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RESEARCH ARTICLE

IMPACT OF BUILDING ON THE PERFORMANCE OF WIMAX COMMUNICATION SYSTEM

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ABSTRACT

In the last era, the technology of WiMAX (3G) was broadly used for wireless communication systems in many reigns around the world due to its rich set of features with promising broadband wireless access networks. In this paper the ray tracing combined with uniform theory of diffraction (UTD),intention UTD modified heuristic diffraction coefficient for non-perfectly conducting wedges will be used to evaluate the normalized received signal at the end user versus the mobile distance. The combination of single and double diffracted, reflected and direct rays will produce 8 different rays are considered. The required mathematical propagation model of given model will be derived and implemented using Matlab simulator. The mobile movement from base station that is potentially in Non-Line-Of-Sight (NLOS) and Line-Of-Sight due to lossy building will be tested within three residential areas. Free space loss and fading due to multipath channel are the main causes of signal degradation of the propagated signal. The simulations were based on the changes of system parameters which are base station's antenna height, horizontal distance between base station and mobile station, mobile station's height and building dimensions.

Key Words: Signal Strength, Propagation, Ray Tracing, Diffraction.

INTRODUCTION

Due to the advance needs for mobility and wireless broadband systems. WiMAX is a wireless communication system that can provide long distance wireless broadband access with high data throughput in a point to multipoint connection and line of sight or non-line of sight environment. Mobile WiMAX delivers high-speed access wirelessly, enabling seamless mobile broadband services over large coverage areas. Much activity is instigated by the increment of mobile devices and mobile applications. A mobile extension to the low-frequency 802.16 standard is now being developed by the IEEE 802.16e working group. This extension will support delivery of broadband data to a moving wireless terminal, such as a laptop computer with an integrated WiMAX modem (Yegani, Parviz, 2005). While the performance measurement over mobile WiMAX/IEEE 802.16e network as a subset of IEEE 802.16e, WiBro employs orthogonal frequency division multiple access (OFDMA) and time division duplexing (TDD) schemes operating at 2.3 GHz bands was analyzed (Kim, Dongmyoung, *et al*., 2008).

And WiMAX has potential success in its line-of-sight (LOS) and non-line-of-sight (NLOS) conditions which operating below 11 GHz frequency to compare and analyze five path loss models (i.e. COST 231 Hata model, ECC-33 model, SUI model, Ericsson model and COST 231 Walfish-Ikegami model) in urban, suburban and rural environments in NLOS condition (Shahajahan *et al*., 2009). Therefore, different path loss models are compared depending on various parameters like frequency, height of receiver antenna, distance between transmitter and receiver etc (Alam *et al*., 2013). One of these models is a deterministic model which make use of the laws governing electromagnetic wave propagation to determine the received signal power at a particular location. An example of a deterministic model is ray tracing model (Athanasiadou *et al*., 2000).

And there are numerous papers explain the use of ray tracing in wimax (Luntovskyy *et al*., 2006). For the calculation of the ray contributions in deterministic methods, a combination of geometrical optics (GO) and uniform theory of diffraction (UTD) was applied (Ramirez *et al*., 2003). An expression for the diffracted electric field is derived in closed form and given in terms of the UTD transition function, where the diffraction contributions are evaluated by means of uniform asymptotic physical optics solution (Gennarelli and Riccio, 2009). This diffraction model of lossy wedge is intended for predicting the electric field in microcellular environments. In this paper, the received signal at mobile terminal is predicted by using uniform theory of diffraction (UTD) with ray optics to model the radio wave propagation in a WiMAX cell when the lossy building is a blockage between the base station and the mobile.

An Omni dimensional base station antenna radiates the signal of frequency 2.3GHz. A mathematical model is introduced by deriving equations to calculate the received signal due to each path which reaches the mobile phone from base station antenna, and predicting the signal strength at mobile by adding the received signals of each path.

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The model takes into account all significant multi path signals that originate from base station to the mobile station including direct, reflected and diffracted paths, or any complicated of these paths. Furthermore, the propagation attenuation and fading statistics are the main causes of signal degradation. Therefore, the performance is checked by computing the signal level versus mobile location.

Suggested Propagation Model

The downlink communication in WiMAX cellular system is sheds light of this research; taking into consideration the impact of building on communication performance. The geometry of the propagation model is illustrated in Figure 1.A mobile antenna of height h_m moving above the surface of ground behind the building of height and width h_b,w_b respectively, with the distance x_m. A base station antenna of height h_{bs} is installed away from the building at a distance x_b to radiates a spherical wave that can be represented as rays reaching a mobile terminal where these rays obstructed by the building. The received signals from different paths encounter the same gain. The incident ray from the base station antenna might undergo reflection from ground surface, diffraction from building edges A and B shown in Figure 1.

As the uniform theory of diffraction (UTD) (Kouyoumjian and Pathak, 1974) considers diffraction from only perfectly conducting wedges, we used a UTD modified heuristic diffraction coefficient for non-perfectly conducting wedges (Holm, 2000) in order to compute the diffraction coefficients of the points A and B shown in Figure 1. The frequency of transmitted signal from WiMax base station to the mobile is 2.3 GHz. At this frequency, the building is assumed to be lossy dielectric and the earth is assumed to be locally flat. The values of conductivity σ are 0.005 S/m, 0.092 S/m for ground and building, respectively, whereas the relative permittivity ε_r is 15, 5.5 for ground and building, respectively, at frequency of 900 MHz. (Pena *et al*., 2003), by increasing the frequency to 2.3 GHz, same values will be used in the calculation of reflection and diffraction coefficients because the error caused by ignoring the conductivity is less than 5%, even when the conductivity is as high as 0.1 S/m (Zhou, Chenming *et al*., 2013). However, the model can be applied for other dimensions, parameters, and frequencies provided that the base station height is greater than the building height.

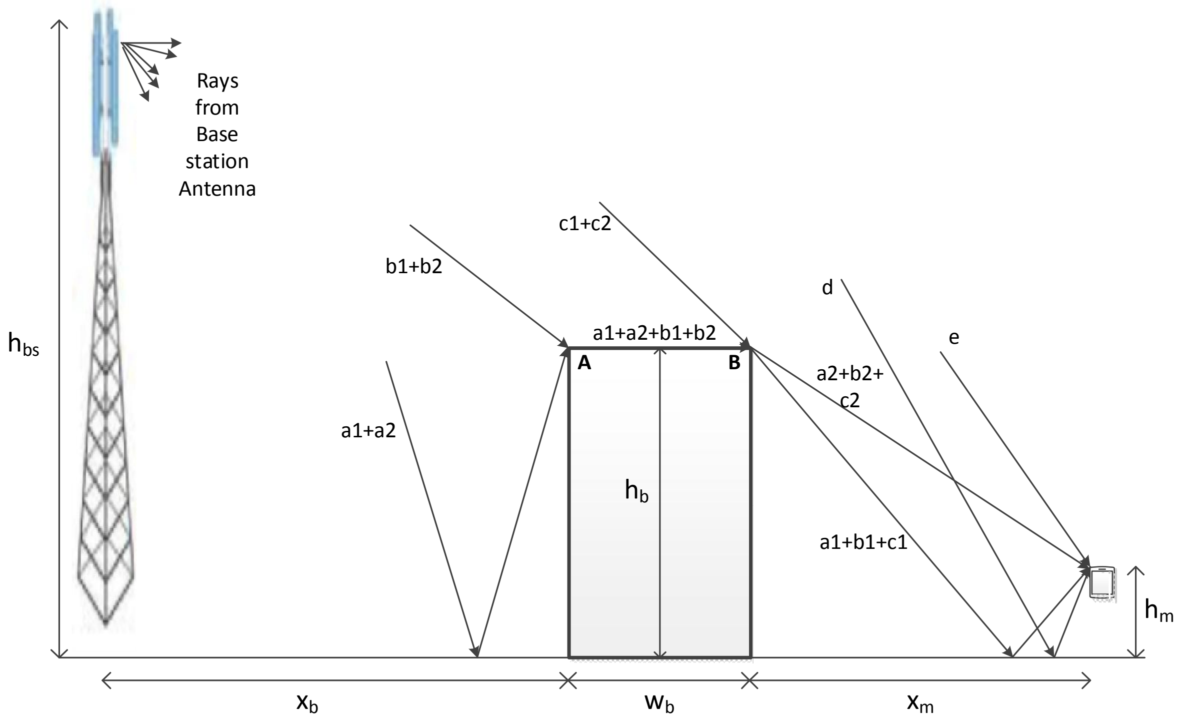

Figure 1. Propagation model: different received ray contributions at mobile

Ray Tracing

The received signal at the mobile antenna is estimated for different ray paths with different angles. The most significant ray contributions are taken into account. Depending on elevation angle θ of incident ray, different ray contributions can reach the mobile, and they contribute to the intensity of the electromagnetic field at the mobile antenna.

The ray contributions referring to Figure1are:

a1) ground reflection then second order diffraction then ground reflection.
a2) ground reflection then second order diffraction.
b1) second order diffraction then ground reflection.

b2) second order diffraction
c1) first order diffraction then ground reflection
c2) first order diffraction
d) Ground reflection
e) Directory

The angles shown in Figure 2 are as follows:

$\theta = \tan^{-1}\frac{h_{bs}-h_m}{x_b+w_b+x_m}$... (1)

$\theta_B = \tan^{-1}\frac{h_{bs}-h_b}{x_b+w_b}$... (2)

$\theta_{dx} = \tan^{-1}\frac{h_{bs}+h_m}{x_b+w_b+x_m}$ ... (3)

Where

θ:Elevation angle of incident ray.
θ_B:Minimum angle at which a direct ray is seen by the mobile.
θ_{dx}:Minimum angle at which a reflected ray is seen by the mobile.

As explained below, the elevation angle of the incident ray$\theta$is divided into three zones as shown in Figure 2 and Figure 1, according to ray contributions to the received signal.

1) $\theta_B \le \theta$, the mobile receives total rays ofa1, a2, b1, b2, c1and c2.
2) $\theta_{dx} \le \theta < \theta_B$, the mobile receives total rays of a1, a2, b1, b2, c1, c2 and d.
3) $\theta < \theta_{dx}$, the mobile receives total rays of a1, a2, b1, b2, c1, c2, d and e.

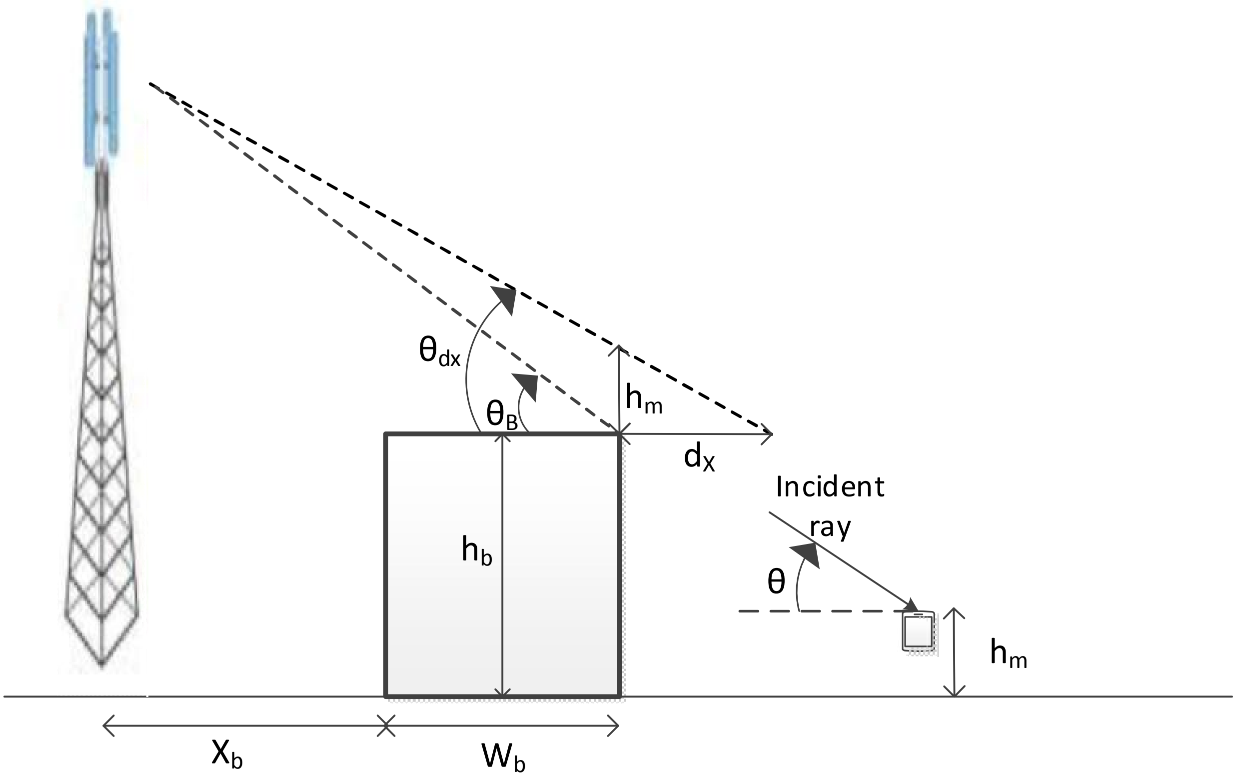

Figure 2. Zones for ray contributions due to building blockage

Formulation of the ray contribution

The polarization soft (horizontal) equations are presents, for the signal that reaches the mobile phone is given in terms of the incident electric field at mobile denoted by E_n^i, while for hard (vertical) polarization, the signal is given in terms of magnetic field H_n^i. The path length from base station antenna to the mobile terminal is called r for non-diffracted rays and is split into s_1, s_2 and sometimes s_3 for diffracted rays. The number n indicates the path number identified in the equations below, these equations includes the 8 different ray paths derived to implement this model. The rays reach the mobile antenna by different paths with different angles. The reflection coefficients of lossy ground ($\Gamma^s$and Γ^h) for vertical and horizontal polarizations, respectively, can be found in (Haupt, 2010). The complex permittivity of the ground is expressed as $\varepsilon_r = 15 - j90/f$, where f is the frequency in MHz. For parameters $(D_A^s, D_A^h, D_B^s, D_B^h)$ D refers to the diffraction coefficient, superscript s refers to soft polarization, h hard polarization, subscripts A and B are diffraction points shown in Figure1.

In the following equation, from simple geometrical considerations, mathematical representation for each significant ray contribution is given. These rays are depicted in Figures 2 and 3.

a1) Ground reflection then second order diffraction then ground reflection.

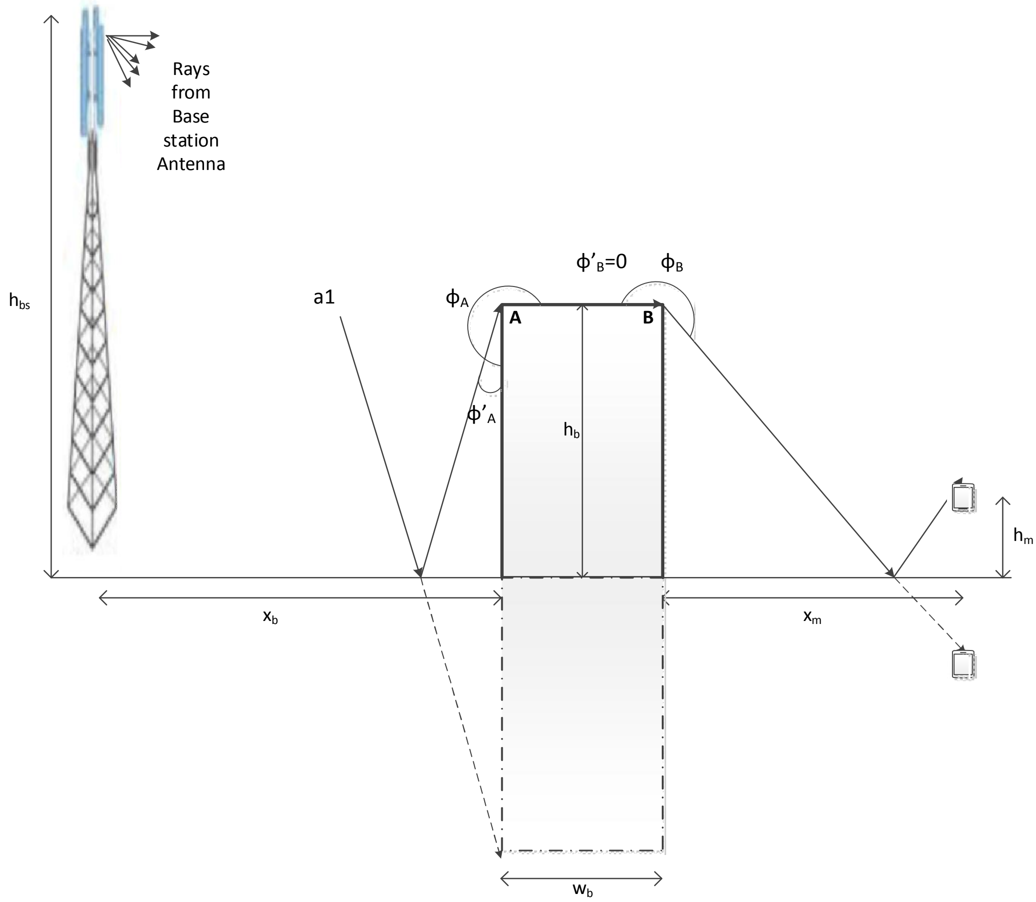

Figure 3. Formulation of ray a1

$$E_1^i = E_0 \frac{e^{-jks_T}}{s_T} \Gamma^s\left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_b}{x_b}\right)\right) \Gamma^s\left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_m}\right)\right) D_A^s D_B^s \ldots (4)$$

$$H_1^i = H_0 \frac{e^{-jks_T}}{s_T} \Gamma^h\left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_b}{x_b}\right)\right) \Gamma^h\left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_m}\right)\right) D_A^h D_B^h \sqrt{\frac{s_T}{s_1 s_2 s_3}} \ldots (5)$$

$$s_{T=} \; s_1 + s_2 + s_3 \ldots (6)$$

$$s_1 = \sqrt{(h_{bs} + h_b)^2 + (x_b)^2} \ldots (7)$$

$$s_{2=w_b} \ldots (8)$$

$$s_3 = \sqrt{(h_b + h_m)^2 + (x_m)^2} \ldots (9)$$

$$\acute{\emptyset}_A = \frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_b}{x_b}\right) \ldots (10)$$

$$\emptyset_A = \frac{3\pi}{2} \ldots (11)$$

$\acute{\emptyset}_B = 0 \ldots (12)$

$\emptyset_B = \frac{3\pi}{2} - \tan^{-1}(\frac{x_m}{h_b+h_m}) \ldots (13)$

a2) Ground reflection then second order diffraction.

$$E_2^i = E_o \frac{e^{-jks_T}}{s_T} \Gamma^s \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_b}{x_b}\right)\right) D_A^s D_B^s \sqrt{\frac{s_T}{s_1 s_2 s_3}} \ldots (14)$$

$s_{T=}\ s_1 + s_2 + s_3 \ldots (15)$

$s_1 = \sqrt{(h_{bs}+h_b)^2 + (x_b)^2} \ \ldots\ (16)$

$s_2 = w_b \ldots (17)$

$s_3 = \sqrt{(h_b - h_m)^2 + (x_m)^2} \ldots (18)$

b1) Second order diffraction then ground reflection.

$$E_3^i = E_o \frac{e^{-jks_T}}{s_T} \Gamma^s \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_m}\right)\right) D_A^s D_B^s \sqrt{\frac{s_T}{s_1 s_2 s_3}} \ldots (19)$$

$$H_3^i = H_o \frac{e^{-jks_T}}{s_T} \Gamma^h \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_m}\right)\right) D_A^h D_B^h \sqrt{\frac{s_T}{s_1 s_2 s_3}} \ldots (20)$$

$s_{T=}\ s_1 + s_2 + s_3 \ldots (21)$

$s_1 = \sqrt{(h_{bs} - h_b)^2 + (x_b)^2} \ldots (22)$

$s_2 = w_b \ldots (23)$

$s_3 = \sqrt{(h_b + h_m)^2 + (x_m)^2} \ldots (24)$

b2) Second order diffraction

$$E_4^i = E_o \frac{e^{-jks_T}}{s_T} D_A^s D_B^s \sqrt{\frac{s_T}{s_1 s_2 s_3}} \ldots (25)$$

$$E_4^i = H_o \frac{e^{-jks_T}}{s_T} D_A^h D_B^h \sqrt{\frac{s_T}{s_1 s_2 s_3}} \ldots (26)$$

$s_{T=}s_1 + s_2 + s_3 \ldots (27)$

$s_1 = \sqrt{(h_{bs} - h_b)^2 + (x_b)^2} \ldots (28)$

$s_2 = w_b \ldots (29)$

$s_3 = \sqrt{(h_b - h_m)^2 + (x_m)^2} \ldots (30)$

c1) First order diffraction then ground reflection

$$E_5^i = E_o \frac{e^{-jks_T}}{s_T} \Gamma^s \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_m}\right)\right) D_B^s \sqrt{\frac{s_T}{s_1 s_2}} \ldots (31)$$

$$H_5^i = H_o \frac{e^{-jks_T}}{s_T} \Gamma^h \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_m}\right)\right) D_B^h \sqrt{\frac{s_T}{s_1 s_2}} \ldots (32)$$

$s_{T=}s_1\ + s_2 \ldots (33)$

$s_1 = \sqrt{(h_{bs} - h_b)^2 + (x_b + w_b)^2} \ldots (34)$

$s_2 = \sqrt{(h_b + h_m)^2 + (x_m)^2}$ … (35)

c2) First order diffraction

$$E_6^i = E_o \frac{e^{-jks_T}}{s_T} D_B^s \sqrt{\frac{s_T}{s_1 s_2}} \dots (36)$$

$$H_6^i = E_o \frac{e^{-jks_T}}{s_T} D_B^h \sqrt{\frac{s_T}{s_1 s_2}} \dots (37)$$

$$s_T = s_1 + s_2 \dots (38)$$

$$s_1 = \sqrt{(h_{bs} - h_b)^2 + (x_b + w_b)^2} \dots (39)$$

$$s_2 = \sqrt{(h_b - h_m)^2 + (x_m)^2} \dots (40)$$

d) Ground reflection

$$E_7^i = E_0 \Gamma^s \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_b+w_b+x_m}\right)\right) e^{-jkr} \frac{1}{r} \dots (41)$$

$$H_7^i = E_0 \Gamma^h \left(\frac{\pi}{2} - \tan^{-1}\left(\frac{h_{bs}+h_m}{x_b+w_b+x_m}\right)\right) e^{-jkr} \frac{1}{r} \dots (42)$$

$$r = \sqrt{(h_{bs} + h_m)^2 + (x_b + w_b + x_m)^2} \dots (43)$$

e) Direct ray

$$E_8^i = E_0 e^{-jkr} \frac{1}{r} \dots (44)$$

$$H_8^i = H_0 e^{-jkr} \frac{1}{r} \dots (45)$$

RESULTS AND DISCUSSION

This section analyzes the normalized signal strength for soft and hard polarizations of the received signal level at the moving mobile terminal behind the building versus the mobile distance. The transmitted fields from the base station are normalized (set to unity value) at 1 m away from the transmitted base station Omni-directional antenna. The simulation results are verified by using a Matlab simulator. As a mobile WiMAX application undergo to IEEE 802.16e standard, the current implemented operating frequency at one of its licensed band 2.3 GHz. This model is deemed in urban, suburban and rural environments, which have typical parameters applied for heights of the mobile, base station antenna, building dimensions and horizontal distance between the building and mobile station according to Table 1.

Table 1. Simulation Parameters

Parameters	Urban	Suburban	Rural
Base station antenna height	30 m	30 m	20 m
Mobile antenna height	1.5 m, 3 m	1.5 m, 3 m	1.5 m, 3m
Horizontal distance between the base station and the building	50 m,100 m	50 m,100 m	50 m,100 m
Building height	15 m	12 m	6 m
Building Width	10 m	8 m	4 m

From Fig. 4, for all environments (urban, suburban and rural) it is seen that the received signal decreases as the mobile distance increased due to free space attenuation. In urban environment, the mobile is being in non-line of sight when the distance between the building and the mobile is less than 53.98m (the elevation angle $\theta = 0.245$), since the first six rays from a1….c2 reaching the mobile, and during that it is seen at first few meters the average signal level is very low due to the diffracted field is low with high diffracted angle (approximately a few degrees less than $3\pi/2$) and as long as the distance increases the diffracted angle is gradually decreases that leading to raising the diffracted fields from edge B shown in Fig.1. After that distance range, the direct ray will reach the mobile to be in line of sight. At the distance 66.1m the reflected ray from the ground plane will reach the mobile, at this distance point the maximum signal has been achieved (-35.62 dB) because the minimum signal path distance in case all rays are reaching the mobile is obtained.

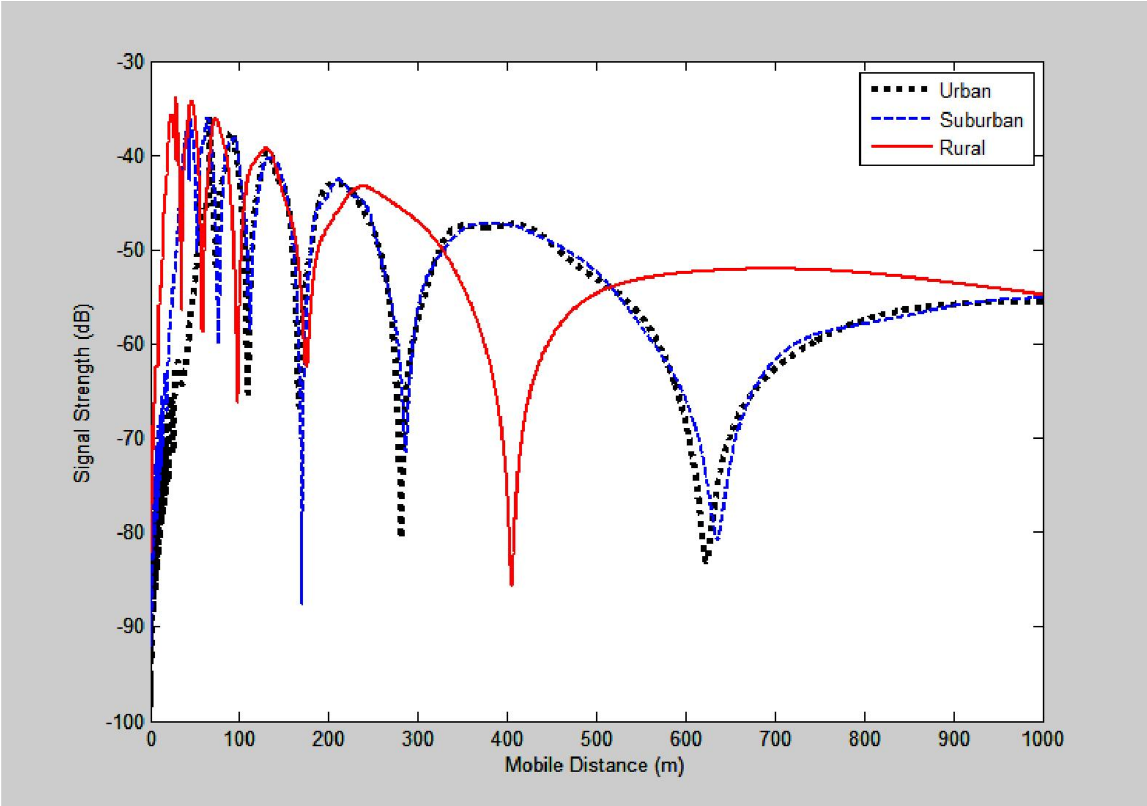

Figure 4. Normalized signal strength for soft polarization signal at x_b=50, h_m=1.5 in urban, suburban, rural environments

It is seen that the received signal increases due to the increase in BS antenna height for all the environments and it is seen that the received signal increases with the increase in MS antenna height for all the environments. Ripples in the received signal, for distances less than 700 m, are attributed to the constructive and destructive interferences between the multiple ray paths. The curve strictly decreasing due to the difference between the multiple rays is minimizing.

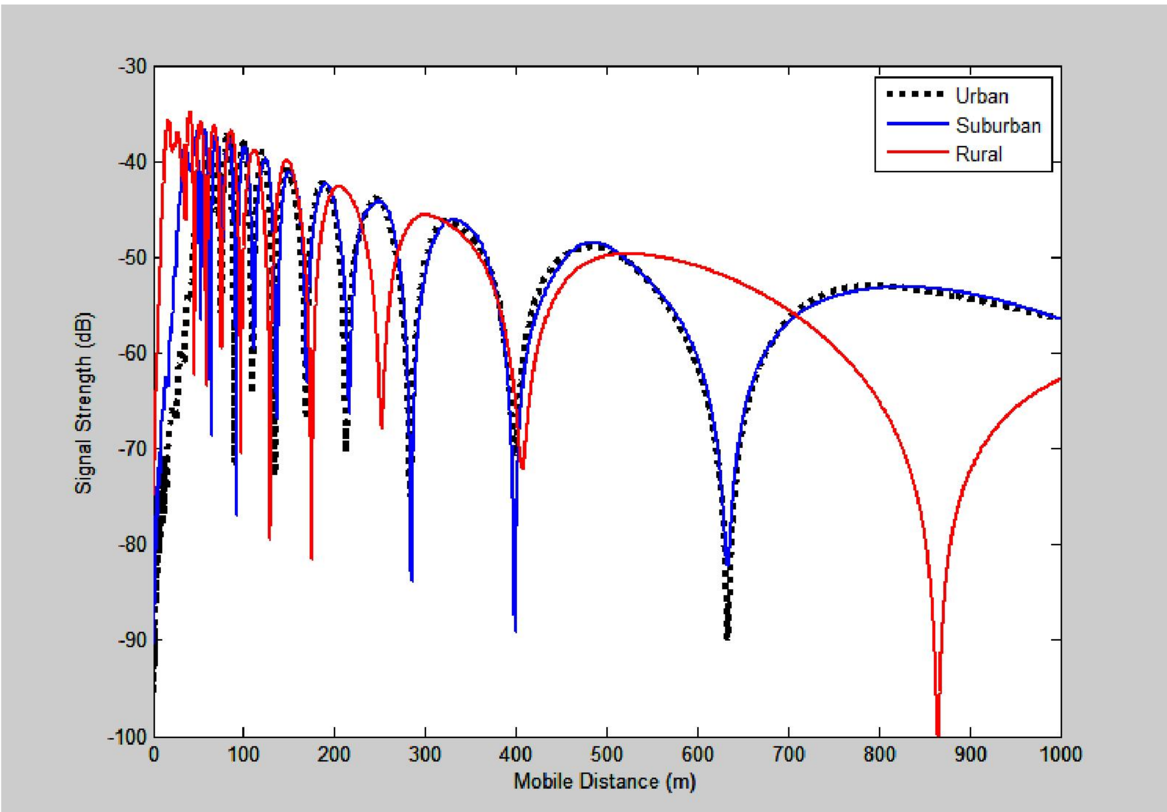

Figure 5. Normalized signal strength for soft polarization signal at x_b=50m, h_m=3m in urban, suburban, rural environments

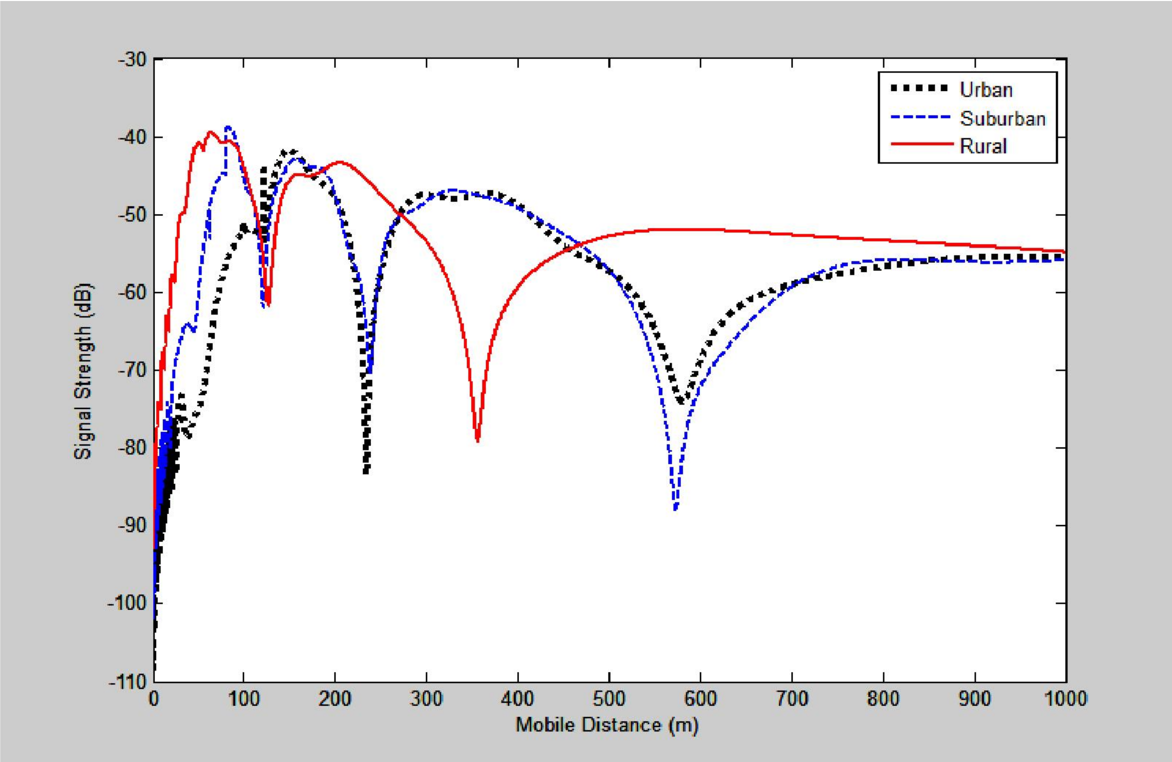

Figure 6. Normalized signal strength for soft polarization signal at x_b=100m, h_m=1.5m in urban, suburban, rural environments

In Fig. 5 three curves is the same behavior of Fig. 4 but the fading is smoother because at hm=3m the elevation angles of incident ray it has less difference than at hm=1.5m, so the harmonics of destructive and constructive interference is going to be less. In Fig. 7 the received signals strength has roughly the same trend of the signal strengths in Fig. 4-Fig. 6. Fig. 8 show soft and hard normalized signals, the signal level difference between soft and hard signals is come from the variation of diffraction and reflection coefficients for two signals.

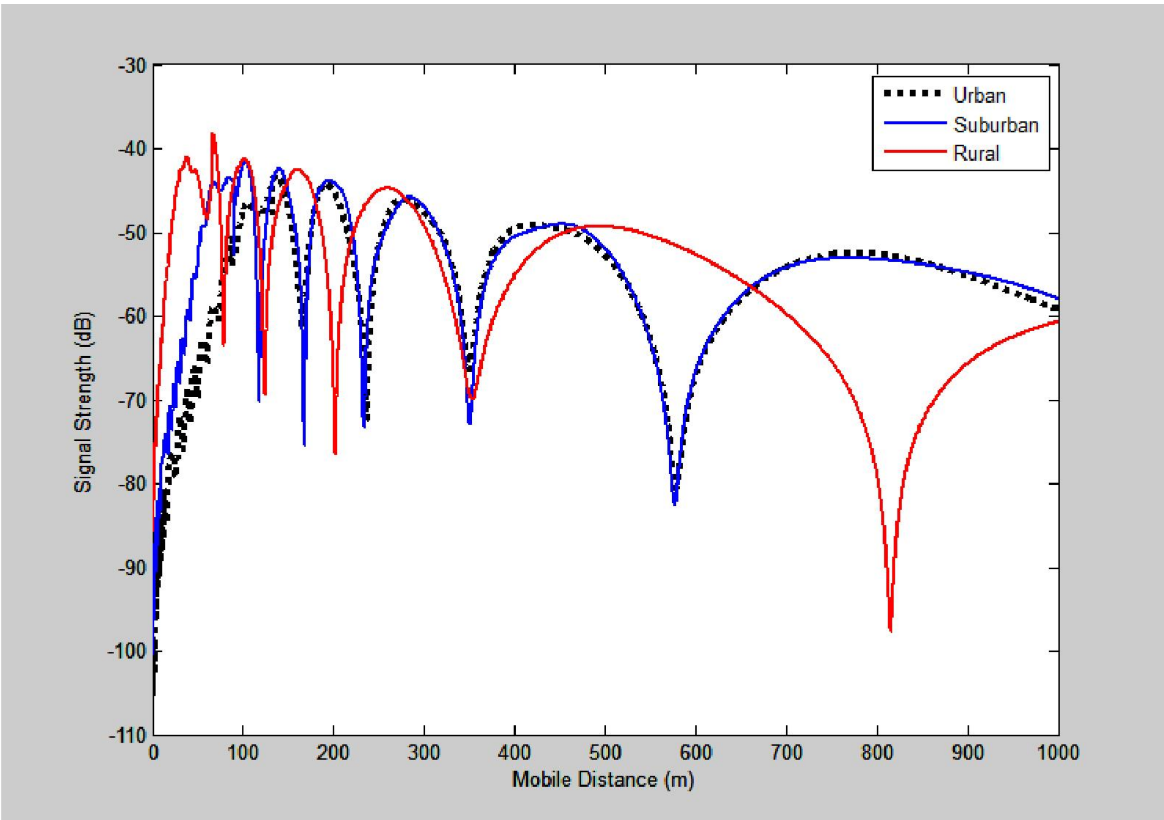

Figure 7. Normalized signal strength for soft polarization signal at x_b=100m, h_m=3m in urban, suburban, rural environments

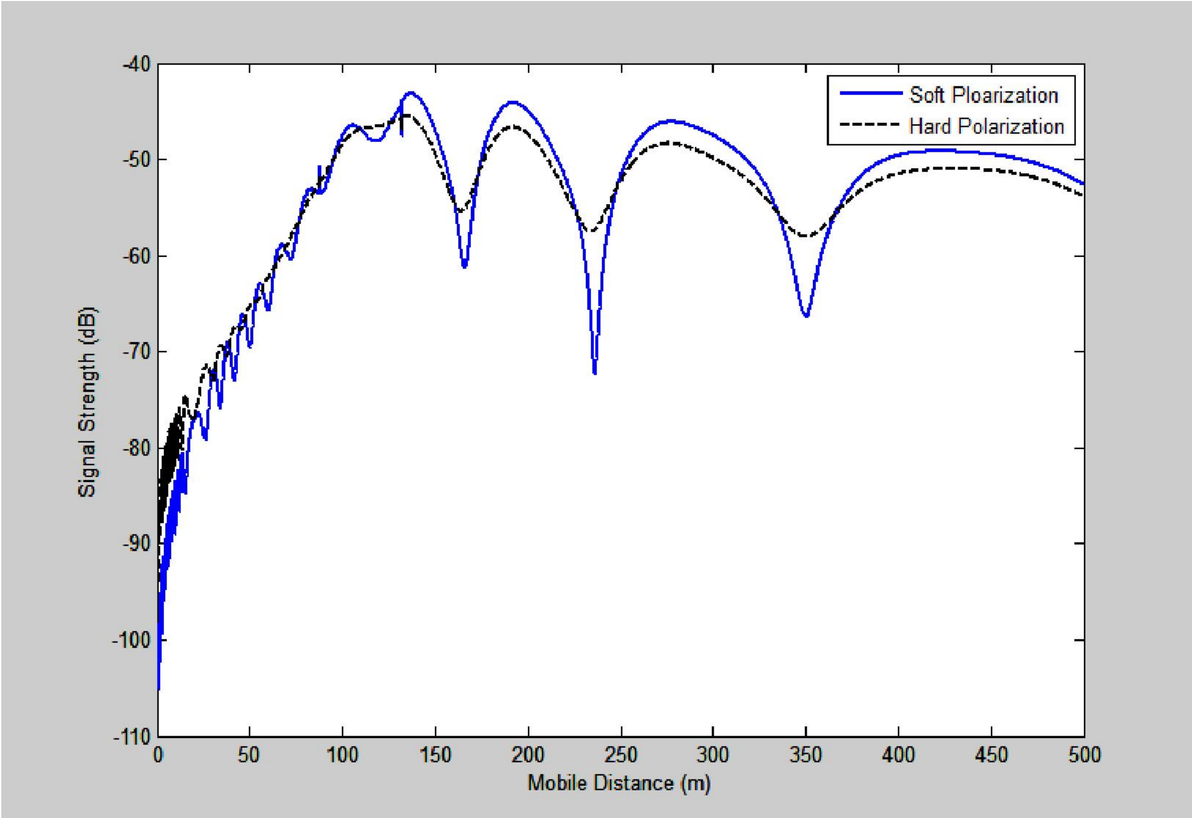

Figure 8. Normalized signal strength for soft polarization and hard polarization signal at x_b=100m, h_m=3m

Conclusions

The propagation model in cellular WiMAX communication system presented. it is considering the base station radiates a signal that reaching the mobile in multipath channel with the presence of lossy building blockage. The signal analysis was performed using ray tracing techniques and the uniform theory of diffraction (UTD). The signal available at the mobile antenna is the result of a direct ray in addition to other reflected and diffracted rays induced by the two roof edges and surfaces of a building and the ground. Each ray contribution is formulated by a mathematical equation. The received horizontal and vertical signal levels are calculated versus the mobile distance where the mobile was moving behind the building in reverse direction of base station. The results computed in typical building dimensions in urban, suburban and rural areas were considered.

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