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ASSESSMENT OF DIFFERENT PATH LOSS MODELS FOR WIMAX IN THE URBAN ENVIRONMENT

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Abstract- WiMAX technology is renowned for its ability to facilitate high-speed data transmission. One of the crucial aspects in the early stages of network planning is the accurate prediction of path losses. This research endeavors to compare different path loss models suitable for both mobile and fixed wireless systems, such as WiMAX. To initiate this study, we first introduce various factors contributing to path losses in wireless communication. Subsequently, we meticulously assess the effectiveness of these path loss models within urban settings, spanning across multiple frequency ranges, including those extending to the gigahertz (GHz) spectrum.

Keywords: WiMAX, Path Loss, Models, free space.

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (WiMAX) stands as the latest wireless technology standardized under IEEE 802.16. This cutting-edge system harnesses Orthogonal Frequency Division Multiplexing (OFDM) to achieve high-speed data transmission, operating within the radio frequency range of 2 to 11 GHz.

Under optimal conditions, WiMAX suggests achieving speeds of up to 1 Gbps (in line with the revised IEEE 802.16m standard) with a coverage range of approximately 50 km in a direct line of sight between the transmitter and receiver. However, empirical measurements often yield results quite distinct from these ideal scenarios, offering bit rates that typically range between 7 to 20 Mbps and coverage areas spanning 5 to 8 km. To approach the intended level of performance, researchers have identified several factors that challenge the seamless transmission from transmitter to receiver. These factors include path loss, fading, Doppler spread, and multipath delay spread.

Path loss (PL) arises when an electromagnetic wave travels through space from a transmitter to a receiver. This phenomenon leads to a reduction in signal strength due to various factors, including the distance between transmitter and receiver, reflections, diffraction scattering, free-space loss, and absorption by environmental objects. Additionally, path loss is sensitive to the surrounding environment, including urban, suburban, and rural settings, and can also be affected by changes in the heights of transmitter and receiver antennas.

Path loss (PL) can be quantified using the formula:

PL = Power Transmitted / Power Received (in dB)

This paper encompasses an in-depth examination of various path loss models in Section II. Subsequently, we estimate path loss specifically within a rural environment using MATLAB. The essential parameters used in these models, such as frequency, the distance between the Access Point (AP) and Customer Premises Equipment (CPE), base station height above sea level, building height, road width, building separation, road orientation, and more, have been acquired from Ericsson India to enhance the precision of our estimations.

II. PATH LOSS MODELS

A. FREE SPACE PATH LOSS MODEL

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

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

where,

f: Frequency (MHz)
d: Distance between transmitter and receiver (m) Power is usually expressed in decibels (dBm).

B. COST-231 Hata Model

The COST-231 Hata model is a commonly utilized tool for predicting path loss in mobile wireless systems. This model is an extension of the Hata-Okumura model [2] [3] and is specifically designed for the frequency band ranging from 500 MHz to 2000 MHz. It incorporates adjustments for urban, suburban, and rural (flat) environments. Despite its frequency range slightly exceeding that of empirical measurements, its widespread adoption can be attributed to its simplicity and the ready availability of correction factors for path loss prediction within this frequency band. The fundamental equation for calculating path loss in dB, as outlined in [1], is as follows:

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

In this context, where 'f' represents the frequency in MHz, 'd' denotes the separation between the Access Point (AP) and Customer Premises Equipment (CPE) antennas in kilometers, and 'h' signifies the height of the AP antenna above ground level in meters. The parameter 'cm' is set to 0 dB in suburban or open environments and 3 dB in urban environments. Additionally, the parameter [4] is defined specifically for urban environments.

$$ah_m = 3.20\left(log_{10}(11.75h_r)\right)^2 - 4.97 \quad (2)$$

and for suburban or rural (flat) environments,

$$for\ f > 400MHz ah_m = (1.1log_{10}f - 0.7)h_r - (1.5log_{10}f - 0.8) \quad (3)$$

where, hr is the CPE antenna height above ground level. Observation of (1) to (3) reveals that the path loss exponent of the predictions made by COST-231 Hata model is given by,

nCOST = (44.9 − 6.55 log10(hb))/10. (4)

To evaluate the applicability of the COST-231 model for the 3.5 GHz band, the model predictions are compared against measurements for three different environments namely, rural (flat), suburban and urban

C. ECC-33 Path Loss Model The original Okumura experimental data were gathered in the suburbs of Tokyo [3]. The authors refer to urban areas subdivided into 'large city' and 'medium city' categories. They also give correction factors for 'suburban' and 'open' areas. Since the characteristics of a highly built-up area such as Tokyo are quite different to those found in typical European suburban areas, use of the 'medium city' model is recommended for European cities [5], [6]. Although the Hata- Okumura model [2] is widely used for UHF bands its accuracy is questionable for higher frequencies. The COST-231 model extended its use up to 2 GHz, but it was proposed for mobile systems having omni-directional CPE antennas sited less than 3 m above ground level. A different approach was taken in [7], which extrapolated the original measurements by Okumura and modified its assumptions so that it more closely represents a FWA system. The path loss model presented in [7], is referred to here as the ECC-33 model. The path loss is defined as,

$$PL = A_{fs} + A_{bm} - G_b - G_r \quad (5)$$

where A_{fs}, A_{bm}, G_b and G_r are the free space attenuation, the basic median path loss, the BS height gain factor and the terminal (CPE) height gain factor. They are individually defined as,

$$A_{fs} = 92.4 + 20log_{10}(d) + 20log_{10}(f) \qquad (6)$$

$$A_{bm} = 20.41 + 9.83log_{10}(d) + 7.984log_{10}(f) + 9.56[log_{10}(f)]^2 \qquad (7)$$

$$G_b = log_{10}(h_b/200)\{13.958 + 5.8[log_{10}(d)]^2\} \qquad (8)$$

and for medium city environments,

$$G_b = [42.57 + 13.7log_{10}(f)][log_{10}(h_r) - 0.585] \qquad (9)$$

where, f is the frequency in GHz, d is the distance between AP and CPE in km, is the BS antenna height in meters and hr is the CPE antenna height in meters. The medium city model is more appropriate for European cities whereas the large city environment should only be used for cities having tall buildings. It is interesting to note that the predictions produced by the ECC-33 model do not lie on straight lines when plotted against distance having a log scale. For the sake of completeness, the path loss gradient at 2km will be compared with the path loss predicted by other models. The predictions using the ECC-33 model with the medium city option are compared with the measurements taken in suburban and urban environments.

D. COST Walfisch-Ikegami model

This is the COST 231 proposed Walfisch and Ikigami combined model [8]. This gives a better path loss prediction. Characteristics of urban environment such as, height of buildings (hroof) in m, width of roads (w) in m, building separation (b) in m, and road orientation with respect to the direct radio path ( ). In our analysis we have used 10m for hroof , 12m for w, 20m for b and 630 for . The model has separate equations for Line of Sight (LOS) and Non LOS (NLOS) conditions. Equation (10) gives the equation for NLOS conditions, which we used in our analysis.

PLNLOS(dB) = LFS + Lrts(wr, f, hm,) + LMSD(ht, ht, d, f, bs) (10)

LFS gives free space loss, which is defined in (13), Lrts gives the Roof-to-street loss (14), and LMSD is the multiple screen diffraction loss (16). hm is given by (11) and ht is givenby (12). hm = ht - hroof (11) ht = ht - hroof (12)

where ht gives base station height (m) and hroof gives the height of the building (m).

LFS = 32.4 + 20log10(d) + 20log10(fc) (13) Lrts = -8.8 + 10log10(fc) + 20log10(hm) - 10log10(w) + Lori (14)

In the above equation hm gives the CPE height in m and Lori is the street orientation function which depends on . We used the function (10) for this. Lori = 4.0 - 0.114(- 55) since 550 _ *p*_ 900 (15)

LMSD = Lbsh + ka + kdlog10(d) + kf log10(f) - 9log10(b) (16)

In equation (16), Lbsh is given by (17), Ka is 54, Kd is 18, and Kf is given by (18).

Lbsh = -18 * log10(1 + ht) (17) Kf = -4 + 0.7((fc/925) - 1) (18)

E. Erceg model

This model, developed by Erceg et al., is grounded in empirical data gathered from various suburban areas across the United States, including New Jersey, Seattle, Chicago, Atlanta, and Dallas. The data collection involved diverse base antenna heights, spanning from 12 to 79 meters [9]. The model classifies terrains into three distinct categories:

The highest path loss category corresponds to hilly terrain with moderate-to-heavy tree densities, labeled as Category A.

The lowest path loss category represents mostly flat terrain with light tree densities, designated as Category C.

The intermediate category can be characterized as either mostly flat terrain with moderate-to-heavy tree densities or hilly terrain with light tree densities, referred to as Type B.

This model comes highly recommended by the IEEE 802.16 Broadband Wireless Access Working Group [10]. The calculation of Path Loss in dB is defined by equation (19).

$$PL = A + 10\gamma log_{10}\left(\frac{d}{d_0}\right) + X_f + s \; for\, d > d_0 \quad (20)$$

where, A gives decibel path loss at distance (21), gives path loss exponent (22) and is the shadowing component given by (23). (21) In this λ gives the wavelength in m. (22) The parameter is the base station antenna height in meters (80m 10m), is a zero-mean Gaussian variable of unit standard deviation N[0,1] and a, b, c and are constants for each terrain category given by Table 1.

$$A = 20log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \quad (21)$$

In this λ gives the wavelength in m.

$$\gamma = a - bh_b + {}^{c}/_{h_b} \quad (22)$$

The parameter is the base station antenna height in meters (80m 10m), is a zero-mean Gaussian variable of unit standard deviation N[0,1] and a, b, c and are constants for each terrain category given by Table 1.

$$s = y\sigma \quad (23)$$

Table 1 numerical values of erceg model parameters

Model Parameter	Terrain Type A	Terrain Type B	Terrain Type C
A	4.6	4.0	3.6
B	0.0075	0.0065	0.0050
C	1.26	17.1	20.0
σ_γ	0.57	0.75	0.59
μ_σ	10.6	9.6	82
σ_σ	2.3	3.0	1.6

F. Hata-Okumura model

This model is best suited for large cell coverage (distances up to 100 km), and it can extrapolate predictions in the 150 - 1500 MHz band. Also, this is the widely used model for most of the signal strength predictions in macro-cellular environment [2], [3]. Although, its frequency band is outside the band of Fixed WiMAX, its simplicity has made it used widely in propagation predictions. The path loss equation is given by (2).

$$PL_{urb} = 69.55 + 26.16log_{10}(f_c) - 13.82log_{10}(h_t) - a(h_m) + [44.9 - 6.55log_{10}(h_t)]log_{10}(d) \quad (24)$$

f_c is the operating frequency in MHz, and are the BTS antenna height and the CPE height in m, d is the distance from BTS to CPE in km and is the Correction factor for mobile unit antenna height in dB.

$$a(h_m) = 3.2(log_{10}(11.75h_m))^2 - 4.97 \quad (25)$$

III. RESULTS

The following graphs represent the variation of path loss with distance between transmitter and receiver. The base station height has been kept constant at 30m.

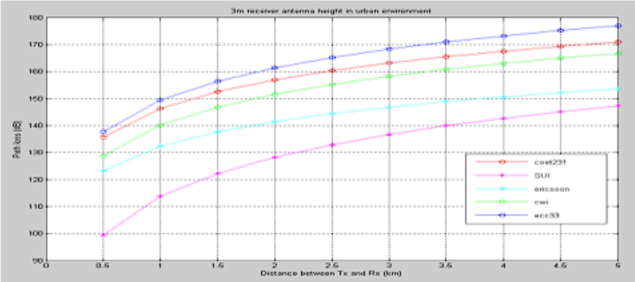

Figure1: 3m receiver antenna height

In Figure 1, a graphical representation displays plots for a receiver antenna height of 3 meters, where the SUI path loss model demonstrates the lowest path loss among the compared models, under specific conditions.
Figure 2 and Figure 3 depict graphical representations showcasing plots for receiver antenna heights of 6 meters and 10 meters, respectively. In both cases, the SUI path loss model emerges as the one with the minimum path loss among the compared models, under the same specified conditions.

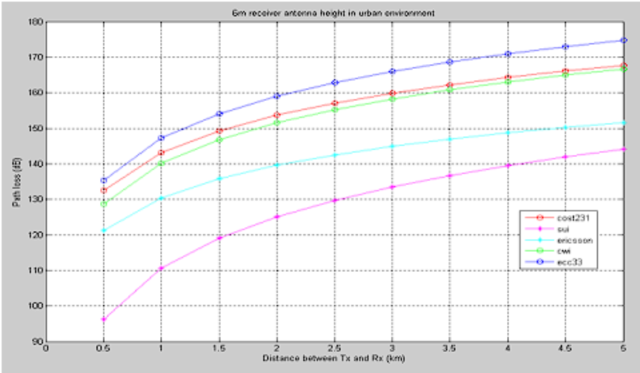

Figure: 6m receiver antenna height

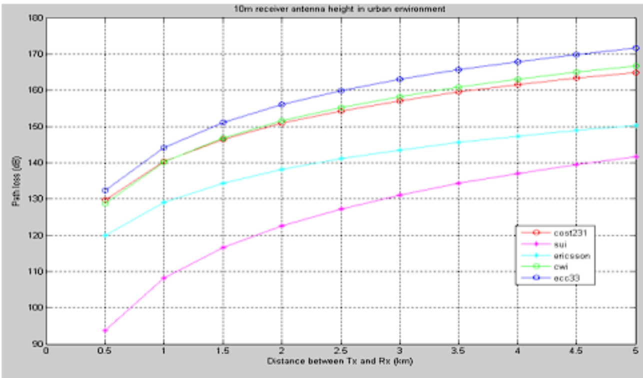

Figure: 10m receiver antenna height

IV CONCLUSION

Propagation models serve a dual role, being essential not just for installation guidance but also as a critical element in interference mitigation-oriented design. Specifically in urban environments, the SUI path loss model has exhibited the least path loss when compared to alternative models, under specified conditions.

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