Performance Analysis and Comparison between the Fixed & Mobile WiMAX Physical Layer

Tapan Kumar Godder, Md. Sipon Miah, Paresh Chandra Barman, Bikash Chandra Singh *and* Md. Azizur Rahman

Abstract—This project details and summarizes the basic concept of WiMAX Physical layer and MAC layer and the work performed in developing computer simulation models for fixed and mobile WiMAX physical layers. The development was divided into 3 phases during which various simulation models of increasing complexity were produced. The models were coded using Matlab software. Emphasis was placed on developing source code in strict accordance with WiMAX standard specifications. The initial software models simulated a fixed WiMAX physical layer during which key concepts and technologies were investigated. The software models developed during the last phase provided a partial simulation of a mobile WiMAX physical layer. An excellent understanding was gained of mobile WiMAX technology and its limitations in a simulated environment. Simulations showed that the performance of the WiMAX physical layer is dependent strongly on the propagation channel through which the RF signals propagate.

Index Terms— WiMAX, MAC, BER and OFDM.

1 INTRODUCTION

WORLDWIDE Inter-operability for Microwave Access, largely known as WiMAX is a telecommunication technology designed to provide effective transmission of data using transmission modes "from point-multipoint links to portable and fully mobile Internet access" . The technology is so advanced that it can provide up to 72 Mbps symmetric broadband speed without cables. The traditional cable-based access networks can deliver content only to subscribers at fixed points. This technology appears to be outdated for the modern world where an alarming rate of people use cell phones and other portable electronic devices such as laptops to do their daily work at mobile locations. Therefore, there is an increasing demand for a new technology that can deliver information to mobile users . WiMAX is intended to surpass the current, expensive network transmission technologies such as Asynchronous Digital Subscriber Line (ADSL) and T1 line and provide fast and cheap broadband access especially to rural areas lacking the necessary infrastructure such as optical fiber and copper wires. WiMAX operates in the frequency range of 10GHz - 66GHz as it has less interference and more bandwidth. A lower range of frequency band was later introduced which operates between 2GHz and 11GHz .

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There are two main types of WiMAX services: mobile and fixed. Mobile WiMAX enables users access Internet while traveling whereas fixed WiMAX stations provide wireless Internet access to clients within a fixed radius. Moreover, WiMAX is capable of delivering high speed wireless services up to a range of approximately 50km which is far longer than that of DSL, cable modem, etc. which has a span of approximately 5.5km.

WiMAX is an evolving set of the commercialization of IEEE 802.16 standard which was initiated at the National Institute of Standards and Technologies in 1998. In June 2004, it was transferred to the IEEE for the purpose of forming a working group 802.16. The WiMAX forum, which was established in 2001comprises of a group of industry leaders such as Intel, AT&T, Samsung, Motorola, Cisco etc who are entitled to support as well as promote the technology by certifying products that conform to the WiMAX standards .

In order to provide effective transmission of data with minimum delay, it is necessary for the WiMAX base station and the subscribers to obtain a clear line-of-sight. Large objects such as buildings and trees can interfere with the signals which would result in packet loss and delay. In order to avoid this unfortunate scenario WiMAX uses mesh mode topology that allows subscriber stations to communicate directly with each other while communicating with the base station. This way, if the line-of-sight between one client and the base station is interfered, the base station can route the information to that client via another client that has a clear line-of-sight. Furthermore, WiMAX uses a scheduling algorithm for exchange of data meaning the subscriber stations transmit data in their scheduled slots which helps minimize interference within networks.

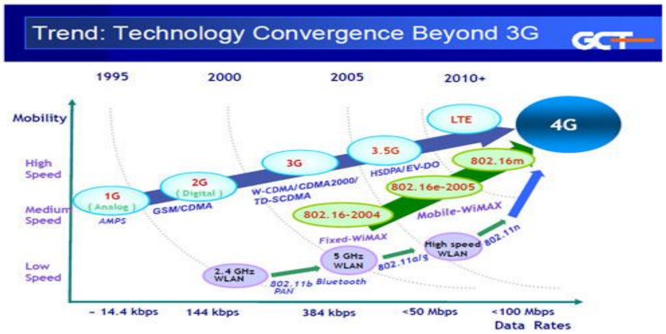

Fig. 1. Technology Convergence from 1G to 4G.

This project studies the performance of data communication under physical layer of WiMAX network model. Bit Error Rate (BER) for several PSK based digital transmission schemes used to measured in the WiMAX technology (mobile wireless communications). The growing demands for voice and multimedia services on mobile wireless communications spur the advancement of the wireless communication field in the recent decade. The evolving technologies enable this to happen. One of the major underlying technologies is the digital modulation technique which allows digitized data to be carried or transmitted via the analog radio frequency (RF) channels that is used in wireless communication.

2 SIMULATION VERSION

This project proposal is submitted to verify the performance of WiMAX physical layer network simulation model that is divided into three simulation versions.

2.1 Version 1- Basic Fixed WiMAX PHY Layer Simulation

WiMAX is an emerging wireless broadband technology. Several companies have implemented computer simulation models of the WiMAX PHY layer; however the source code of such simulations is not readily distributed. In order to get the started quickly, existing code had to be found to serve as a take-off point or baseline. This first step was essential in order not having to develop a WiMAX simulation model from scratch. As the WiMAX standard is complex and extensive, developing a computer model from direct interpretation of the standard would have been too time consuming. The Matlab Source file names are shown in Table 1 [2].

TABLE 1

THE ORIGINAL AND BASELINE VERSION FILES ARE LISTED

File number	Ferrer version (Spanish)	Simulation baseline version
1	aleatorio	randomize
2	BERteorica	BERtheoretical
3	Bin_coef	Bin_coef
4	bit _simbolo	bit _symbol
5	canalSUI channelSUI	channelSUI
6	CIRpowers	CIRpowers
7	codificador	encoder
8	creacionsimbolo	createsymbol
9	cyclic	cyclic
10	decodificador	decoder
11	dibujar	draw
12	estimacioncanal	estimatechanne
13	Extraer_datos	Extract_data
14	find index	find index
15	generapiloto	genpilots
16	generodatos	gendata
17	genh	genh
18	gray2bi	gray2b
19	graytable	graytable
20	interleaving	inteleaving
21	maper	map
22	Parameteros_conste lacion	Constellation_pa rameters
23	parametros SUI	parameters SUI
24	Pb_pam_ray	Pb_pam_ray
25	Pb_psk_ray	Pb_psk_ray
26	Pb_qam_ray	Pb_qam_ray
27	PruebaBW	BW_test
28	PuebaCanales	Channel_test
29	PruebaCodifico	Encode_test
30	PruebaGuarda	Guard test
31	PruebaModula	Modulation test
32	receptor	receiver
33	ReedSalomon	ReedSolomo
34	ruido	noise
35	systema	System_simulato r
36	subtrleft	subtrleft
37	Transmitor	Transmitor
38	viterbi	Vitebi
39	wimax	Wimax

The results of Ferrer WiMAX PHY layer simulation are output plots of the bit error rate (BER) versus the Eb/N0 (bit energy to noise power spectral density ratio). Several different scenarios can be simulated in which parameters for modulation types, communications channel types, encoding, nominal bandwidth, and cyclic prefix length can be varied. The Ferrer simulation does not allow multiple users and is for a fixed WiMAX network. The program allows the number of OFDM symbols transmitted to be specified by the user. The BER converges to a more accurate value as the number of symbols transmitted increases. The program simulates only the downlink; the transmission interface from the base station to the subscriber station. The Ferrer simulation was adopted as the baseline for further code development as it served as a good take-off point for further understanding and interpretation of the WiMAX standard.

2.2 Version 3- Improved Fixed WiMAX PHY Layer Simulation

During the first phase of code development a baseline version (V1) of the simulation model was produced. This simulation model was limited to the modeling of a fixed WiMAX PHY layer per the original IEEE802.16-2004 standard. During the 2nd phase of development an extensive study was undertaken to extend the baseline version to include components defined for mobile WiMAX applications per the IEEE802.16e-2005 standard. A mobile WiMAX system is based on scalable orthogonal frequency division multiple access (SOFDMA) and includes other advanced concepts such as subchannelization, channel estimation techniques, adaptive modulation and coding (AMC) and use of multiple transmit and receive antennas (MIMO).

The Version 3 (V3) simulation software models an OFDM-based fixed WiMAX PHY layer. The user can enter simulation parameters such as the channel model, nominal bandwidth, modulation type, coding rate, cyclic prefix length and others. However instead of transmitting random data, the program simulates the transmission of an image across the physical layer. This approach gives much better qualitative results, as the received image can be easily compared to the original image. For a quantitative description of the simulation a graph of the calculated bit error rate (BER) versus the bit energy to noise power spectral density ratio (Eb/N0) is plotted. The Matlab source file names for Version 3 are as shown in Table 2 [2].

TABLE 2

VERSION SOURCE FILE NAME

File number	File name
1	bit symbol
2	ChannelSUI
3	constellation parameters
4	Createsymbol
5	Cyclic
6	Decoder
7	Encoder
8	Estimatechanne
9	Extract_data
10	Find_index
11	Gendata
12	Genpilots
13	Interleaving
14	Map
15	Parameters_SUI
16	Randomize
17	Receiver
18	ReedSolomon
19	Run_rgswimax_sim
20	system simulation
21	Transmitter
22	validate_input
23	Viterbi

2.3 Version 5- Basic Mobile WiMAX PHY Layer Simulation

During the 1st and 2nd phase of simulation development, important fundamental concepts were learned. These concepts were essential to develop an accurate, although limited, simulation model of a mobile WiMAX PHY layer as specified by the IEEE 802.16e-2005 standard. Version 5 of the software models the downlink (DL) from the base station (BS) to a mobile station (MS). The model employs scalable OFDMA, subchannelization, and preamble-based channel estimation techniques. The software partially models the MAC layer as it generates pseudo-MAC layer management messages to the PHY layer. The simulation consists of the Matlab files shown in Table 3 [2].

TABLE 3

VERSION 5 SOURCE FILE NAMES

File number	File name
1	Bit_symbol
2	constellation_parameters
3	cyclic
4	estimatechannel
5	Find_index
6	Find_preamble_128
7	Find_preamble_512
8	Find_preamble_1024
9	Find_preamble_2048
10	Form_preamble_128
11	Form_preamble_512
12	Form_preamble_1024
13	Form_preamble_2048
14	Gensubchan
15	gray2bi
16	interleaving
17	MAC_DL_MAP_msg
18	map
19	parameters SUI
20	randomize
21	scpm_dl fusc_128
22	scpm_dl fusc_512
23	cpm_dl_fusc_1024
24	cpm_dl_fusc_2048
25	scpm_dl_pusc_128
26	scpm_dl_pusc_512
27	cpm_dl_pusc_1024
28	cpm_dl_pusc_2048

29	viterbi
30	WiMAX

3 Result and Discussion

3.1 Fading Channels

The simulation of the WiMAX PHY layer begins with modeling of the communications channel through which signals propagate from the transmitter to the receiver. Proper channel modeling is a critical part of the simulation as the signals experience attenuation, delay spread, Doppler frequency shifts (in case of a moving receiver), and multipath re-flections that degrade the signal's quality as it passes through the channel. The signal propagation can be via line-of-sight and non-line-of-sight paths. The model uses the SUI (Stanford University Interim) channel models to describe the fading channels for various urban and rural environments and terrain types. Six SUI channel models have been adopted that adequately describe various parameters that define a communications channel. These parameters include path loss, multipath delay spread, fading characteristics, Doppler spread and co-channel interference. Upon review and examination of the Ferrer model, it was concluded that the channel modeling was not correctly implemented. The Doppler spectrum for the SUI channel models was being set up as a classical Jakes model, which the SUI channels are not.

3.2 OFDM Symbol Creation

The WiMAX PHY layer uses OFDM to combat multipath effects such as channel fades, intersymbol interference and delay spread through the use of orthogonal subcarrier frequencies. OFDM is a key component of WiMAX and is a combination of modulation and multiplexing. How an OFDM symbol is created is essential to the understanding of WiMAX The fixed WiMAX standard specifies that the available bandwidth is divided into 256 subcarrier frequencies. A total of 64 subcarrier frequencies are reserved for guard bands, pilot frequencies and a DC component, leaving the remaining 192 subcarriers for data transmission. The transmitted data is multiplexed and modulated onto the 192 orthogonal subcarriers. The orthogonal nature of the subcarriers assures that these frequencies do not produce intermodulation products. The first step of the OFDM symbol creation begins with determining how many bits need to be generated. This function is implemented in the gendata.m file. For each modulation type and coding rate combination, the WiMAX standard specifies the uncoded block size (UBS) required to form the OFDM symbol, however the UBS is easily calculated.

The WiMAX standard specifies the constellation maps for BPSK, QPSK, 16-QAM and 64- QAM modulation types. For each constellation the standard also specifies a normalization factor 'c' to achieve equal average power. Two changes were implemented to the map.m function and its sub functions of the original Ferrer simulation model. The bit symbol.m function is called by map.m to calculate the symbol alphabet. The alphabet calculated did not conform to the WiMAX standard. Changes were made so that the symbol alphabet is calculated correctly.

The cyclic prefix (CP) is inserted before the OFDM symbol is sent over the channel to combat delay spread and inter-symbol interference. The WiMAX standard specifies CP values of 1/4, 1/8, 1/16, and 1/32. This is done by the cyclic.m function. The last samples of the OFDM are copied to the beginning of the symbol. The spectrum of the OFDM symbol after addition of the CP is shown in Figure 2. A CP length of 1/4 is used in this example; therefore the output symbol length is 256 *1/4 = 48 + 256 = 320-bits or 40-bytes. It is interesting to note how the magnitude of the spectra fluctuates as compared to the underlying constant amplitude carriers. The OFDM symbol is very noise-like.

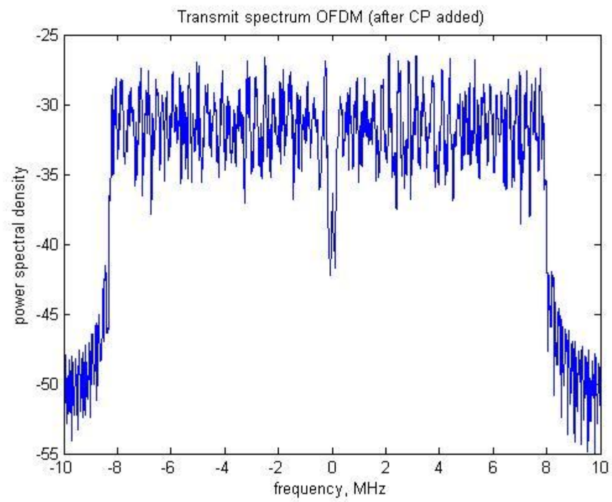

Fig. 2. Spectrum of OFDM symbol after CP added

3.3 BER Calculation

The bit error rate (BER) is calculated from the input and output vectors. This is done using the Matlab 'biterr' function which returns the number of bits that are different and the calculated ratio of bits that are in error to the total bits. The latter quantity is the BER which is plotted against the Eb/N0 value. This version of the simulation assumes thatthe BER and Eb/N0 values are one and the same, which they are not. These quantities are related by 'k' which is the number of bits per symbol and the coding rate. This discrepancy is addressed in subsequent simulation versions. Figure 3 shows a typical plot generated by the simulation.

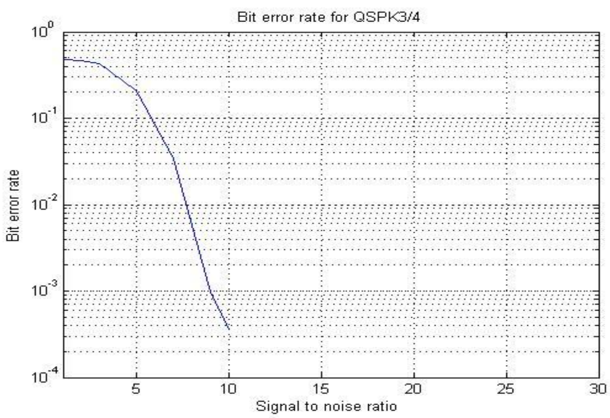

Fig. 3. Typical BER vs. Eb/N0 plot of 20 OFDM symbols transmitted

3.4 Stanford University Interim (Sui) Channel Models

SUI channel models are an extension of the earlier work by AT&T Wireless and Ercegetal. In this model a set of six channels was selected to address three different terrain types that are typical of the continental US. This model can be used for simulations.

TABLE 4

TERRAIN TYPE FOR SUI CHANNEL

Terrain Type	SUI Channels
C (Mostly flat terrain with light tree densities)	SUI-1, SUI-2
B (Hilly terrain with light tree density or flat terrain with moderate to heavy tree density)	SUI-3, SUI-4
A (Hilly terrain with moderate-to- heavy tree density)	SUI-5, SUI-6

TABLE 5

ERRAIN GENERAL CHARACTERISTICS OF SUI CHANNELS

Doppler	Low delay spread	Moderate delay spread	High delay spread
Low	SUI-1,2 (High K-Factor) SUI-3		SUI-5
High		SUI-4	SUI-6

3.5 BER Plots of SUI Channel 1

In this section we have presented various BER vs. SNR plots for all the mandatory modulation and coding profiles as specified in the standard on same channel models. Figure 4 show the performance on SUI-1, 2 and 3 channel models respectively. It can be seen from this figures that the lower modulation and coding scheme provide s better performance with less SNR. This can be easily visualized if we look at their constellation mapping; larger distance between adjacent points can tolerate larger noise (which makes the point shift from the original place) at the cost of coding rate. By setting threshold SNR, adaptive modulation schemes can be used to attain-3 highest transmission speed with a target BER. SNR required to attain BER level at 10 are tabulated in Table 6.

TABLE 6

SNR REQUIRED AT BER LEVEL 10 FOR DIFFERENT MODULATION AND CODING PROFILE

Mod.	BPSK	QPSK	QPSK	16-QAM	16-QAM	64-QAM	64-QAM
Code rate	1/2	1/2	3/4	1/2	3/4	2/3	3/4
Channel	SNR	(dB)	At BER	Level	10^-3		
SUI-1	4.3	6.6	10	12.3	15.7	19.4	21.3
SUI-2	7.5	10.4	14.1	16.25	19.5	23.3	25.4
SUI-3	12.7	17.2	22.7	22.7	28.3	30	32.7

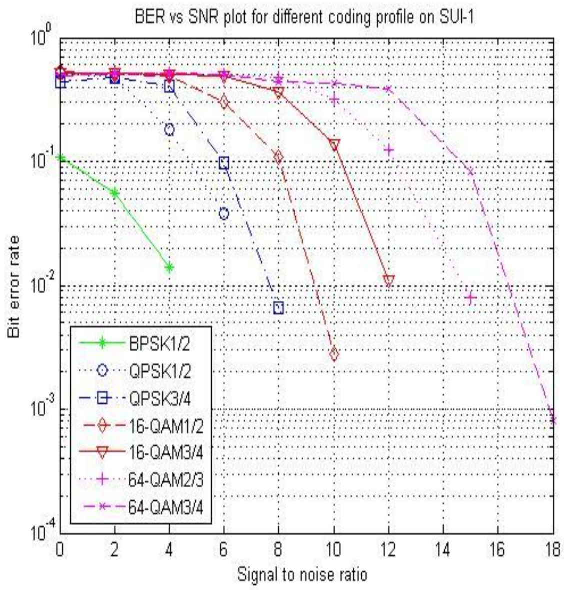

Fig. 4 . BER vs. SNR plot for different coding profiles on SUI-1 channel

Having observed the performance of different profiles under same channel models, let us observe the variations with the change in channel conditions. Figure 4 shows the performance of 16-QAM ½ on SUI-1 channel model. It can be seen from the figure that the severity of corruption is highest on SUI-3 and lowest in SUI-1 channel model. The order of the severity of corruption can be easily understood by analyzing the tap power and delays of the channel models, since the doppler effect is reasonably small for fixed deployment. All the three models have same amount of delays for corresponding tap except tap 3 of SUI-2 models has 0.2 μs larger than the corresponding tap of the other two models. But, in this case tap power dominates in determining the order of severity of corruption. SUI-3 has highest tap power value and SUI-1 has lowest value.

7 CONCLUSION

During the 6-month period from 14 April to 14 November, 2008, five separate simulation models of the WiMAX PHY layer were produced with increasing complexity. The first version (V1) modeled a fixed WiMAX PHY layer based on the original IEEE802.16-2004 standard. The first model was based on existing Matlab code in order to speed up development and gain fast understanding of the basic concepts involved. During the second phase of development two software versions were produced. Version 2 was an interim version. The third version (V3) of the simulation expanded on the original model and incorporated several changes and corrections. The third version was also based on a fixed WiMAX PHY layer and investigated the channel effects on the quality of a transmitted image. A major improvement to the third version was the incorporation of an accurate channel estimation algorithm. Version 4 was an interim version. Although the final version (V5) is incomplete, it employs concepts basic to mobile WiMAX such as scalable OFDMA, subcarrier permutation modes, sectorization, frame generation and preamble-based channel estimation techniques. Version 5 models the downlink and contains limited modeling of the MAC layer.

An important conclusion drawn from the V5 model is the susceptibility of the physical layer to channel quality. As the receiver must first successfully capture, extract and decode the transmitted frame preamble and other control messages, the simulation performance is heavily dependent on the channel's fading characteristics and random noise introduced into the channel. Future simulation versions will focus on testing and evaluating system performance in various fading environments and operating modes.

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