)H_r - (1.56log_{10}f - 0.8) \qquad (6)$$

The SUI model as below;

$$PL(dB) = A + 10\gamma log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + s \qquad (7)$$

where d_o= 100m, d is the distance between BS and CPE antenna in meters, and s is a log-normally distributed factor used to account for tree and clutter shadowing. The values given for s in [13] are between 8.2dB and 10.6dB. Parameter A is known as the intercept parameter. The third model is Egli path loss model and calculated using Eq. (8) [14].

$$PL(dB) = G_B G_M \left[\frac{h_B}{d^e}h_M\right]^2 \left[\frac{40}{f}\right]^2 \qquad (8)$$

In this model, G_B is the gain of the BS antenna, G_M is the gain of the CPE antenna, h_B is the height of the BS antenna from ground level, h_M is the height of the CPE, d is the receiver distance from the BS and f is the operating frequency of the CPE in MHz.

4. Results and Analysis

Fig. 3 shows the path loss estimated by the SUI, COST-231 Hata and Egli models and these path losses are plotted against distance on the same graph as that of the measured path loss. The path loss exponents found from the slopes in Fig. 3 are then summarized in Table I, which also shows the relative errors of the path loss exponent predicted by the models against the measured path loss exponent.
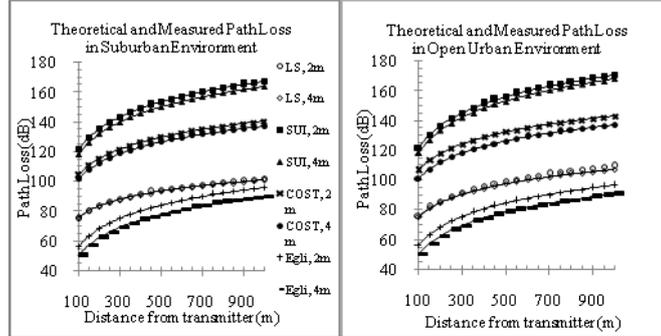

Fig. 3: Comparison of measured path loss (dB) and estimated path loss(dB) from existing models in open urban and suburban environments.

The path loss exponent predicted by the COST-231 Hata model shows the closest agreement to the measured path loss exponents. The Egli and SUI models over predict the path loss exponent by a high relative error percentage. Because the path loss exponent shows the rate of propagation path loss with respect to a distance in a given environment, it is a good way to predict how the signal strength will drop as the signal propagates further away from the transmitter. Based on this, the COST-231 Hata model is determined to be the best model in predicting the path loss experienced by the WiMAX signals in Cyberjaya.

Table I.   Measured and Theoretical Path Loss Exponents, N

Path Loss Model	n for SUBURBAN		n for OPEN URBAN	
	2m	4m	2m	4m
LS (measured path loss)	2.980	2.816	3.655	3.326
SUI	4.571	4.571	4.957	4.957
δ_{SUI}	34.806%	38.394%	26.266%	32.903%
COST-231	3.591	3.591	3.591	3.591
$\delta_{COST-231\ HATA}$	17.015%	21.582%	6.400%	7.380%
Egli	4.000	4.000	4.000	4.000
δ_{EGLI}	25.500%	29.600%	34.500%	16.850%

5. Model Optimisation

The main contribution in this work is the optimization. The optimised models are developed based on the frequency of 2375MHz, which is the centre frequency for the band of 2360-2390MHz. The height of the BS is taken as 23.6095m, which is the height of the building plus half the height of the sectorized antenna. Since higher path loss is suffered by the CPE at 2m, this worst case path loss data is used as the data for the modeling process.

From Eq. (4), the COST-231 Hata model is separated into the three basic elements of an empirical model

$$E_o = 46.3 - ah_m + c_m \qquad (9)$$

$$E_{sys} = 33.9 log_{10}(f) - 13.82 log_{10}(h_b) \qquad (10)$$

$$\beta_{sys} = (44.9 - 6.55 log_{10}(h_b)) log_{10}d \qquad (11)$$

where f is frequency in MHz, d is the distance between BS and CPE antennae in km and h_b is the BS antenna height above ground level in meters.

The difference between the measured path loss and the COST-231 Hata predicted path loss is plotted in Fig. 4 and the new E_o values found are shown in Table II. The E_o values are substituted into the original COST-231 Hata model equation, Eq. (7) and two new Hata optimised models are presented as shown by Eq. (12) and Eq. (13).
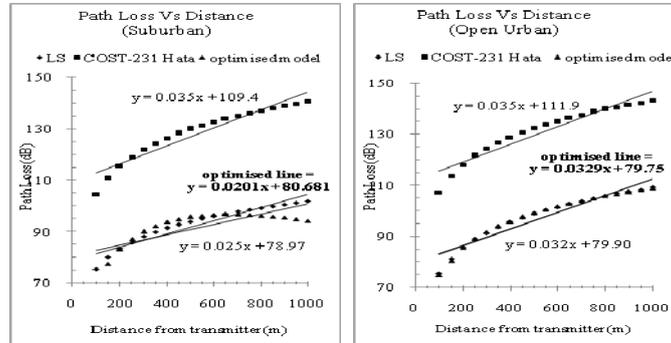

Fig.4: Optimisation for open and suburban environments.

Table II. Summary Of New Initial Offset Parameters,E_o, For Hata Optimised Models

Environment	E_o values suggested by COST-231 Hata model	"a" from "optimised model" linear line (Fig. 4)	$E_{sys} =$ $33.9 \log_{10} f$ $- 13.82 \log_{10} h_B$	$E_{o\,new} =$ $a - E_{sys}$
Suburban	46.3	80.681	55.8287	24.8523
Open Urban	46.3	79.75	55.8287	23.9213

$$PL = 24.8523 + 33.9 \log f - 13.82 \log(h_b) - ah_m + (44.9 - 6.55\log(h_b))\log(d) + c_m \quad (12)$$

for the prediction of path loss in suburban environments.

$$PL = 23.9213 + 33.9 \log f - 13.82 \log(h_b) - ah_m + (44.9 - 6.55\log(h_b))\log(d) + c_m \quad (13)$$

for the prediction of path loss in open urban environments. The path loss (dB) predicted by the Hata optimised models are plotted against measured and COST-231 Hata predicted path losses as shown in Fig. 5.
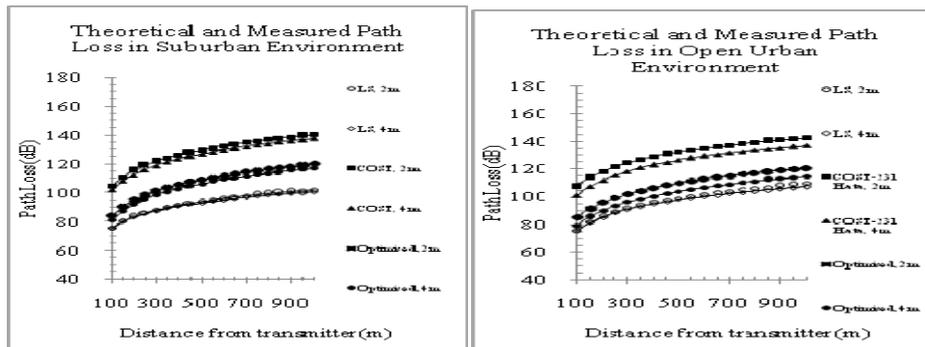

Fig.5: Comparison of optimised model, measured and COST-231 Hata path loss for open urban and suburban environments.

From Fig. 5, the Hata optimised model for the suburban environment showed a standard deviation of errors of between $5.5 - 17.99$dB while the COST-231 Hata model showed a standard deviation of errors of $25.94 - 38.44$dB. The Hata optimised model for open urban environment showed a standard deviation of errors of between $9-11.4$dB while the COST-231 Hata model showed errors of between $31.4-33.8$dB. This shows that the optimised model is able to predict the path loss with an increased accuracy of 25-40% in both the suburban and open urban environments. It was also observed that the standard deviation of errors of the

optimised model are lesser when CPE height is higher, indicating higher accuracy at greater CPE heights. The standard deviation of errors are also lesser when the CPE is closer to the BS.

The Hata optimised models showed relative errors of between 7.24% -17.6% in the suburban environment and 4.34% - 11.91% in the open urban environment. The COST-231 Hata model on the other hand, showed higher relative errors of between 34.19 -38.2% in the suburban environment and 27.91- 41.43% in the open urban environment. It was also observed that the relative errors reduced when the CPE height is higher, again indicating higher accuracy at greater CPE heights.

As a conclusion, the relative errors and the standard deviation of errors for the open urban Hata optimised model are lesser than that of the suburban Hata optimised model, indicating that the open urban Hata optimised model is slightly more accurate than the suburban Hata optimised model.

6.   Conclusion

The objective of this paper is to develop optimised models for the prediction of path loss for WiMAX signal in the 2360-2390MHz band. The models were developed based on measured field strength collected in Cyberjaya, Malaysia. The field strength was collected with a fixed WiMAX receiver which served as the CPE at heights of 2m and 4m. The environment which is served by the base station under study is a mix of suburban and open urban environments.

Three existing path loss models, which is the COST-231 Hata, Egli and SUI models were used to predict the path loss based on the measured field strength. The path loss and path loss exponents of the measured and predicted path loss were discussed, and the best model based on the closest agreement to the measured path loss exponent was determined to be the COST-231 Hata model.

The models were optimised based on the centre frequency of 2375MHz, with the data collected at CPE height of 2m (worst case path loss data). After the optimisation, a new initial offset parameter was introduced to replace the existing initial offset parameter of the COST-231 Hata model. The developed optimised models were then validated using a relative error and standard deviation of error analysis.

The Hata optimised models were able to predict the path loss with an increased accuracy of 25-40% in both the suburban and open urban environments. The analysis on the Hata optimised models also indicated higher accuracy of path loss prediction at greater CPE heights.

Both the Hata optimised models show superior performance to the existing COST-231 Hata model in terms of relative error and standard deviation of error analysis.

7.   References

[1]   T. S. Rappaport, *Wireless Communications, Principles & Practice*. (2nded.). Prentice Hall, 2002.
[2]   E.V. and L. J Greenstein, An empirically based path loss model for wireless channels in suburban environments. *IEEE Journal on Selected Areas of Communications*, vol. 17, pp. 1205–1211, 1999.
[3]   S.F. Hasan, N. H Siddique, and S. Chakraborty, Femtocell versus WiFi – A Survey and Comparison of Architecture and Performance. *Wireless Vitae.*
[4]   Town & Country Planning Department, Malaysia Urban Design Guidelines for Cyberjaya, Malaysia, 2005.
[5]   Wikipedia, Path Loss. [Online] Available: http://en.wikipedia.org/wiki/Path_loss, 2010.
[6]   T. R.Rao , S.V.Bhaskara Rao, M.V.S.N.Prasad, M. Sain, A. Iqbal, and D.R. Lakshmi , Mobile Radio Propagation Path Loss Studies at VHF/UHF Bands in Southern India. *IEEE Trans. on* Broadcasting, Vol.46, No. 2, 2000.
[7]   V. S.Abhayawardhana, I.J.Wassell, D.Crosby, M.P. Sellars & M.G. Brown, Comparison of empirical propagation path loss models for fixed wireless access systems. *Proceedings of IEEE Conference on Vehicular Technolog*y, Stockholm, Sweden, Vol. 1, pp 73-77, 2005.
[8]   L. Jacques, and S. Michel, *Radio Wave Propagation Principles and Techniques.* John Wiley & sons Ltd., 2000.
[9]   Wikipedia, Relative Errors. [Online] Available: http://en.wikipedia.org/wiki/Approximation_error, 2010.
[10] M. Hata, Empirical formula for propagation loss in land mobile radio services. *IEEE Transactions on Vehicular Technology*, vol. VT-29, pp. 317–325, 1981.
[11] Y. Okumura, Field strength and it's variability in VHF and UHF land-mobile radio-services, Review of the Electrical Communications Laboratory, vol. 16, 1968.
[12] COST Action 231 Digital mobile radio towards future generation   systems, final report, *tech.*rep., European Communities, EUR 18957, 1999.
[13] V. Erceg, and K. V. S. Hari, Channel models for fixed wireless applications. *tech. rep., IEEE 802.16 Broadband Wireless Access Working Group,* 2001.
[14] J. J. Egli, Radio Propagation above 40 Mc Over Irregular Terrain. *Proc. IRE*, pp.1383-1391, 1957.