A Comparison of Path Loss Models for WiMAX in Suburban and Open Urban Environments

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Abstract: **WiMAX signals, like all RF signals, are susceptible to path loss as it propagates through various terrains. Path loss is a crucial consideration in the link budget to close a wireless link. This paper investigates the applicability of the COST-231 Hata, the Stanford University Interim (SUI) and the Egli models in estimating the path loss of WiMAX signals in the 2360-2390 MHz. Path loss measured in Cyberjaya, Malaysia is compared to the theoretical path loss estimated by the various models. The results conclude that the COST-231 Hata model is the best model in predicting the path loss in open urban and suburban environments in Cyberjaya. The COST-231 Hata model estimated a path loss exponent of 3.59 at 2m and 4m respectively. For suburban environment, the measured path loss exponent values were 2.68 and 2.50 for 2m and 4m respectively, while for the open urban environment, the measured path loss exponent values at 2m and 4m were 3.31 and 3.14 respectively. In both environments, the SUI and Egli models over-estimated the path loss experienced in the 2360-2390MHz band.**

Keywords – Path loss models; path loss exponents, WiMAX

I. INTRODUCTION

WiMAX is based on the IEEE 802.16 standard which is also called Broadband Wireless Access (BWA) [1]. In Malaysia, the WiMAX role out was pioneered by Packet One Networks (P1) Sdn. Bhd. in 2008 [2]. At present, P1 uses the Standard Propagation Model (SPM) to predict path loss. The SPM is based on COST-HATA parameters that can be calibrated. The feasibility of the use of this model has been validated in the 3.5GHz band in Stuttgart, Vienna and Hamilton [3].

The WiMAX service is envisioned to further enhance the broadband infrastructure in Malaysia. Fixed WiMAX services will boost the use of broadband by consumers and small businesses, as well as serve as backhaul for Wi-Fi hotspots [4]. Mobile WiMAX may be used for mobile services provisioning by existing fixed-line carriers that do not own a 3G spectrum to provide Voice-over-IP (VoIP) and for mobile entertainment services [4].

Among the technical challenges faced in commissioning WiMAX services is the non Line of Sight (NLOS) issue which causes multipath fading and Inter-Symbol Interferences (ISI) [5]. In spite of diversity channel coding being applied to protect the content of the signal [6], the strength of the RF signal that is received at the receiver plays an important role in ensuring that transmitted data is predicted correctly. The prediction of the path loss exponent of an environment is a significant step in determining the path loss of an environment [7]. To ensure sufficient signal strength is received by the receiver, engineers use path loss models to predict the path loss of the channel before optimizing the transmit power to compensate for the losses accordingly.

In previous studies, the feasibility of using of empirical path loss prediction models to predict path loss in BWA [8] has been done.

In this paper, the feasibility of using the SUI model, the COST-231 Hata model and the Egli model for WiMAX path loss predictions in the 2360-2390 MHz will be determined. The received signal strength (RSS) measurements taken in this band in Cyberjaya, Malaysia in March 2010 is translated into path loss and compared against the calculated values using the desired path loss models. The appropriateness of using these path loss models in predicting path loss for fixed WiMAX receivers in the 2360-2390 MHz band in suburban and open urban environments will be validated.

II. TERRAINS DESCRIPTION

Cyberjaya has a mostly suburban terrain profile. It is located in the district of Sepang, Selangor [9]. The Multimedia University (MMU), a major landmark in Cyberjaya, has in the recent years seen rapid development of multiple - story condominiums being built around its campus area to support the growth of the student population.

The development around the MMU campus area has made the area within 1km from the university to take on the terrain profile of a slightly urban environment, with wide roads, car parks and pedestrian pavements. For this study, the terrain profile within 1km from where the field testing was conducted was categorized carefully to be either open urban (multiple-story buildings situated rather closely with roads and car parks) or suburban (small hillocks with medium foliage) .The open urban profile is not considered to be the typical urban environment [7] where skyscrapers and high rise buildings are packed close to each other.

III. FIELD TESTING

The base station in MMU has four WiMAX Base Stations which serve a mixed open urban and suburban environments. It is situated above the main administration building of MMU in Persiaran Silikon with a height of 23m above ground level. Figure 1 shows the estimated coverage area for the selected BS.

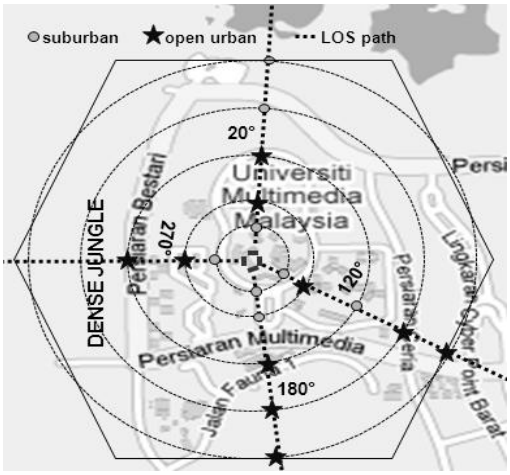

Figure 1. Coverage area for MMU BS

The field testing was conducted within a 1km radius from the site, along the Line of Sight (LOS) of each WBS. The measurements were taken at every 250m radial increment. Due to geographical limitations, the maximum radial increment measurement attainable at 270º was 500m.

The WBSs have sectorized antennas which transmit in a horizontal polarisation and have a 90º horizontal beamwidth. The Customer Premise Equipment (CPE) ,a vertically polarized directional antenna with a 50º beam width, was mounted on a makeshift mast, and was adjustable to 2m and 4 m heights. At each measurement location, a GPS was used to establish the location of the CPE and a compass was used to confirm that the antenna facing towards the LOS path of the selected WBS. The field strength 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. Figure 2 shows the experimental setup for the field testing.

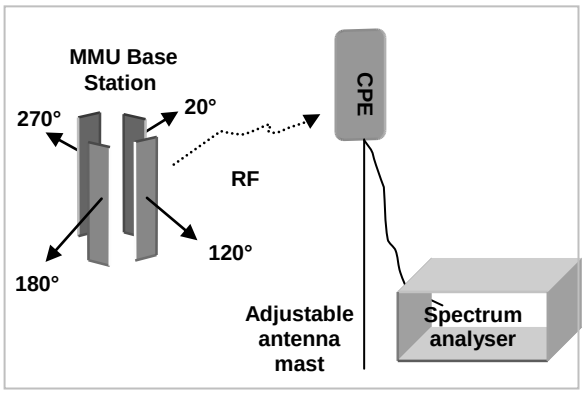

Figure 2. Experimental setup for field testing

IV. SELECTION OF PATH LOSS MODELS

A. *COST-231 Hata Model*

The COST-231 Hata Model is an extension of the Hata-Okumura model [10, 11] and is used for prediction of path loss of mobile wireless systems [10] in urban environments. This model may be used for suburban environments with suitable correction factors [8]. It is for use in 1500-2000MHz with CPE heights up to 10m and BS antenna height of 30-200m [10]. The COST-231 Hata model path loss is calculated using [12]

$$PL(dB) = 46.3 + 33.9log_{10}(f) - 13.82log_{10}(h_b) - ah_m + \left(44.9 - 6.55log_{10}(h_b)\right)log_{10}d + c_m \quad (1)$$

where f is the frequency in MHz, d is the distance between base station an d 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 (2) and (3) for urban and suburban environments respectively [8]. The correction parameter, c_m is given as $c_{m(urban)}$ = 3dB and $c_{m(suburban)}$ = 0dB [12].

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

$$ah_m = (1.1log_{10}f - 0.7)H_r - (1.56log_{10}f - 0.8) \quad (3)$$

where H_r is the height of the CPE antenna in meters.

B. *Stanford University Interim (SUI) Model*

The SUI model was developed under the Institute of Electrical and Electronics Engineers (IEEE) 802.16 working group for prediction of path loss in urban, suburban and rural environments in the 2.5-2.7GHz range [13]. The applicability of this model in the 2.3GHz band has not been validated. The SUI model path loss is calculated using [13, 14],

$$PL(dB) = A + 10\gamma log_{10}\left(\frac{d}{d_o}\right) + X_f + X_h + s \quad (4)$$

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 [14] are between 8.2dB and 10.6dB.

The path loss exponent for the SUI model, γ, is determined from constants used in TABLE I, and were developed through studies in [14].

Table 1. Constant for determination of γ for SUI model

SUI model parameter	Terrain A	Terrain B
a	4.6	4.0
b (m^{-1})	0.0075	0.0065
c (m)	12.6	17.1

The path loss exponent, γ is determined by

$$\gamma = a - bh_b + \frac{c}{h_b} \quad (5)$$

where h_b is the height of the BS in meters and should be between 10m and 80m above ground level [13].

Parameter A is known as the intercept parameter [14] and is defined as

$$A = 20\ log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \quad (6)$$

In this model, three types of terrains are used [14]. Terrain C, for rural conditions, is not discussed in this paper. Terrain A is used for maximum path loss, depicting urban conditions, while terrain B is used for hilly terrains with light tree densities, depicting suburban conditions.

$$X_f = 6.0\ log_{10}\left(\frac{f}{2000}\right) \quad (7)$$

$$X_H = -10.8\ log_{10}\frac{H_r}{2000}\ for\ Terrains\ A\ and\ B \quad (8)$$

The SUI model also provides correction factors for operating frequency, X_f, and the CPE antenna height, X_H as depicted by (7) and (8) respectively [13]. In (7) and (7), H_r is the CPE antenna height in meters while f is the operating frequency in MHz.

C. Egli Model

The Egli model is suitable for use in mobile systems in the bands of 3MHz- 3GHz and is normally used when there is LOS between one fixed antenna and one mobile antenna [15]. The Egli model can be used when there is propagation over irregular terrain [15]. It should be noted that the Egli model does not provide correction factors for different environments.

The Egli path loss is calculated using [15]

$$PL(dB) = G_B G_M \left[\frac{h_B}{d^2} h_M\right]^2 \left[\frac{40}{f}\right]^2 \quad (9)$$

where 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.

IV. DETERMINATION OF MEASURED PATH LOSS EXPONENT

The rate of propagation path loss with respect to a distance is shown by the path loss exponent. If the path loss exponent value is 2, then the environment propagation characteristics is close to free space propagation [7], or one that has less clutter. A path loss of 2- 4 indicates an environment that is urban [1, 7].

The path loss exponent is determined using [7]

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

where d is the distance from the transmitter.

The Least Square (LS) regression analysis is used to determine the path loss at a given location with respect the path loss at a reference distance, do. The LS analysis is shown in (11) where shows the path loss at distance d is [8],

$$PL_d(dB) = PL_{d_o} + 10nlog_{10}\left(\frac{d}{d_o}\right) \quad (11)$$

where d_o is the reference point at 100m and n is the path loss exponent. The path loss exponent obtained from the slope of the Path Loss (dB) versus log d graph using (10) is then used in (11) to determine the actual path loss of the area within 1km from the MMU site.

The received signal strength collected during the field testing is translated into path loss using (12) after taking into account the losses contributed by the cable and the connectors which connected the CPE to the spectrum analyse. The path loss is calculated using [16].

$$PL_{(dBm)} = P_t - P_r \quad (12)$$

where P_r is the received power in dB and P_t is the transmitted power in dBm. The transmit gain of the BS sector antennas are taken into account for the transmit power.

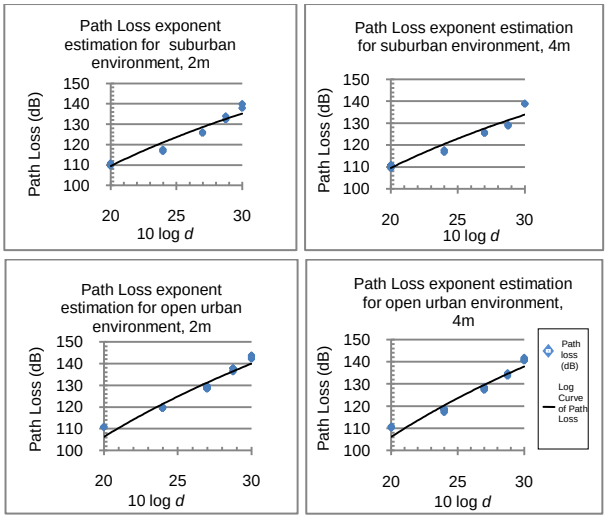

Figure 3. Field strength (dBm) versus distance (m) for open and suburban environments with CPE heights 2m and 4m

The path loss (dB) is then plotted against the distance (dB). For each graph shown in Figure 3, the slope was calculated to determine the path loss exponents [7] in open urban and suburban environments for CPE heights of 2m and 4m. Figure 3 shows that path loss increases as the distance between the transmitter and the receiver is increased. Figure 3 also shows that the path loss at a given distance is more in open urban environment than in suburban environments.

The path loss exponents found from the graphs in Figure 3 are summarized in Table 2.

Table 2. Measured path loss exponents from slope of measured path loss vs distance graph

	SUBURBAN		OPEN URBAN	
	2m	4m	2m	4m
Path loss exponent	2.676	2.502	3.314	3.143

The path loss exponents in Table 2 show that the path loss exponents are higher in open urban conditions, indicating higher path loss. Higher path loss is experienced by a CPE which is further away from the BS because the signal experiences more multipath fading as it propagates further away from the transmitter [7], [16].

Higher path loss is also experienced in open urban conditions because the clutter of the buildings will cause multipath fading and signal strength deterioration, in comparison to suburban conditions in which a LOS between transmitter and receiver may exist and allows the signal to propagate without suffering from diffractions, reflections, absorption and scattering [7].

VI. COMPARISON WITH PATH LOSS MODELS

The path loss estimated by the SUI, COST-231 Hata and Egli models are calculated, and plotted against distance on the same graph as that of the measured path loss.

Figures 4 and 5 show the comparison of path loss measurements in suburban and open urban environments respectively with the theoretical values calculated from the SUI, COST-231 and Egli models.

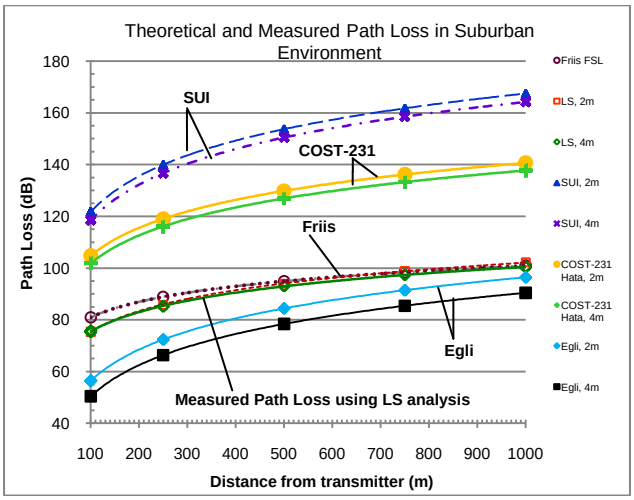

Figure 4. Comparison of measured and theoretical path loss in suburban environments for CPE heights of 2m and 4m

An analysis on Figures 4 and 5 show that the measured path loss (PL) in suburban environment is less than in open urban environment. More path loss is expected in open urban conditions since the clutter of buildings will cause an increase in multipath fading, which ultimately increases path loss in an environment. For suburban environment, the LS analysis indicates that measured path loss is lesser than path loss estimated through the Friis equation, but as the distance from the transmitter increases, the LS curve follows the Friis curve very closely. This could be due to the existence of Line of Sight (LOS) between the BS and CPE, with the main losses being absorption by foliage and trees.

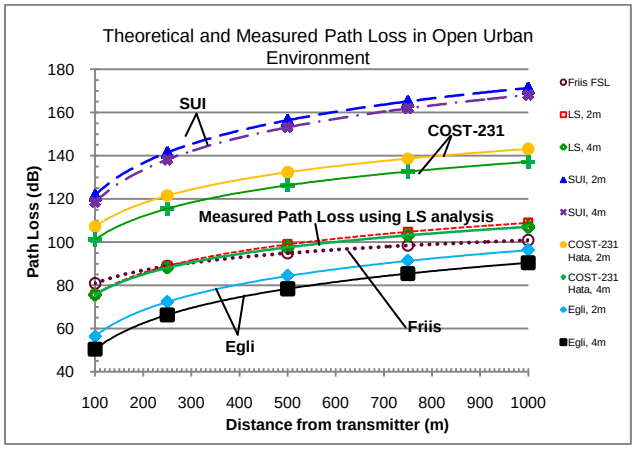

Figure 5. Comparison of measured and theoretical path loss in open urban environments for CPE heights of 2m and 4m

The path loss exponents found from the slopes in Figure 4 and Figure 5 are summarised in Table 3. An analysis on Table 3 shows that the SUI and Egli models over-predict path loss of fixed WiMAX receivers in the suburban and open urban environments in the 2360-2390MHz band. For both open urban and suburban environments, Table 3 shows that the path loss exponent estimated by the COST-231 Hata model is in closest agreement with the LS analysis, which shows the actual path loss characteristics in Cyberjaya. This is especially true for the open urban environment.

Table 3. Measured and theoretical path loss exponents

Path loss exponent	SUBURBAN		OPEN URBAN	
	2m	4m	2m	4m
LS (measured)	2.676	2.502	3.314	3.143
SUI	4.571	4.571	4.957	4.957
COST-231	3.591	3.591	3.591	3.591
Egli	4.000	4.000	4.000	4.000

Table 3 also shows that in both environments, higher losses are experienced by lower CPEs. For suburban environment, a possible explanation to this observation is that in Cyberjaya, the terrain is generally less hilly and thus the absorption by trees at a greater CPE height may be less. For open urban environments, the lack of very high rise buildings and the large numbers of open car parks cause greater multipath to be experienced by CPEs at low heights, thus causing more path loss.

Table 4 shows the prediction error between the measured path loss and the path loss predicted by the path loss models for suburban and open urban environments. The standard deviation method is used to estimate this error, where $\sigma_{error} = \sigma_{LS} - \sigma_{other\ models}$ [17].

Table 4. Path loss models prediction errors

	SUBURBAN		OPEN URBAN	
	2m	4m	2m	4m
SUI	7.68	8.39	4.86	5.37
COST-231	3.71	4.41	0.82	1.32
Egli	5.37	6.07	1.98	2.54

The COST-231 Hata model shows the least standard deviation of errors in both environments. This model shows a very small standard deviation error in the open urban environment, suggesting its high applicability in predicting path loss in this environment. The SUI model shows the highest deviation of errors for both environments.

Based on the connection between Tables 3 and 4, the COST-231 Hata model is most likely the best model for prediction of fixed WiMAX receiver path loss in open urban environments in the 2360-2390MHZ band. It is also the most suitable model to be used in predicting path loss in suburban environments for this frequency band.

VII. CONCLUSION

This project was targeted to study the feasibility of using the SUI, COST-231 Hata and Egli models in predicting path loss for fixed WiMAX receivers in the 2360-2390MHz band in open urban and suburban environments. Similar past studies have been done in other frequency bands to verify the usage of these models to predict path loss. The WBSs of the base station covered a mix of suburban and open urban environments. The open urban environment is defined to be less urban than a typical urban environment. The field strength of WiMAX signals in Cyberjaya were captured at CPE heights of 2m and 4m and was translated into path loss. The results showed that path loss increased faster in open urban than in suburban environment as the distance between transmitter and receiver was increased. The corresponding path loss exponents were then calculated from the path loss graphs and were compared against theoretical path loss exponents from the SUI, COST-231 Hata and Egli models. In suburban environments, the measured path loss exponent reduced at greater CPE heights, possibly due to lesser absorption by foliage. This is because the trees in Cyberjaya are neither very tall nor have very dense leaves. In open urban environments, the measured path loss exponent also reduced as CPE heights were increased, indicating that more multipath is present at lower CPE heights due to clutter caused by car parks and parked vehicles. Since Cyberjaya does not have very high rise buildings, there is also less blockage to the signal propagating from the transmitter to CPEs at greater heights. From the comparison analysis on the measured with the theoretical path loss exponents, it was found that the COST-231 Hata model best estimated the path loss for fixed WiMAX receivers in 2360-2390MHz, especially in open urban environments. The SUI and Egli models over estimated the path loss for both environments.

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