Comparison of Propagation Models Accuracy for WiMAX on 3.5 GHz

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Abstract— **Fixed Wireless Access (FWA) networks based on WiMAX technology provide efficient packet radio interface enabling high data transmission rates. The accurate prediction of path losses is a crucial element in the first step of network planning. This paper presents few empirical models suitable for path loss prediction in mobile as well as fixed wireless systems like WiMAX. Experimental measurements of received power for the 3.5 GHz WiMAX system are made in urban and suburban areas of Osijek, Croatia. Measured data are compared with those obtained by four prediction models: SUI model, COST 231 Hata, Macro Model and Model 9999. Analysis is made separately for location with NLOS and LOS propagation conditions. Standard deviation of the prediction error for NLOS condition is the lowest for the SUI model. The Macro Model achieved the lowest error standard deviation for LOS propagation conditions.**

I. INTRODUCTION

Worldwide Interoperability for Microwave Access (WiMAX) is the newest wireless broadband Internet technology based on the IEEE 802.16 standard. WiMAX is a Fixed Wireless Access (FWA) network suitable for broadband services on areas without adequate cable infrastructure. This system is based on the Orthogonal Frequency Division Multiplex (OFDM) and realizes broadband data transmission by using a radio-frequency range of 2-11 GHz and 10-66 GHz. An important feature of an OFDM system is a possibility of successful communication even under non-line-of-sight (NLOS) propagation condition. WiMAX uses adaptive modulation which is dependent on the signal to noise ratio (SNR). In a difficult propagation condition with a high level of interference or with a weak signal on the receiver antenna, the system chooses a more robust and slower modulation and ensures transmission.

In an ideal condition, WiMAX offers a bit rate of up to 75 Mbps, within the range of 50 km, which depends on radio-optical visibility between the transmitter and the receiver. So far, measurements on the field, under real conditions show significant degradation of declared characteristics, i.e. the coverage range between 5 and 8 km and the bit rate of up to 2 Mbps.

Installation of WiMAX systems is in the early phase in different countries across the world, so practical application results of this system are only expected in the future. WiMAX as broadband access technology is being introduced in the Republic of Croatia on 3.5 GHz. In this paper, measurement results of received power are compared with results obtained by different prediction models. Measurements are taken in Osijek, Croatia in the Spring of 2007.

II. RADIO PROPAGATION MODELS

In wireless communication systems information is transmitted between the transmitter and the receiver antenna by electromagnetic waves. During propagation, electromagnetic waves interact with environment what causes the path loss. Path loss (PL) is defined as the difference between transmitted and received power (in dB) as shown in (1)

$$PL = P_T + G_T + G_R - P_R - L_T - L_R \quad [dB] \quad (1)$$

where P_T and P_R are transmitted and received power, G_T and G_R are the gain of transmitting and receiving antenna, respectively, and L_T and L_R are feeder losses.

WiMAX systems operating in the frequency range of 2-11 GHz are suitable for communication even in NLOS conditions, when direct visibility between the transmitting and the receiving antenna does not exist. In this scenario the receiver exploits reflected, diffracted and scattered components of a radio wave, which reach the receiving antenna.

For the purpose of wireless network planning, propagation models are used for the electric field strength calculation. There are two main types of models for characterizing path loss: deterministic (site-specific theoretical) and empirical (statistical) models. The former makes use of some physical laws governing electromagnetic wave propagation and calculates received signal power at a particular location. These models require detailed geometric information on terrain profile, location and dimensions of buildings, and so on. Empirical models are based on measurements and predict mean path loss as a function of various parameters, e.g. antenna heights, distance, frequency, etc. Empirical models are easier to implement, with less computational cost, but they are less accurate.

Propagation prediction for WiMAX systems is usually conducted with one of empirical models. Most often used are various extensions of Hata model, [1], as Stanford University Interim model (SUI), [2], COST-231 Hata [3], Macro Model, [4], and Ericsson Model 9999, [4].

A. Stanford University Interim (SUI) model

SUI prediction model is developed under the Institute of Electrical and Electronic Engineers (IEEE) 802.16 Broadband Wireless Access Working Group. This model is an extension of the Hata model with correction parameters for frequencies above 1900 MHz. SUI model is proposed as a solution for planning the WiMAX network on a 3.5 GHz band.

SUI model can be used for the base station antenna height from 10 m to 80 m, the receiving antenna height between 2 m and 10 m and the cell radius between 0.1 km and 8 km, [2].

Novelty of this model is the introduction of the path loss exponent, γ, and the weak fading standard deviation, s, as random variables obtained through a statistical procedure. The model distinguishes three types of terrain, called A, B and C. Type A presents a terrain with the highest path loss and can be used for hilly areas with moderate or very dense vegetation. Type B is mainly characteristic of flat terrains with moderate or very dense vegetation or hilly terrains with rare vegetation. Type C is suitable for flat terrains with rare vegetation where path loss is the lowest.

The basic expression for path loss calculation according to the SUI model is given by (2)

$$PL = A + 10\gamma \log_{10}(\frac{d}{d_0}) + X_f + X_h + s \quad for \ d > d_0 \quad (2)$$

where d (in meters) is the distance between the base station and the receiving antenna, d_0=100 m, X_f is a correction for frequency above 2 GHz, X_h is a correction for the receiver antenna height, and s is a correction for shadowing because of trees and other clutters on a propagation path. Parameter A is defined as follows

$$A = 20\log_{10}(\frac{4\pi d_0}{\lambda}) \quad (3)$$

where λ is the wavelength in meters. Path loss exponent γ is given by (4)

$$\gamma = a - bh_B + \frac{c}{h_B} \quad (4)$$

where h_B is the base station antenna height in meters, and a, b and c are constants dependent on the terrain type, as given in Table 1. For free space propagation in an urban area the path loss exponent γ=2, in urban NLOS environment $3<\gamma<5$, and for indoor propagation $\gamma>5$.

TABLE I.   TERRAIN TYPE FOR SUI MODEL

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

The correction factors for the operating frequency and for the receiver antenna height for the model are

$$X_f = 6.0\log(\frac{f}{2000}) \quad (5)$$

and,

$$X_h = -10.8\log(\frac{h_r}{2000}) \quad \text{for terrain types A and B} \quad (6)$$

$$X_h = -20.0\log(\frac{h_r}{2000}) \quad \text{for terrain type C} \quad (7)$$

where, f is the frequency in MHz, and h_r is the receiver antenna height in meters. The SUI model is used for path loss prediction in rural, suburban and urban environments.

B. COST 231 Hata propagation model

The Hata model, [1], gives a mathematical expression fitting the values of graphical data provided by the Okumura model, [5]. The Hata model gives prediction of the median path loss for the frequency range of 150 MHz ≤ f ≤ 1500 MHz, for distance d from the base station to the receiver antenna up to 20 km, the transmitting antenna height between 30 m and 200 m, and the receiving antenna height between 1 m and 10 m. COST 231 Hata model is an extension of Hata model for the frequency range which is 1500<f (MHz)< 2000. The expression for median path loss, PL_U, in urban areas is given by

$$PL_U = 46.3 + 33.9\log(f) - 13.82\log(h_B) - a(h_r) + (44.9 - 6.55\log(h_B))\log(d) + c_m \qquad (8)$$

where d is the distance in meters, f is frequency in MHz, h_B and h_r are effective heights of the base station and receiver antennas in meters, respectively. The parameter c_m is defined as 0 dB for suburban of open rural environments and 3 dB for urban environments.

For small-to-medium-sized cities $a(h_r)$ is given by:

$$a(h_r) = (1.1 \cdot \log(f) - 0.7) \cdot h_r - (1.56 \cdot f - 0.8) \qquad (9)$$

For a large city, it is given by

$$a(h_r) = 3.20 \cdot (\log(11.75 h_r))^2 - 4.97 \qquad (10)$$

C. *Macro Model*

Macro Model, [4] is based on the Hata model and includes correction of every factor that influences the propagation path loss. Therefore, this model can be calibrated by changing parameters to better fit propagation conditions.

Path loss, PL_U, is given by the following expression

$$PL_U = k_{off} + k_{\log(d)} \cdot \log(d) + k_{hr} \cdot h_r + k_{\log(hr)} \cdot \log(h_r) + k_{\log(hB)} \cdot \log(h_B) + k_{\log(hB) \cdot \log(d)} \cdot \log(h_B) \cdot \log(d) \qquad (11)$$

where k_{off} is a constant which regulates the absolute value of path losses, $k_{log(d)}$ regulates path loss dependence on the distance, k_{hr} is correction factor for receiver antenna height gain, $k_{log(hr)}$ is the Okumura-Hata multiplying factor for h_r, $k_{log(hB)}$ is the base station antenna height gain factor and $k_{log(hb)log(d)}$ is the Okumura-Hata multiplying factor for $log(h_B)log(d)$.

D. *Ericsson Model*

Model 9999, [4] is the Ericsson's implementation of the Hata model. In this model a change of model parameters is possible according to propagation environment.

Path loss is given by the expression

$$PL_U = a_0 + a_1 \cdot \log(d) + a_2 \cdot \log(h_B) + a_3 \cdot \log(h_B) \cdot \log(d) - 3.2(\log(11.75 \cdot h_r))^2 + g(f) \qquad (12)$$

where $g(f)$ is defined by

$$g(f) = 44.49 \cdot \log(f) - 4.78(\log(f))^2 \qquad (13)$$

Parameters a_0, a_1, a_2 and a_3 are constants, which can be changed for better fitting specific propagation conditions. Default values are: a_0=36.2, a_1=30.2, a_2=-12.0 and a_3=0.1.

III. EXPERIMENTAL RESULTS

Experimental measurements of radio propagation characteristics are made in urban and suburban areas for a WiMAX system working at 3.5GHz. Measurements are carried out in the Osijek city area and its suburban region. Osijek is a medium-sized city in Croatia, with a high percent of residential areas. Transmitting antenna height, h_B, is 59 m, and receiving antenna height, h_r, is 3 m. Receiver power is measured at 28 locations, which are selected to reflect two distinctive propagation scenarios: LOS propagation path with direct visibility between antennas, and NLOS propagation path without direct visibility. At each location 33 measurements were taken, i.e. every 20 cm along with the line connecting the base station and receiver antennas, as well as every 20 cm perpendicular to that line. The mean value of measurements at each location is compared with results obtained with four statistical models: SUI for C terrain type, COST 231 Hata, Model 9999 and Macro Model.

Results of measurements as well as predictions of the receiver power obtained by models are given in Fig. 1. for NLOS propagation condition. In this case, the best prediction model is SUI with the prediction error standard deviation σ_{NLOS}=3.5 dB. The COST 231 Hata model underestimates receiver power until the Macro Model and the Model 9999 overestimate receiver power. Prediction error standard deviations for LOS and NLOS measurement are given in Table 2. Standard deviation for the COST 231 Hata is σ_{NLOS}=6.5 dB, for the Macro Model σ_{NLOS}=10.29 dB, and for the Model 9999 σ_{NLOS}=8.8 dB. Fig. 2 shows measurement and prediction results for LOS propagation conditions. The best prediction model in this case is the Macro Model, and the Model 9999 is only slightly worse. For LOS propagation condition the SUI model gives σ_{LOS}=13.15, what is higher than referred to in literature, [6].

TABLE II. ERROR STANDARD DEVIATION

Error standard deviation, σ	SUI Terrain type C	COST 231 Hata	Macro Model	Model 9999
σ_{NLOS} (dB)	3.5	6.5	10.29	8.8
σ_{LOS} (dB)	13.15	17.81	5.27	6.36

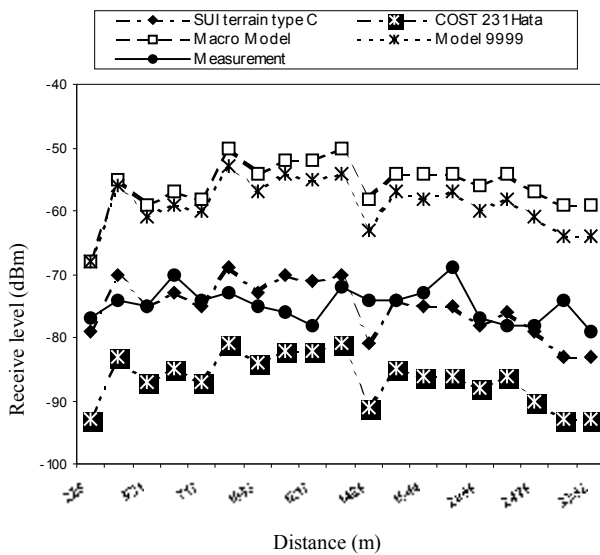Figure 1. Dependency of receive level on distance for different propagation models in NLOS conditions

Figure 2. Dependency of receive level on distance for different propagation models in LOS conditions

Measurements show a very interesting feature that receiver power does not decrease with the distance. This phenomenon can be explained with a wave-guiding effect of city streets as well as the existence of radio wave components reflected and diffracted on buildings reaching the receiver antenna. The OFDM system can effectively use these multipath components because of the guard period incorporated in the signal.

IV. CONCLUSION

The goal of this paper is a comparison of propagation model accuracy under different propagation conditions in a 3.5 GHz frequency band. Measurements are taken for an installed WiMAX system in Osijek, Croatia. The SUI model gives most accurate results for NLOS, but with a high level of prediction error for the location with LOS propagation. Although this model adapts different parameters to a specific propagation condition, its main shortcoming is the lack of distinguishing urban, suburban and rural environments. In the SUI model terrains are divided into three categories, A, B, C, which may be chosen arbitrarily and therefore it is a source of an additional error. The error propagation standard deviation for the SUI model for joined NLOS and LOS results is $\sigma_{LOS+NLOS}$=9.10 dB, what agrees with results referred to in literature, [6].

The Macro Model and the Model 9999 show worse

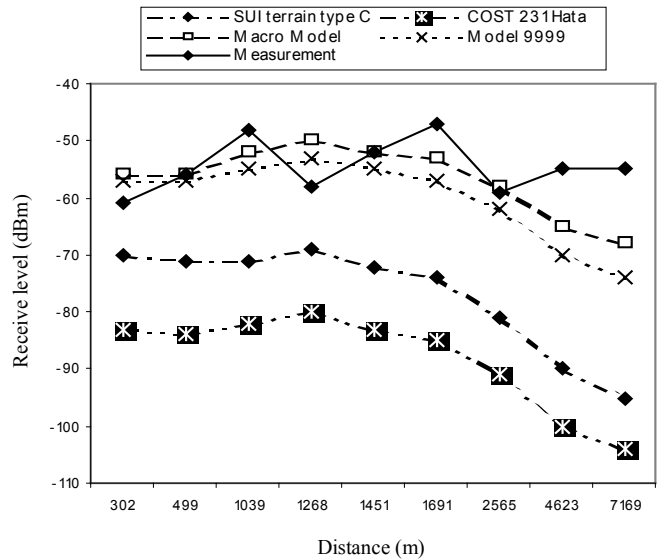performance for NLOS propagation, while the results for LOS propagation condition obtained with this prediction model are better than the results obtained with the SUI and the COST 231 Hata model.

Neither of the prediction models used has been suitable for both NLOS and LOS propagation in our experiment. Experimental results show that separation of prediction for NLOS and LOS conditions improves prediction accuracy if the most suitable model is chosen for a given location.

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