Study of OPNET and Performance Evaluation of WiMAX Network under Various Path Loss Models and Terrain Conditions in OPNET

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***Abstract*— With various wireless technologies coming up, performance of the wireless networks has become a concern. Mobile WiMAX is expected to be the wireless technology of the next generation as it supports vehicular mobility with broad coverage area. Among various other parameters which affect network performance, the terrain feature on which the network is deployed and the pathloss model affects the network performance substantially. Air being the communicating medium in wireless networks, any hindrance on the communication path like buildings, trees, etc., affects the wireless signal propagation. Hence, prior network deployment, analysis of the terrain is essential. Voice over IP is expected to be the communication medium of the next generation and File Transfer Protocol is the most popular data transfer protocol. Hence, our target is to study the behaviour of various propagation models in WiMAX network with respect to path loss, throughput and delay for various terrain models with voice and FTP applications. OPNET Modeler provides comprehensive development environment and provides a real life simulation environment and hence is chosen to simulate the networks.**

***Index Terms*—OPNET, WiMAX, terrain, pathloss, VoIP, FTP**

I. INTRODUCTION

WiMAX or Worldwide Interoperability for Microwave Access is a broadband wireless technology designed for provisioning high-speed data access over long distances. It is an access technology for the deployment of Wireless Metropolitan Area Networks (wireless MAN) based on the IEEE 802.16 standards [1]. The first standardized WiMAX system was based on the IEEE 802.16-2004 standard, commonly known as fixed WiMAX. It provided wireless access to subscriber stations (SS) through a base station (BS) using point-to-multipoint (PMP) and optional mesh topologies. This standard was further extended to support mobility of Subscriber Stations by enabling low-latency handover between Base Stations. The resulting new standard is the IEEE 802.16e-2005[1], or more commonly known as Mobile WiMAX.

Mobile WiMAX or IEEE 802.16e is a solution that enables the convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. The Mobile WiMAX Air Interface uses Orthogonal Frequency Division Multiple Access (OFDMA) technology for improving multi-path performance and supporting Non Line-Of-Sight (NLOS) environments operation in the 2-11 GHz band [2]. The pathloss, delay and throughput of mobile WiMAX network with mobile nodes moving at 50 km/hr is analysed and compared using the common path loss models in OPNET to verify the results and to show that OPNET modeler provides us with a real time environment.

IEEE 802.16 support 5 types of service classes, namely UGS (Unsolicited Grant Service), rtPS (real time Polling Service), nrtPS (non-real time Polling Service), BE (Best Effort Service), ertPS (extended rtPS service) [3]. UGS supports fixed-size data packets at a constant bit rate (CBR). It also supports real time applications like VoIP or streaming applications but it wastes bandwidth during the off periods. RTPS supports variable bit rate real-time service such as VoIP. Delay-tolerant data streams such as an FTP is designed to be supported by the nrtPS type of service. This requires variable-size data grants at a minimum guaranteed rate. The nrtPS is very similar to the rtPS except that it allows contention based polling. Data streams, such as Web browsing, that do not require a minimum service-level guarantee is designed to be supported by BE service. BE connections are never polled but they can only receive resources through contention. ertPS was introduced to support variable rate real-time services such as VoIP and video streaming. It has an advantage over UGS and rtPS for VoIP applications because it carries lower overhead than UGS and rtPS [4] and hence is modeled is the system.

VoIP has been widely accepted for its cost effectiveness and easy implementation. PSTN quality of voice is achieved by using G 711 as the voice codec. PSTN voice quality is the best voice quality achieved. Hence, we have considered it to evaluate the network performance. File Transfer Protocol (FTP) is a very commonly used protocol for data transfer. Hence, we have considered high load FTP to exhibit the behaviour of data packets.

II. BACKGROUND

The common propagation models namely free Space path loss model, Suburban Fixed (Erceg), Outdoor to Indoor and

Pedestrian Environment and Vehicular Environment are discussed in this paper. The Suburban Fixed path loss model is further subdivided in three categories based on the building and tree density namely terrain type A, B and C. The models are briefly discussed in the next sections.

A. Free Space Propagation model:

The free space propagation model is mathematically given by:

$$P_{rx}(r) = \frac{P_{tx}\, G_{tx} G_{rx} \lambda^2}{(4\pi)^2 r^2 L} \quad (1)$$

where P_{rx} is received power in watts and is a function of distance between transmitter and receiver, P_{tx} is the transmitted power in watts, G_{rx} and G_{tx} are the gain of the receiving and transmitting antennas respectively, L is the system-loss factor and is not related to propagation. It is usually greater than 1 and λ is the wavelength in meters [8].

B. Erceg's Suburban Fixed Model:

The Erceg model is based on extensive experimental data collected at 1.9GHz in 95 macrocells of suburban areas across the United States [5]. This model is a slope intercept model given by [5]:

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

Where PL is the instantaneous attenuation, H is the intercept and is given by free space path loss at the desired frequency over a distance of d_0 = 100 meters:

$$H = 20\, log_{10}\left(\frac{4\pi d_0}{\lambda}\right) \quad (3)$$

where λ is the wavelength. The parameter γ is a Gaussian random variable over the population of macro cells within each terrain category. It can be written as [2] [5].

$$\gamma = (e - g h_b + k/h_b) + x\sigma_\gamma \quad (4)$$

where h_b is the height of the base station antenna in meters, σ_α is the standard deviation of γ, x is a zero-mean Gaussian variable of unity standard deviation N[0, 1], and *e, g, k* and σ_γ are all data-derived constants for each terrain category. The shadow fading components varies randomly from one terminal location to another within any given macro-cell. It is a zero-mean Gaussian variable and can be expressed as [2] [5].

$$s = y\sigma \quad (5)$$

$$\sigma = \mu + z \quad (6)$$

where y and z are the zero-mean Gaussian variables of unit standard deviation N[0, 1], σ is the standard deviation of s, μ_σ is the mean of σ, and σ_σ is the standard deviation of σ. μ_σ and σ_σ are both data-derived constants for each terrain category. The numerical values of the above parameters are given in Table I.

The correlation factors of the model for the operating frequency and for the MS antenna height are [2]

$$X_f = 6.01 \log_{10}\left(\frac{f}{2000}\right) \quad (7)$$

$$X_h = -10.8 \log_{10}\left(\frac{h_r}{2}\right) \text{ for Terrain type A and B}$$

$$= -20.0\, log_{10}\left(\frac{h_r}{2}\right) \text{ for Terrain type C,}$$

where f is the frequency in MHz and h_r is the height is the MS antenna above ground in meters.

The Terrain Type A is considered as hilly terrain with moderate to heavy tree density, representing rural environments and is associated with the highest path loss. Terrain Type B is characterized by either a mostly flat terrain with moderate to heavy tree density or a hilly terrain with light tree density. Terrain Type C is a flat terrain with light tree density and is associated with the lowest path loss for rural environments [2].

TABLE I. NUMERICAL VALUES CONSIDERED FOR THE PARAMETERS [2]

Parameters	Terrain Type A	Terrain Type B	Terrain Type C
e	4.6	4.0	3.6
$g(m^{-1})$	0.0075	0.0065	0.005
$k(m)$	12.6	17.1	20.0
σ_γ	0.57	0.75	0.59
μ_σ	10.6	9.6	8.2
σ_σ	2.3	3.0	1.6

C. Outdoor-to-Indoor and pedestrian pathloss environment

This environment is characterized by small cells and low transmits power. Base stations with low antenna heights are located outdoors; pedestrian users are located on streets and inside buildings and residences.

$$PL = 40 log_{10} R + 30\, log_{10} f + 49 \quad (8)$$

The above equation describes the path loss in dB where R is the distance between the base station and the mobile station in kilometres and 'f' is the carrier frequency of 2000 MHz for IMT-2000 band application [9].

D. Vehicular environment

This environment is characterized by larger cells and higher transmits power. The path loss in vehicular environment in dB is given by:

$$PL = 40(1 - 4 \times 10^{-3}\Delta h_b) log_{10} R - 18 log_{10} \Delta h_b - 21 log_{10} f + 80\, dB \quad (9)$$

where R is the distance between the base station and the mobile station, and f is the carrier frequency of 2000 MHz and is the base station antenna height in meters measured from the average roof top level.

III. Network Architecture

A. Network Simulator

OPNET (OPtimized Network Engineering Tool) [6] provides a comprehensive development environment supporting the modeling of communication networks and distributed systems [7]. Both behaviour and performance of modeled systems can be analysed by performing discrete event simulations. The OPNET environment incorporates tools for all phases of a study, including model design, simulation, data collection, and data analysis. OPNET provides many constructs relating to communications and information processing, providing high leverage for modeling of networks and distributed systems. OPNET provides Graphical specification of model wherever possible; models are entered via graphical editors. These editors provide an intuitive mapping from the modeled system to the OPNET model specification. OPNET provides four tools called editors to develop a new simulation model. These editors, the Network, Node, Process and Parameter Editors, are organized in a hierarchical fashion, which supports the concept of model level reuse. Models developed at one layer can be used by another model at a higher layer. All OPNET simulations automatically incorporate support for analysis via a sophisticated interactive debugger.

To analyse the effect of different terrain and path loss models in a network, it is necessary to study real life scenarios. Hence OPNET 15.0.A is chosen as the simulation tool such that the simulation set up would reflect the actual deployment of the WiMAX network and the actual effects due to the terrain type of the land. OPNET 15.0.A is equipped with all necessary modules required like WiMAX, that includes the physical and MAC layer implementation of the mobile WiMAX, and the wireless module that includes the various path loss models.

B. Network Setup

The Wireless Deployment Wizard of OPNET is used to deploy a 7 celled WiMAX network, with multiple subscriber stations in the range of a base station as shown in figure 1.
The base stations are connected to the core network by an IP backbone. There is a server backbone containing the voice server which is configured as the SIP server. The IP backbone is connected to the server backbone via an ASN gateway. This node, configured as the ASN gateway basically supports the mobility in the WiMAX network. These nodes represent the service provider company network. The green bidirectional dotted lines represent the generic routing encapsulation (GRE) tunnels. The cell radius is set to 30 kilometres. There are 10 nodes under the base station 2. 5 of these nodes are communicating with 5 mobile nodes under base station 7 and other 5 are communicating with 5 mobile nodes under base station 3. Voice call of PSTN quality is configured between these mobile nodes. The nodes participating in the same session are connected by the blue bidirectional dotted lines. The mobile nodes under base station 2 are configured to move at a speed of 50 km/hr in the path as shown by the white lines in Figure 1. The remaining key network configuration parameters in OPNET are summarized as shown in Table II and the attributes of the network components are shown in Table III.

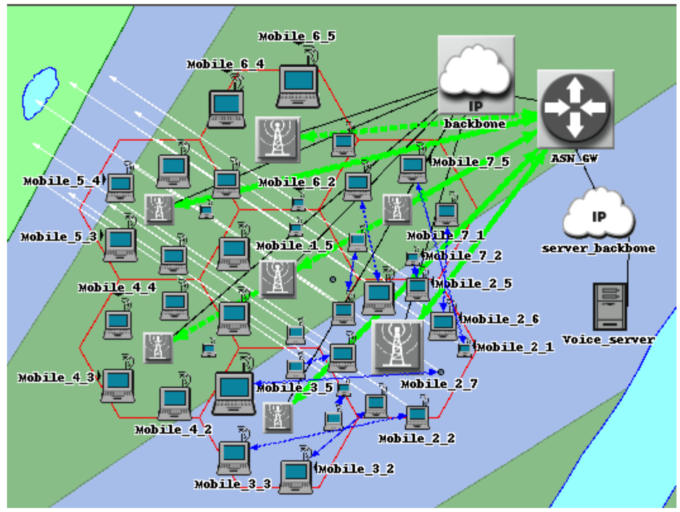

Figure 1. Network Model for WiMAX.

TABLE II. Network Configuration Details

Simulator used	OPNET 14.5.A
Network	7 celled WiMAX network
Cell Radius	30km
No. of Base Stations	7
No. of Subscriber Stations per BS	10
No. of Mobile nodes in the network	10
Speed of the mobile nodes	50 km/hr
Simulation time	600 sec
Base Station Model	wimax_bs_ethernet4_slip4_router
Subscriber Station Model	wimax_ss_wkstn
ASN Gateway Model	ethernet4_slip8_gtwy
IP Backbone Model	ip32_cloud
Voice Server Model	ppp_server
Link Model (BS-Backbone)	PPP_DS3
Link Model (ASN - Backbone)	PPP_SONET_OC12

TABLE III. Attributes of the Network Components

Attributes	Value
Pathloss Model	Suburban Fixed(Erceg)
Physical Layer Model	OFDMA 20Mhz
MAC Protocol	IEEE 802.16e
Multipath Channel Model	ITU Vehicular A
No. of Transmitter per BS	SISO
Traffic Type of Service	Interactive Voice and Data
Scheduling Type	ertPS, nrtPS
Application	Voice (PSTN quality), FTP
Voice Codec	G 711
FTP Load	High

IV. Simulation Results and Discussion

The performance metric used to analyse the network performance is path loss, average throughput of the WiMAX network and packet end to end delay. Using OPNET, the simulation is conducted for the common path loss models and the three types of terrains: Terrain Types A, B, C of erceg path loss model. We are interested to investigate the combined effect of terrain (buildings, trees, etc.) and vehicular mobility on the Mobile WiMAX performance in OPNET. To investigate the combined effect of terrain and vehicular mobility, the terrains are simulated by choosing the terrain type in OPNET which is thereby selected by the simulator based on the actual location and surrounding terrain of the transmitter-receiver pair.

A. Pathloss

Path loss models are broadly classified into four groups namely free space, Suburban fixed, Outdoor to indoor and pedestrian, vehicular environment. The path loss due to these models in a WiMAX network with mobile nodes moving at a speed of 50 km/hr is modeled in OPNET modeler and the result is shown in fig 2.

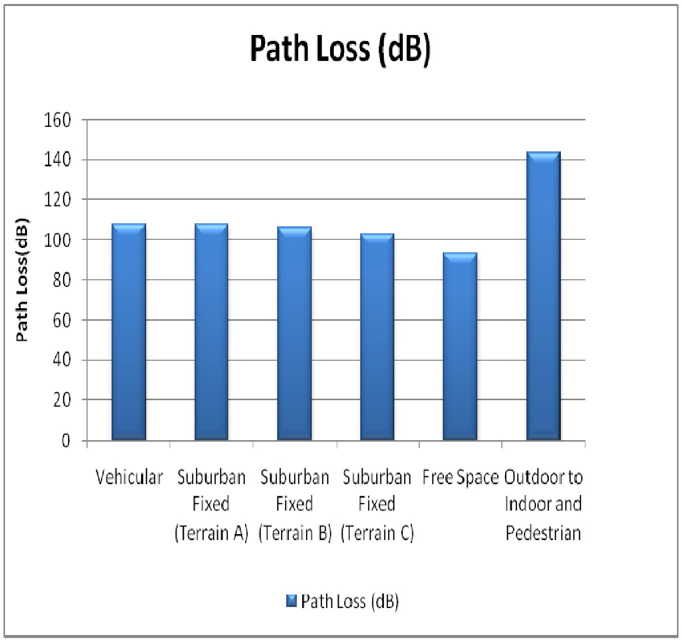

Figure 2. Path loss due to various pathloss models in decibel.

From the graph it is observed that the path loss for outdoor to indoor and pedestrian is the highest and the same for free space is the lowest. This is due to the fact that the path loss value varies with the amount of reflection in the communicating path. As a mobile node moves from outdoor to indoor the number of reflections in the communicating path increases rapidly thereby causing huge path loss. Also, we see that the path loss for free space is the least. This is concluded in [2] that the path loss increases with the number of obstructions in the communication path and our result confirms it.

B. Average Throughput

This metric measure the amount of voice traffic and FTP traffic received in bits per second on average for each connection. From Figure 3, it is observed that the throughput of the network with free space path loss model is the highest and the same for outdoor to indoor and pedestrian is the lowest for both voice and FTP traffic. This is due to the fact that as the density of obstacles increases, the Line of Sight (LOS) gets affected. Thus the number of times the signal gets obstructed and reflected is more. This results in increasing attenuation and diffraction due to the building structures, trees or mountains. As the Line of Sight (LOS) between the transmitting and receiving nodes decreases, it causes delay. This results in packet loss thereby causing fall in the average throughput.

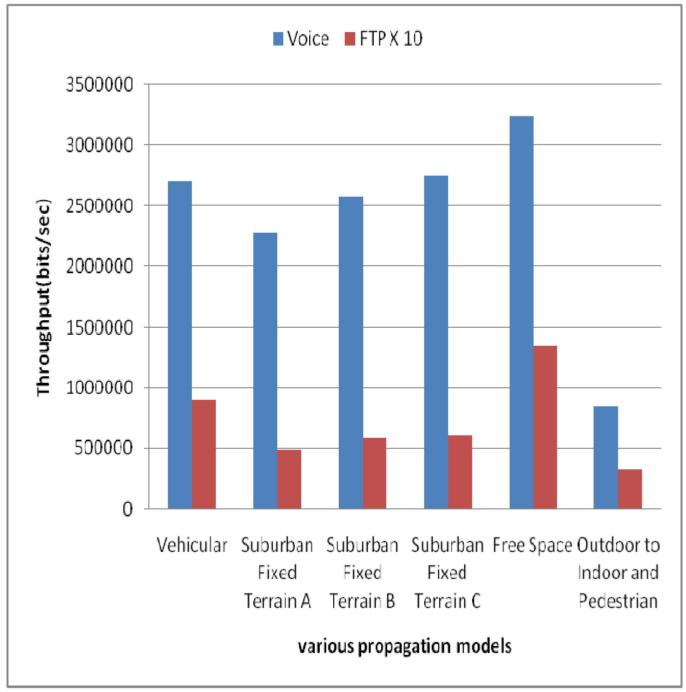

Figure 3. WiMAX Network Throughput in Bits per second

C. Average Packet end to end delay

This metric measures the time taken by each voice packet to travel from the mouth of the transmitter to the ear of the receiver and each FTP packet from the application layer of the sender to the application layer of the receiver, on average for each connection. From Figure 4, it is observed that the packet end to end delay of the network with free space as the pathloss model is the lowest and the same for outdoor to indoor and pedestrian is the highest irrespective of the application. This is due to the fact that as the density of the building structures, trees or mountains increases, the number of times the signal gets obstructed and reflected is more thereby increasing attenuation and diffraction. Hence, the LOS between the transmitting and receiving nodes decreases. This causes the mobile node to get disconnected from the base stations and thereby perform re-registration [8] to get re-connected to a base station.

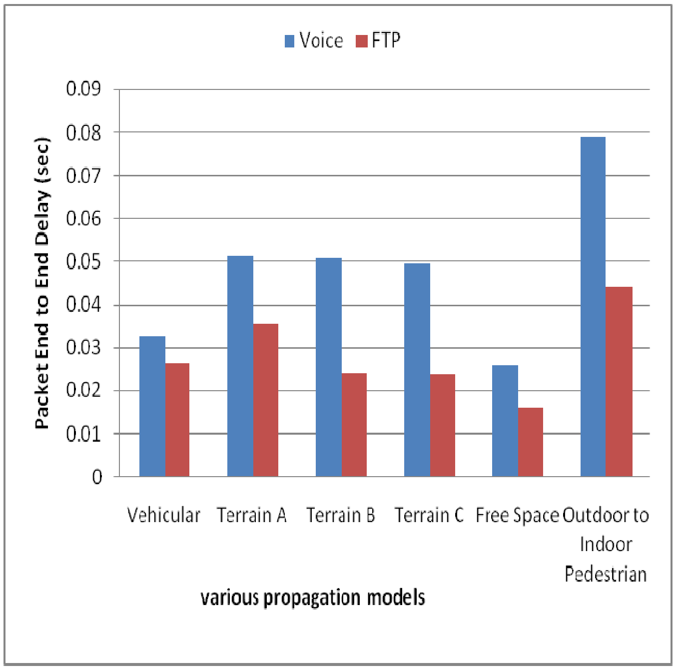

Figure 4. Packets end to end delay in seconds

The registration procedure is time consuming and hence adds up to the packet end to end delay. With flat terrain model and very less or nil obstructions, the mobile node remains connected to some or the other base stations and thus the network scanning and registration process is avoided thereby causing less delay as shown in fig.4.

V. CONCLUSION

The target of this paper is to create awareness among the researchers working with wireless networks. This paper shows the variation in performance of a WiMAX network with varying path loss models deployed over suburban areas of terrain types varying from hilly terrain with moderate to heavy tree density to flat terrain with light tree density for VoIP and FTP application with mobile nodes moving at a speed of 50 km/hr. Our aim was to evaluate the effect of various path loss models over varying suburban terrains, on the basis of average throughput and packet end to end delay and path loss of Mobile WiMAX. The reduction in Line-Of-Sight due to the terrain model of any area influences the network throughput directly by increasing the attenuation and diffraction losses, and indirectly affects the packet end to end delay by causing nodes to initiate network re-registration more frequently under fluctuating cell coverage. This is already mentioned in [1] [2] [5]. We conclude that OPNET provides a real life simulation environment and our results tally with the already taken measurements of the various path loss models in [1] [2] [5]. Thus, any experiment related to wireless network should take into consideration the terrain on which the network is deployed because this affects the network performance substantially.

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