Performance Analysis of WiMAX IEEE 802.16e

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ABSTRACT
WiMAX systems are increasingly popular for modern metro cities. WiMAX system is designed for communication over long distances point–to-point link and full length cellular mobile communication with higher speed rates – typically over 30 MBPS. In this paper, we analyze a stylistic WiMAX system through rigorous numerical simulation based experiments. In particular, we have used the ITU-R based setting in SUI based simulation framework. We present insights that would aid in understanding and thereby leveraging the power of WiMAX systems in a better way.

General Terms
Wireless, Communications, Networks, Simulation, MATLAB, ITU-R.

Keywords
WiMAX, IEEE802.16, Path Loss, Multi Path Interference, Fading, Doppler Spread, SUI Model.

1. INTRODUCTION
WiMAX (World Interoperability for Microwave Access) was designed for long distance communication which includes point-to-point communication and full-length communication. This follows the IEEE 802.16 standard. This technology can provide Broadband wireless Access up-to 30 miles for fixed stations and up to 3-10 miles for mobile station [1]. The unique feature of WiMAX is higher speed for data transmission – typically in the order of 1GBPS for fixed station while in the order of 30-40 MBPS for mobile station. WiMAX has been viewed by the industry and researchers as an alternative to the DSL cable usually referred as the last mile in mobile communications. Majority of the technical innovations in the mobile communications space happens in the last-leg. By far, WiMAX could be viewed as a major technological innovation during the last decade.

WiMAX forum refers WiMAX as the interoperable implementations of the IEEE 802.16 family of wireless-networks standards ratified by them. Performance analysis of WiMAX systems is gaining attention and interest from industry practitioners and researchers.

A typical list of parameters that are considered for performance analysis of WiMAX systems are listed below: Path Loss, Shadowing, Multipath Interference, Delay and Doppler Spread. [1]

1.1 Path Loss
Path loss refers to the reduction in power density of an electromagnetic wave as it propagates through space. It forms a major component in the analysis and design of the link budget of a telecommunication system.

Path loss may be due to many effects, such as free-space loss, refraction, diffraction, reflection, medium coupling loss, and absorption. Path loss is influenced by terrain contours, environmental conditions, propagation media, the distance between the transmitter and the receiver, the height and location of antennas, and the orientation angle of antennas – modulation choice etc.

1.2 Shadowing - Fading
Shadowing is deviation of the attenuation affecting a signal over certain propagation media. The fading may vary with time, geographical position or radio frequency, and is a stochastic process. A fading channel is a communication channel comprising fading. Fading could be attributed to Multipath interference as well, this is discussed in the following subsection.

1.3 Multipath Interference
Multipath interference is a phenomenon in the physics of waves whereby a wave from a source travels to a detector via two or more paths and, under the right condition, the two (or more) components of the wave interference.

1.4 Delay
The delay of a network specifies how long it takes for a bit of data to travel across the network from one node or endpoint to another. It is typically measured in multiples or fractions of seconds. Delay may differ slightly, depending on the location of the specific pair of communicating nodes. Processing delay - time routers take to process the packet header, Queuing delay - time the packet spends in routing queues (us-ms order), Transmission delay - time it takes to push the packet's bits onto the link. It is the store forward delay Propagation delay - time for a signal to reach its destination, there is a certain minimum level of delay that will be experienced due to the time it takes to transmit a packet serially through a link. Onto this is added a more variable level of delay due to network congestion.

1.5 Doppler Spread
The coherence time of the channel is related to a quantity known as the Doppler spread of the channel. When a user (or reflectors in its environment) is moving, the user's velocity causes a shift in the frequency of the signal transmitted along each signal path. This phenomenon is known as the Doppler shift. Signals travelling along different paths can have different Doppler shifts, corresponding to different rates of change in phase. The difference in Doppler shifts between different signal components contributing to a single fading channel tap is known as the Doppler spread. Channels with a large Doppler spread have signal components that are each changing independently in phase over time. Since fading

depends on whether signal components add constructively or destructively, such channels have a very short coherence time.

In general, coherence time is inversely related to Doppler spread, typically expressed as

$$T_c = \frac{1}{D_s}$$

where T_c is the coherence time, D_s is the Doppler spread.

1.6 Our Contributions:

We have the following contributions to the literature in our current research:

Extension of the simulation framework of WiMAX to wide range of parameters. Applying the IUT(R) setting in SUI based simulation framework to generate corresponding QoS parameters of WiMAX. Such an integrated implementation is unique in the WiMAX literature. Extent literature focus was restricted to 2 phase and 30^o antenna [6], in contrast, we considered a generically positionable antenna and implemented 64 QAX setting.

It is to the best our knowledge that our experimentation with new set of parameters and extended scope has not been witnessed in the literature for WiMAX.

The rest of this paper is organized as follows: In section II, we review the literature that is in line with our work and section III gives a detailed overview of the work including the simulation model and performance analysis framework for WiMAX model. In section IV, we present our analysis and results – followed by conclusions and directions for future research in section V.

2. WiMAX MODEL PERFORMANCE ANALYSIS

In this section, we discuss various models for WiMAX focusing on the five QOS parameters that are identified in section 1.

2.1 Path Loss Models

With no obstacles, the received power of the antenna is

$$P_r = P_t \left[\frac{\sqrt{G_1\lambda}}{4\pi d}\right]^2$$

P_t= power of transmitting antenna

P_r=power of receiving antenna

$G_{1=}$ product of transmitting and receiving antenna field

λ=wavelength

d=distance

Theoretically, the power falls off in proportion to the square of the distance. In practice, the power falls off more quickly, typically 3rd or 4th power of distance.

The presence of ground causes some of the waves to reflect and reach the transmitter. These reflected waves may sometime have a phase shift of 180 ° and so may reduce the net received power. A simple two-ray approximation for path loss can be shown to be

$$p_r = p_t \frac{G_t G_r h_t^2 h_r^2}{d^4}$$

where h_t, h_r are the transmitting and receiving antenna heights respectively

With this the empirical formula for the path loss can be given as

$$p_r = p_t p_o \left(\frac{d_o}{d}\right)^{\alpha}$$

Where P_o is the power at the distance d_o and α is path loss exponent. The loss is given by

$$PL(d)dB = \overline{PL}(d_o) + 10\alpha \log\left(\frac{d}{d_o}\right)$$

$\overline{PL}(d_o)$ is the path loss exponent at the distance d_o

2.2 Shadowing Models

If there are any obstacles in the path of the signal some part of the signal is lost due to absorption, reflection, scattering and diffraction.

The path loss due to shadowing is given by [1]

$$PL(d)dB = \overline{PL}(d_o) + 10\alpha \log\left(\frac{d}{d_o}\right) + \chi$$

χ is effect due to shadowing which is modeled as lognormal distribution given by

$\chi=10^{x/10}$ where x≈$N(0,\sigma_s^2)$

where $N(0,\sigma_s^2)$ is the Gaussian (normal) distribution with mean 0 and variance σ_s^2 .

2.3 Multipath Models

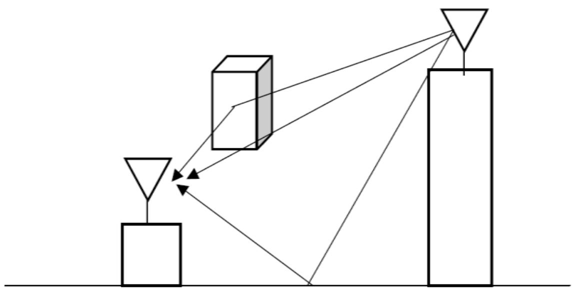

Fig1: A channel with a few major paths of different lengths, with the receiver seeing a number of locally scattered versions of those paths.

The objects which are around the path of the wireless signal reflect the signal. These waves are also receiver along with the normal waves with different amplitude and phase. The received power decreased due to the effect of path loss and various combinations of all three factors can be seen below.

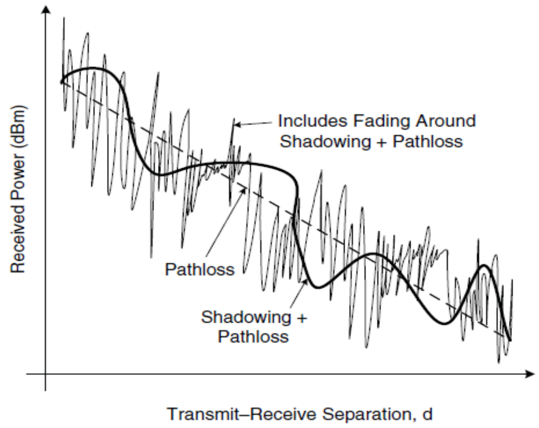

Fig2: Plot showing the three major trends: path loss, shadowing and multipath fading all on the same plot

Thick solid line which shows the combined effect of all three factors results in a complete disperse signal.

2.4 Delay

If single impulse is transmitted in such multipath environment then multiple impulses will be received at the receiver with the time delay of τ. The response of the multipath channel is represented by a set of discrete impulses which can be shown as

$$h_t = \sum_{i=1}^{N} c_i(t)\delta(\tau - \tau_i)$$

Here, response h and coefficients $c_i(t)$ depend on time t. The value of N depends upon the significant level of τ_i

When the transmitter receiver is in motion the characteristics change and the delay spread increases which is inversely related to coherence time.

2.5 Doppler Spread

The power delay profile gives the statistical power distribution of the channel over time for a signal transmitted for just an instant. Similarly, Doppler power spectrum gives the statistical power distribution of the channel for a signal transmitted at just one frequency f. While the power delay profile is caused by multipath, the Doppler spectrum is caused by motion of the intermediate objects in the channel. The Doppler power spectrum is nonzero for (f-fD, f+fD), where fD is the maximum Doppler spread or Doppler spread..The coherence time and Doppler spread are inversely related:

$$Doppplerspread \approx \frac{1}{coherencetime}$$

Table1: Some Typical Doppler Spreads and Approximate Coherence Times for various WIMAX applications [1]

Carrier Frequency	Speed	Max Doppler spread	Coherence time
2.5GHz	2km/hr	4.6Hz	200ms
2.5GHz	45km/hr	104.2Hz	10ms
2.5GHz	100km/hr	231.5Hz	4ms
5.8GHz	2km/hr	107Hz	93ms
5.8GHz	45km/hr	241.7Hz	4ms
5.8GHz	100km/hr	537Hz	2ms

3. SIMULATION OF WIMAX – PATH LOSS MODELS

A comprehensive analytical study of WIMAX via a closed form of expression is difficult due to the underlying Complexity in WIMAX system. Hence we intend to model the WIMAX system with the help of stylized simulation models in MATLAB.

3.1 Hata model for Path loss

According to this model the path loss in the urban areas is approximated as

$$P_{L,urban}(d)dB = 69.55 + 26.16\log_{10}(f_c) - 13.82\log_{10}(h_t) - a(h_r) + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d)$$

Where fc is the carrier frequency, h_t is the height of transmitting antenna, h_r is the height of receiving antenna, $a(h_r)$ is correction factor for mobile antenna height.

But, this model was designed for the frequencies of 150-1500MHz and large cells. This is not suitable for WiMAX applications.

3.2 COST 231 Extended Hata Model

European Cooperative for scientific and Technical research (COST) extended the Hata model to include small macro cells i.e., whose base station antenna height is above the roof top level of adjacent base station antenna. [3]

$$P_{L,urban}(d)dB = 46.3 + 33.9\log_{10}(h_t) - a(h_r) + c_M + (44.9 - 6.55\log_{10}(h_t))\log_{10}(d)$$

C_M is 0dB for medium sized cities and 3dB for metropolitan areas. This has carrier frequencies of 1.5 to 2 GHz, Base station antenna height of 30m to 300m, Mobile antenna height of 1m -10m, Distance of 1 to 20km.

3.3 COST 231-Walfish-Ikegami Model

In addition to the above model COST proposed another model for micro-cells and small macro cell by combining the models proposed by Walfish and Ikegami. The include some of the characteristics of the urban environment such as height of buildings h_{Roof} , width of the roads w, building separation b and road orientation with respect to the direct radio path φ.

This model proposes path loss for both Line Of Sight and Non-Line Of Sight [3].

For LOS the path loss is given as

$$P_L dB = 42.6 + 26\log(d) + 20\log(f_c)$$

For NLOS

$$P_L dB = \begin{cases} P_{Lo} + L_{rts} + L_{msd} \; for L_{rts} + L_{msd} > 0 \\ P_{Lo} \; for L_{rts} + L_{msd} = 0 \end{cases}$$

Where P_{L0} is the free space path loss which is given by

$$P_{Lo} dB = 32.4 + 20\log d + 20\log f_c$$

L_{rts} is the roof top to street diffraction which is given by

$$L_{rts} = -16.9 - 10\log\omega + 10\log f_c + 20\log\Delta h_m + L_{ori}$$

Here the difference between building height and mobile station height is given by

$$\Delta h_m = h_{Roof} - h_m$$

L_{ori} represents the street orientation loss which is given by

$$L_{ori} = \begin{cases} -10 + 0.345\varphi \; for 0° \le \varphi \le 35° \\ 2.5 + 0.075(\varphi - 35) \; for 35° \le \varphi \le 55° \\ 4.0 - 0.114(\varphi - 55) \; for 55° \le \varphi \le 90° \end{cases}$$

Where φ is the ratio of street orientation to the direction of incidence which was proposed by Ikegami.

Multi-screen loss L_{msd} is obtained by modelling building edges as screen which is given by

$$L_{msd} = L_{bsh} + K_a + K_d \log d + K_f \log f_c - 9\log b$$

$$L_{bsh} = \begin{cases} 18\log(1 + \Delta h_b) \; for h_b > h_{Roof} \\ 0 \; for h_b \le h_{Roof} \end{cases}$$

Where the distance between two buildings is given by

$$K_a = \begin{cases} 54 \; for h_b > h_{Roof} \\ 54 - 0.8\Delta h_b \; for d \ge 0.5 \text{Km and } h_b \le h_{Roof} \\ 54 - 0.8\Delta h_b / 0.5 \; for d < 0.5 Km and h_b = h_{Roof} \end{cases}$$

Here

$$\Delta h_b = h_b - h_{Roof}$$

The path loss depends on distance and frequency which are given K_d and K_f .The values of K_d and K_f are given by

$$K_d = \begin{cases} 18 \; for h_b > h_{Roof} \; for h_b > h_{Roof} \\ 18 - 15\Delta h_b / h_{Roof} \; for h_b \le h_{Roof} \end{cases}$$

$$K_f = \begin{cases} 0.7\left(\frac{f_c}{925} - 1\right) for medium sized cities \\ suburban areas with average vegetation \\ 1.5\left(\frac{f_c}{925} - 1\right) for metropoliton areas \end{cases}$$

The range of this model is given as carrier frequency (f_c) is 800MHz to 2000MHz, Base station antenna height (h_b) 4-50m, Mobile station antenna height 1-3m and it is valid for a distance of 0.02km to 5km.

This model was recommended by ITU-R. But this is not used in mobile WIMAX applications due to the following disadvantages

The prediction error becomes large for the cases $h_{Base}=h_{Roof}$, $h_{Base} << h_{Roof}$ and the performance of the system becomes poor for $h_{Base} >> h_{Roof}$.

The received field strength and hence the reliability of the system decreases if the terrain is not flat or if the land cover is homogeneous

3.4 Erceg Model

This model was proposed based on the experimental data collected by AT&T wireless services across the United States in 95 existing macro cells at 1.9GHz. [4]

In this model three kinds of terrains are classified with A being the hilly terrain and C is being the flat terrain. B is the intermediate terrain.

The median path loss for all the three terrains is given by [4]

$$P_L = 20\log_{10}\left(\frac{4\pi d_o}{\lambda}\right) + 10\gamma\log_{10}(d/d_o) + s \; for d > d_o$$

Here λ is the wavelength in meters and γ is the path loss exponent given by

$$\gamma = a - bh_b + c/h_b$$

Here h_b is height of base station antenna which is around 10m to 80m and the initial distance do is 10m. Here a, b and c are constants which are tabulated as below for all the three terrains.

Table2: Erceg model parameters

Model Parameter	Terrain Type A	Terrain Type B	Terrain Type C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	12.6	20

Here‘s’ represents the effect of shadowing which follows the lognormal distribution with a standard deviation of 8.2 to 10.6 dB.

This model is for a range of frequencies around 2GHz and base station antenna height of around 2m. In order to extend the model for other frequencies and height around 2m to 10m following corrections have to be made for path loss

$$P_{L\,modified} = P_L + \Delta PL_f + \Delta PL_h$$

Where P_L is the initial path loss ΔP_{L_f} is the frequency term and ΔP_{L_h} is the receiver antenna correction factor given by

$$\Delta P_{L_f} = 6\log_{10}\left(f/2000\right)$$

$$\Delta P_{L_h} = \begin{cases} -10.8\log_{10}(h/2)\; for A \& B \\ 20\log_{10}(h/2)\; for c \end{cases}$$

This model did not consider the Doppler Spread and delay line conditions.

3.5 Stanford University Interim (SUI) channel models

This is a set of 6 channel models with three tapped delay line models which are designed for all the three kinds of terrains as described above and also variety of Doppler spreads. These models are designed by considering various Line of Sight/ Non Line of Sight conditions across the United States. Generic structure of SUI models can be shown as in Fig 3.

Input Mixing Matrix:
This is used to model the correlation between the input signals if multiple no of transmitting antennas are used.

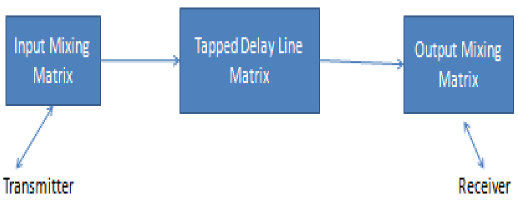

Fig3: Generic structure of SUI model [5]

Tapped Delay Line Matrix:
This multipath fading is modeled by a 3 tapped delay line matrices with non-uniform delays. The gain of multipath fading is characterized by Rician distribution for K-factor>0 and Rayleigh distribution for K-factor=0 and maximum Doppler Spread.

Output Mixing Matrix:
This is used for correlation of output signals if multiple receiving antennas are used. The parameters for the SUI channels have been specified for all six channel model parameters [6].

3.6 ITU Path loss models

Another commonly used set of empirical channel models is that specified in ITU-R recommendation M.1225 [8]. The recommendation specifies three different test environments: Indoor office, outdoor-to-indoor pedestrian and vehicular high antenna. Since the delay spread can vary significantly, the recommendation specifies two different delay spreads for each test environment: low delay spread (A) and medium delay spread (B). In all there are 6 cases. For each of these cases, a multipath tap delay profile is specified. The number of multipath components in each model is different.

From all these models Vehicular-A model and Pedestrian-B model are only used for WIMAX mobile communication because they have reduced error and have maximum capacity. Tabular form of the Vehicular-A and Pedestrian-B model can be obtained from Ref [7].

4. RESULTS: ANALYSIS/DISCUSSION

Simulation results for the IEEE 802.16e for WiMAX communication with the QAM modulation have been generated for with 64 QAM for ITU-R vehicular-A & Pedestrian-B model, in addition to existing models in literature for evaluating relative performance.

Though many models have been proposed we use these models because of low multipath fading and low error rate respectively. SUI models contain three multipath delays where as ITU-R models contain 6 different cases.

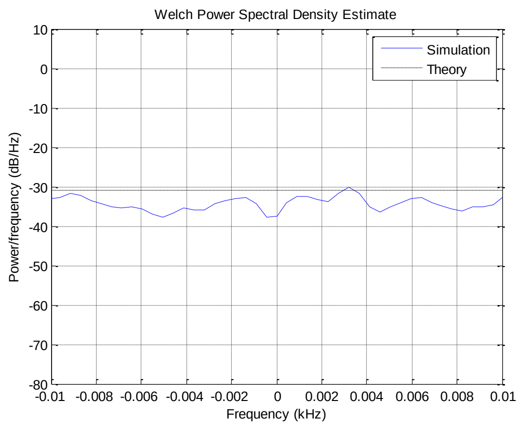

Fig4: Doppler spectrum for first transmission path in ITU-R Vehicle-A

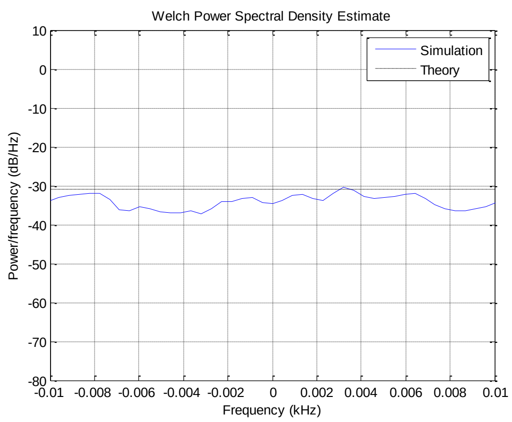

Fig5: Doppler spectrum for second transmission Path in ITU-R Vehicle-A

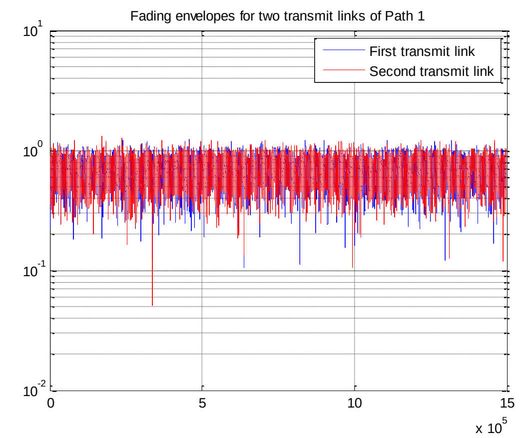

Fig6: Fading envelope for first path for ITU-R Vehicle-A model

Fig7: Fading envelope of second path For ITU-R Vehicle-A

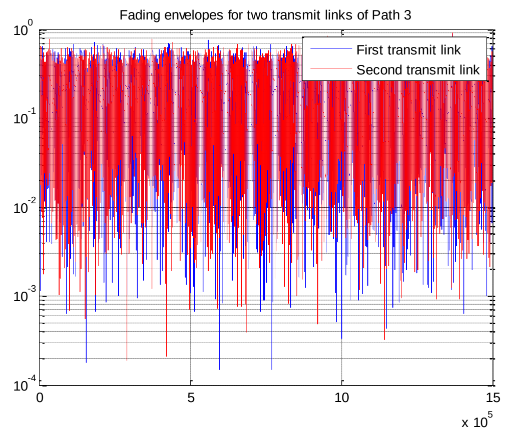

Fig8: Fading envelope of third path for ITU-R Vehicle-A

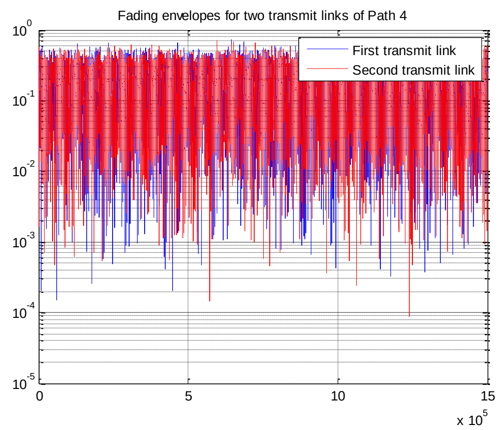

Fig9: Fading envelope of fourth path for ITU-R Vehicle-A

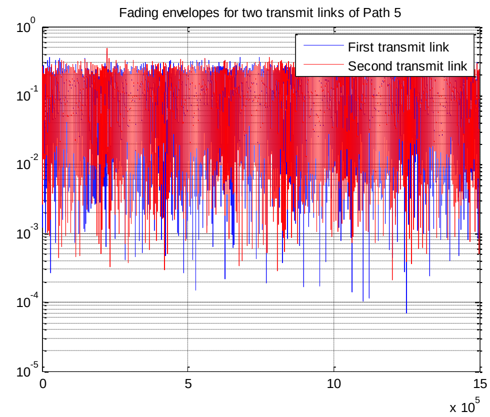

Fig10: Fading envelope of fifth path for ITU-R Vehicle-A Model

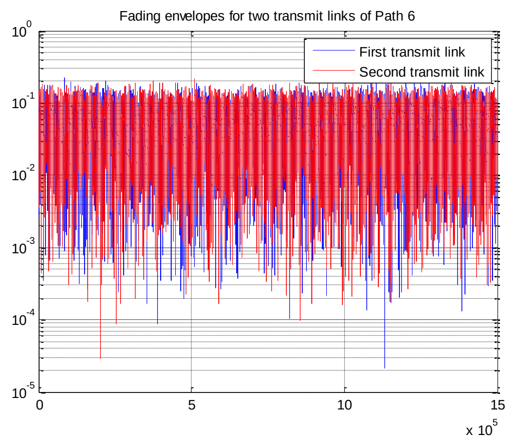

Fig11: Fading envelope of sixth path for ITU-R Vehicle-A Model

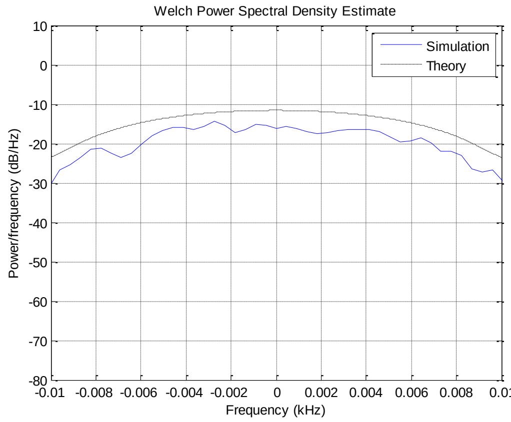

Fig12: Doppler spectrum for first transmission antenna Pedestrian-B Model

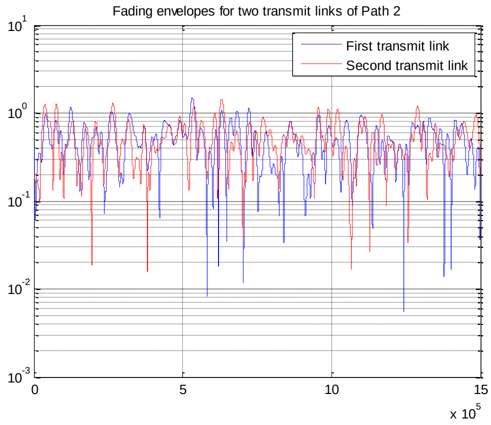

Fig15: Fading envelope of second path for Pedestrian-B Model

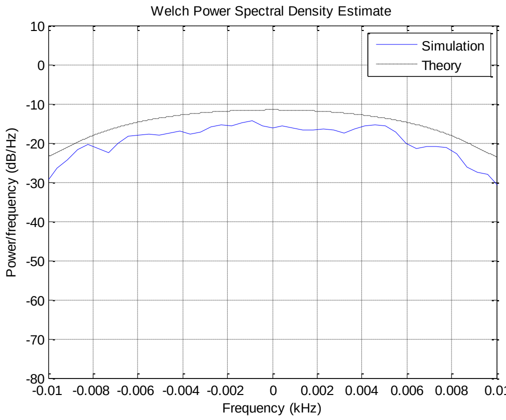

Fig13: Doppler spectrum of second transmission antenna for
Pedestrian-B Model

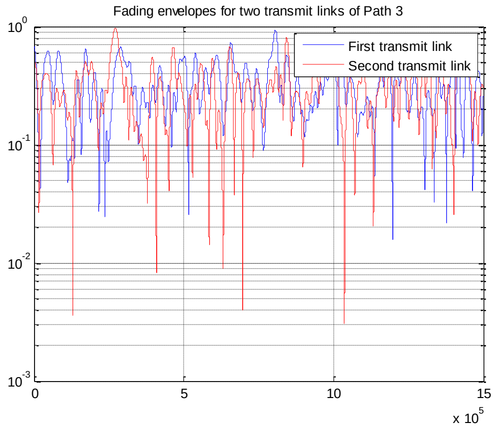

Fig16: Fading envelope of third path for Pedestrian-B Model

Fig14: Fading envelope of first path for Pedestrian-B Model

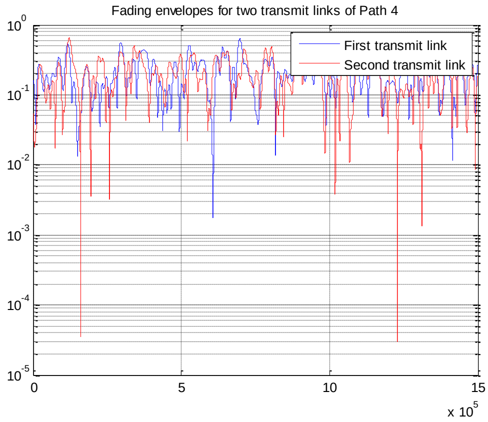

Fig17: Fading envelope of fourth path for Pedestrian-B Model

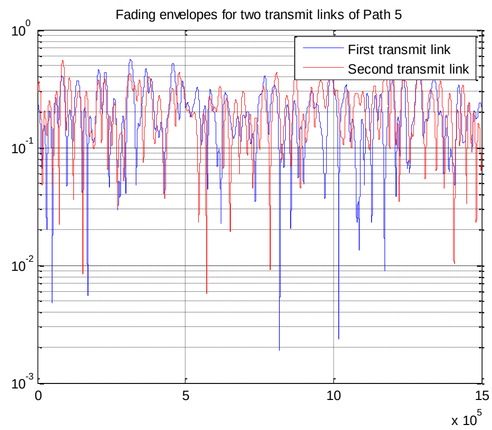

Fig18: Fading envelope of fifth path for Pedestrian-B Model

We have implemented the model of SUI for 90% coverage with Omni-directional antenna instead of 30 degree antenna model proposed in [9] because 30degree Antenna has loss of about 12dB. Fading envelopes have been generated for two transmitting antenna and one receiving antenna.

Figure 4 and 5 represent the Doppler Spread for the ITU-R Vehicle-A model. Here we have considered the Doppler spread identical for all the paths which is 833dB. Here we have considered the K-factor as 10. Fading envelopes have been generated for all the six paths with the tap delays as specified for Vehicle-A model. Figures 6, 7, 8, 9, 10 & 11 represents the fading envelope by using Rician fading for all the six tap delay lines with respective delays as specified for Vehicular-A model.

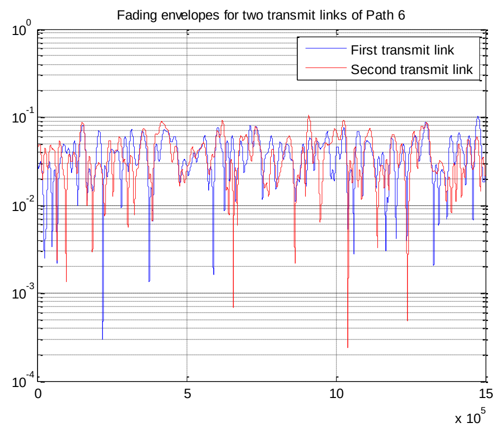

Fig19: Fading envelope of sixth path for Pedestrian-B Model

Figure 12 and 13 represent the Doppler Spread for the ITU-R Pedestrian-B model. Here we have considered the Doppler spread identical for all the paths which is 100dB.Here we have considered the K-factor as 7. Fading envelopes have been generated for all the six paths with the tap delays as specified for Vehicle-A model. Figures 14, 15, 16, 17, 18 & 19 represents the fading envelope by using Rician fading for all the six tap delay lines with respective delays as specified for Vehicular-A model.

In both the cases blue line represents the fading envelope for first transmitting antenna and red line represents the fading envelope for second transmitting path.

5. CONCLUSION

Path loss is the main problem which effects the propagation of the signal. Various path loss models have been proposed from which SUI-1 models and ITU-R models are best suitable for IEEE 802.16e which is the standard for mobile WiMAX communication. Simulation models for Path Loss with Doppler Spread and Multipath Fading have been proposed using MATLAB and also correlation for each path has been calculated. It has been observed that capacity i.e., number of users increases per cell by using ITU-R model. SUI-1 model have relatively low multipath fading and low delay spread. So, these models are suitable for mobile WiMAX implementation.

6. REFERENCES

[1] J. Andrews, A. Gosh, R. Muhamed, Fundamentals of WiMAX, Prentice Hall, 2007.

[2] Roberto Cristi, "Wireless communications with Matlab and Simulink IEEE 802.16 (WiMAX) Physical layer", August 2009.

[3] Zia Nadir, Md. Ahamad, "Pathloss Determination using Okumara-Hata model and Cubic Regression for Missing data in Oman", Proceedings of International Multi Conference of Engineers and Computer Scientists 2010, Vol-II, IMECS 2010, March 17-19, 2010, HongKong.

[4] PaotoAgabio-BrunoCornglia, Roberto Arco. Journal, "A Model for WiMAX coverage & Capacity Performance Estimation", EURASIP Journal on Wireless Communication and Networking.

[5] T. Godder, Md. S. Miah, P. C. Burman, B. Singh, Md. A. Rahaman, "Performance Analysis and Comparison between the fixed and Mobile wimax physical layer" Journal IJCIT, Volume 02, Issue 01, Manuscript Code:110723.

[6] S. Askar, S. Menon, L. Das, M. S. Kalhoro, "Impact of Modeling Different fading channels on Wireless MAN Fixed IEEE 802.1d OFDM System with Diversity Transmission Technique.", World Academy of Science ,Engineering and Technology, 2011.

[7] Kartikeyan V,Malmurgan N,Senthil KumaranD. "Performance Evaluation of Preamble Detection Under ITU and SUI channel models in Mobile WiMAX. In Proceedings of Tech.Republic /US.

[8] Recommendation ITU-R M.1225,"Guidelines for Evaluation of Radio Transmission Technologies for IMT-2000"1997.