Design And Implementation Of An Efficient Ofdm Transreceiver Chain For Wimax

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Abstract— The telecommunication industries are insisting on new standardized technologies with high transmission abilities like in IEEE 802.16 versions, which are also referred as WiMAX. WiMAX is a wireless transmission infrastructure that allows fast deployment as well as low maintenance costs. In this system efficient utilization of bandwidth is possible for a wide range of frequencies and can be used as a last mile solution for broadband internet access. It offers both line of sight and non-line of sight wireless communication.

This paper elucidates all compulsory features of the WiMAX OFDM physical layer specified in IEEE 802.16 standards by simulating the WIMAX models and also this paper will manifest a study on WiMAX system by comparing different modulation schemes such as BPSK, QPSK and QAM (Both 16 and 64). The performance of the designed system is evaluated based on BER and SNR with the aid of MATLAB tools.

***Keywords*—WiMAX, OFDM, BPSK, QPSK, QAM, BER, SNR**

I. INTRODUCTION

WiMAX (Worldwide Interoperability for Microwave Access) is introduced by the Institute of Electrical and Electronic Engineers (IEEE) which is designated by 802.16. There are fixed (802.16d) and mobile (802.16e) WiMAX [1] which offers both line of sight and non-line of sight wireless connectivity. This technology offers a high speed, secure, sophisticate, last mile broadband service, ensuring a flexible and cheap solution to certain rural access zones. In a fixed wireless communication, WiMAX can replace the telephone company's copper wire networks, the cable TV's coaxial cable infrastructure. In its mobile variant it can replace cellular networks. In comparison with Wi-Fi and Cellular technology, Wi-Fi provides a high data rate, but only on a short range of distances and with a slow movement of the user. And Cellular offers larger ranges and vehicular mobility, but it provides lower data rates, and requires high investments for its deployment. WiMAX tries to balance this situation. WiMAX fills the gap between Wi-Fi and Cellular, thus providing vehicular mobility, and high service areas and data rates WiMAX developments have been rapidly moving forward.

Many researchers do believe that WiMAX can move the wireless data transmission concept into a new dimension of broadband service. There are basically three limiting factors for transmitting high data rate over the wireless medium that mainly include multipath fading, delay spread and co-channel interference. Standards for Fixed WiMAX (IEEE 802.16d-2004) were announced as final in 2004, followed by Mobile WiMAX (IEEE 802.16e) in 2005, which are based on orthogonal frequency division multiplexing (OFDM) technology [2].OFDM is a transmission technique built for high speed bi-directional wired or wireless data communication.OFDM has high Peak-to-Average Power Ratio (PAPR). The Wireless MAN (metropolitan area network)-OFDM interface can be extremely limited by the presence of fading caused by multipath propagation and as result, the reflected signals arriving at the receiver are multiplied with different delays, which cause Inter-symbol interference (ISI). OFDM basically is designed to overcome this issue and for situations where high data rate is to be transmitted over a channel with a relatively large maximum delay. If the delay of the received signals is larger than the guard interval, ISI may cause severe degradations in system performance.

II. OVERVIEW OF WIMAXTRANSRECEIVER

The basic block of wireless communication is given below figure.1

Figure 1: basic block of wireless communication

Where in WiMAX OFDM physical layer(PHY)[3] specifications are as given below:

The transmitter block consists of:-

1 .Randomized data (Bernoulli Binary/ Stored Data)
2. FEC (Convolution Code, RS Code)
3 Modulation (BPSK and QAM)
4. OFDM Transmitter (IFFT)

The channel used is

Additive White Gaussian Noise (AWGN)

The Receiver block consists of:

1. OFDM Receiver (FFT)
2. Demodulator
3 Decoder (Viterbi decoder, RS Decoder)

As specified WiMAX OFDM PHY layer, transmitter [3] is composed of three major parts: channel coding, modulation, and OFDM transmitter. For the receiver complimentary operations are applied in the reverse order.

Channel coding refers to the class of signal transformations designed to improve communications performance by enabling the transmitted signal to better withstand the effects of various channel impairments, such as noise, fading, and jamming. The goal of channel coding is to improve the bit error rate (BER) performance of power-limited and bandwidth limited channels by adding structured redundancy to the transmitted data [4]. In IEEE 802.16 standard, the channel coding includes randomization, forward error correction (FEC), and interleaving. The FEC block is composed of Reed-Solomon encoder, convolutional coding and puncture (used to adjust different data rate).

Modulation is the process of mapping the digital information to analog form so it can be transmitted over the channel. For an OFDM system the changing of phase and amplitude can be done but the frequency cannot change because they have to be kept orthogonal. The modulation used in WiMAX is BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), 16QAM (Quadrature Amplitude modulation) and 64-QAM. The OFDM transmitter is composed of three parts: assemble OFDM frame, create OFDM signal by performing IFFT/FFT, and add cyclic prefix (guard interval used to cancel inter symbol interference).OFDM in WIMAX technology is implemented by IFFT which uses the formula given in equation (1).

$$x_n = \left(\frac{1}{N}\right)\sum_{k=0}^{N-1} X_k\, e^{2\pi . jnk/N} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where N=0, 1, 2 …N-1.

III. SYSTEM INTEGRATION AND IMPLEMENTATION OF WORK FLOW

In the development and testing of IEEE 802.16 Wireless MAN -OFDM PHY [2],the specifications of communication transfer have varying systems, which are based on the needs. Constraining the work according to these needs, standard communication system box with a map provided by Matlab is considered, which contains the following: Internal Communications Block set, Signal processing Block set, and Simulink Block set. These correspond to use of the hardware development platform in this documentation.

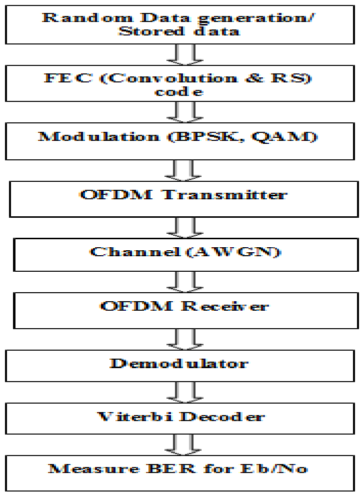

Figure 2: The overall system workflow

The overall WIMAX PHY system construction is simulated on Simulink interface with the assistance of internal functions in Matlab. The main objective is to build a finished system into a module, in accordance with the code of each block. Through this the module can be compiled and made executable on Matlab.The overall system workflow is as shown in figure 2.

The model for WiMAX system using BPSK and QAM modulation is shown.The detailed diagram is given below:

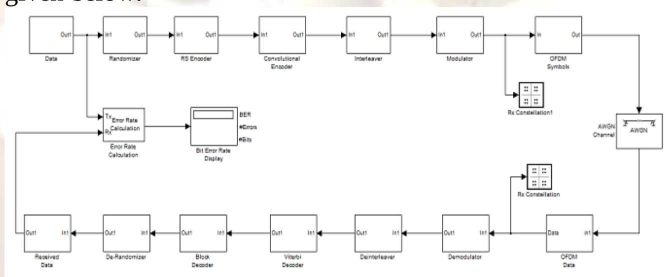

Figure 3: Simulation setup

A. **Randomization:**The first block in the transmitter is randomizer, which is used for randomization of the data. The randomizer is necessary to prevent a long sequence of 1's and 0's, which will cause timing recovery problem at the receiver. In 802.16a standard, the scrambler is implemented with a 15 bits shift register and two XOR gates as shown in figure 4.

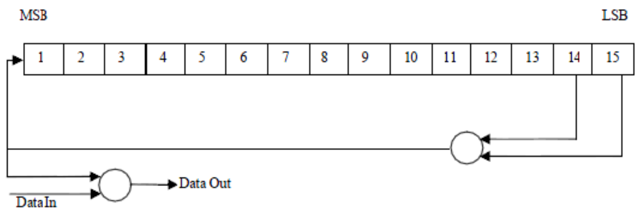

Figure 4: Randomizer

B. Forward Error Correction: The channel encoding setup is as shown in below figure 5.

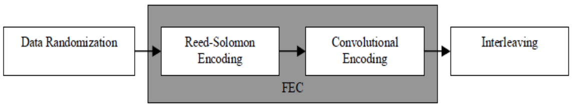

Figure 5: Channel encoding setup

i. **Reed-Solomon Encoder**:FEC introduces redundancy in the data before it is transmitted. The redundant data (check symbols) are transmitted with the original data to the receiver. The first block in FEC is RSencoder[5], are the block codes which are used for correcting burst errors. The codes are referred to in the format RS (N, K, T), where K: number of un-encoded bytes, N: number of coded bytes and T: number of bytes that can be corrected. The RS encoder generates a code such that the first K bits output from the encoder are the information bits and the next N-K bits from the encoder are the check bits added for error correction. The standard RS encoder is RS (255, 239, 8), with the following polynomials equation (2) and (3):

Code Generator Polynomial:

$$g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots\ldots(x+\lambda^{2T-1}), \ldots\ldots (2)$$

$$where\ \lambda = 02_{HEX}$$

Field Generator Polynomial:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

ii. **Convolutional Encoder/ Viterbi Decoder:** The convolutional encoder [5] as shownin Figure 6 is used to enable the correction of random errors. The coding rate is 1/2 and constraint length is 7. Though 6 different data rates are supported in WiMAX OFDM PHY, puncture is needed after Convolutional coding. At the receiver Viterbi decoder [5] is used to decode the convolutional codes with a suitable trace back depth.

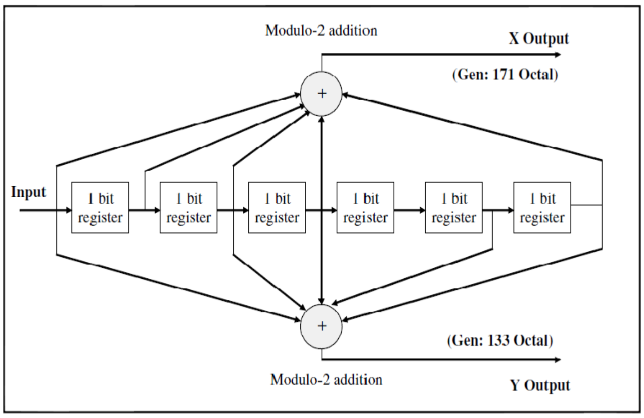

Figure 6:Convolution Encoder

C. **Interleaver/De-interleaver:** After RS-CC encoding all encoded data bits shall be interleaved by a block interleaver with a block size corresponding to the number of coded bits per the specified allocation(Ncbps). Whereas modulation schemes discussed in earlier sections hasNcbps of 192, 384, 768, and 1152 respectively. Hence interleaver is defined by a two-step permutation.

The number of coded bits per carrier(Ncpc), for QPSK, 16-QAM or 64-QAM, are 1, 2, 4 or 6respectively. Let s= Ncpc/2, and let k be the index of the coded bit before the first permutation at transmission; m be the index after the first and before the second permutation; and j be the index afterthe second permutation, just prior to modulation mapping.

First step permutation:

$$m = (N_{cbps}/16).k_{mod\ (16)} + floor(k/16) \ldots\ldots\ldots (4)$$

$$where, k = 0,1,2 \ldots N_{cbps} - 1$$

Second step permutation:

$$j = s.floor(m/s) + \left(m + N_{cbps} - floor(16.m/N_{cbps})\right)_{mod\ (s)} \ldots\ldots\ldots (5)$$

$$where\ m = 0,1,\ldots\ldots N_{cbps} - 1$$

The first permutation given by equation (4) ensures that adjacent coded bits are mapped onto nonadjacentcarriers. This ensures that if a deep fade affects a bit, its neighbouring bitsare likely to remain unaffected by the fade, and therefore is sufficient tocorrect the effects of the fade. The second permutation given by equation (5) ensures thatadjacent coded bits are mapped alternately onto less or more significantbits of the constellation. This makes detection accurate and long runs oflow reliability bits are avoided. De-interleaver is performed in reverseorder of the processed explained above.

D. **Modulation/Demodulation:** The bit interleaved data are then passed to the constellation mapper, where depending upon its size the data was modulated using the following modulation schemes [6]: BPSK, Gray-mapped QPSK, 16-QAM and 64-QAM. Modulation is performed by dividing the incoming bits into groups of i bit, which represents the modulated signal. As a result there are 2i points, and the total number of points represents a constellation. The constellations are presented in the I-Q plane, where I and Q denote the in-phase and quadrature component as shown in below figure 7 where b0 denotes the LSB for each modulation.The size of i for BPSK, QPSK, 16-QAM and 64-QAM are 1, 2, 4 and 6 respectively.

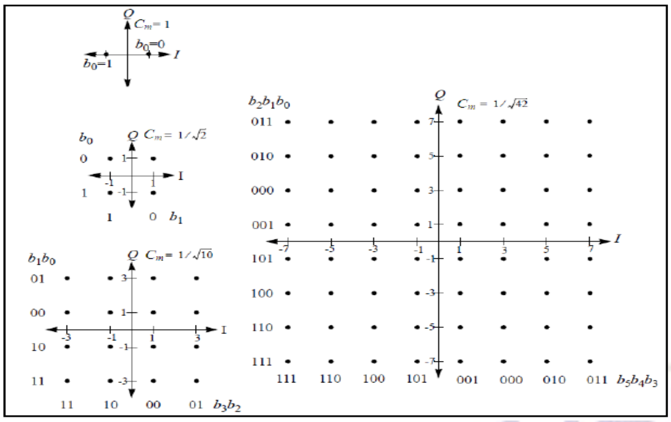

Figure 7: Constellation mapping of different modulations

To achieve equal average symbol power, the constellations described above are normalized by multiplying all of its points by an appropriate factor Cm.

modulation	Uncoded block size (bytes)	Coded block size (bytes)	Overall code rate	RS code	CC code rate
BPSK	12	24	1/2	(12,12,0)	1/2
QPSK	24	48	1/2	(32,24,4)	2/3
QPSK	36	48	3/4	(40,36,2)	5/6
16-QAM	48	96	1/2	(64,48,8)	2/3
16-QAM	72	96	3/4	(80,72,4)	5/6
64-QAM	96	144	2/3	(108,96,6)	3/4
64-QAM	108	144	3/4	(120,108,6)	5/6

Table 1: Mandatory channel coding per modulation in WiMAX

E. **IFFT Transmitter/FFT Receiver:** Two periodic signals are considered orthogonal when the integral of their product, over one period, is equal to zero. The carriers of an OFDM system are sinusoids that are different multiples of a fundamental frequency. Each subcarrier has an integer number of cycles in one period. Figure 8 gives an example of orthogonal subcarriers in OFDM system.

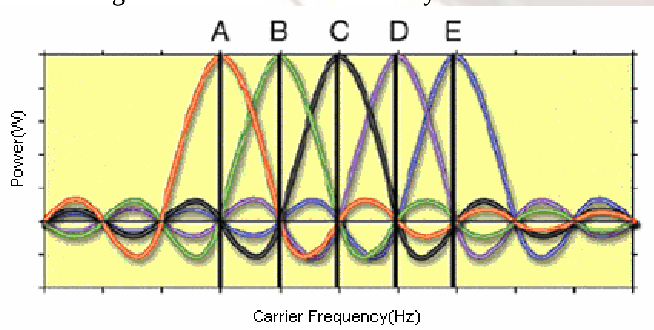

Figure 8: Orthogonal OFDM subcarriers

FFT takes a time domain signal and outputs a frequency domain signal asa function of the sampling period and number of samples. Thefundamental frequency of the FFT is defined as $1/T_{s\_tot}$ (T_{s_tot} is the totalsample time of FFT). The timeduration of the IFFT time signal is equal to the number of FFT binsmultiplied by the sample period. Each sub-stream is then mapped to asubcarrier at a unique frequency and combined together using IFFT toyield the time-domain waveform to be transmitted.An OFDM symbol can be defined by an IFFT, the mathematicalmodel of an OFDM symbol to be transmitted is given by equation (1).Zeros are padded equally at the beginning and end of an OFDM symbolto perform 256 points IFFT at the transmitter. These zero carriers are alsoused as guard band to avoid inter channel interference. At the receiverafter doing FFT zero pads should be removed from the correspondingplaces.

In wireless communication the original signal might be distorted by the echosignals due to multipath delay, this is ISI. Inorder to cope with this problem a CP is inserted before eachtransmitted symbol. If multipath delay is less than the CP duration, ISI iscompletely eliminated by design. Thus after performing IFFT,CP has to be added for each OFDM symbol as shown in figure 9. This is done bysimply copying the last **portion** data in an OFDM symbol to thebeginning. In the 802.16 standard, 1/4, 1/8,1/16,1/32 adaptive CPlength can be applied to the transmitted symbol. At the receiver reverseoperation of the above to be performed.

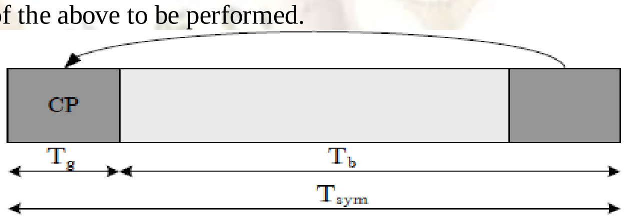

Figure 9: OFDM symbol with the cyclic prefix

F. **Channel model:** In order to evaluate a communication system, an accurate description ofthe channel model is necessary. A wireless channel is characterized by

Path Loss: The path loss depends very much on the terrain and obstacles density inthe path of LOS propagation. Usually high obstacle density and hillyterrain leads to high path loss and vice versa.

Multipath Delay Spread: The transmitted signal propagates through different paths due to thescattering environment, thus they arrive at the receiver at different time.From the receiver point of view, each received signal is acombination of multipath propagated signals.

Fading Characteristics: Fading refers to the signal level variability, which can be characterizedby certain statistical distribution model. When there are a large numberof indirect paths from the base station to the mobile user and if they are greatlypredominated over the direct path, the received signal has a Rayleighdistribution. While in circumstances where the direct path dominatesover indirect paths, the received signal has a Ricean distribution.

Doppler Frequency Shift: Doppler frequency shift is caused by the motion of relative motion, for mobile communication it is assumed that the receiver is movingsuch that the classical Jakes' spectrum is used. While for a fixedwireless communication, both the transmitter and receiver are stationarybut actually some reflectors in the environment move, therefore therounded Doppler PSD model is proposed.

Besides the above channel factors, coherence distances, co-channelinterference, antenna gain reduction factor should be taken intoconsideration when simulating multichannel communicationsystem. Thispaper considers only SISO and single channeltransmission and the channel for simulation is Multipath Rayleigh fadingchannel.

IV. SIMULATION &RESULTS

In this section, simulation results are discussed. During the simulation we used CP to minimize ISI on the basis of following adaptive modulation techniques through Matlab mentioned in earlier sections. The performance of the module is analysed based on following parameters.

a) **BER:** When number of bits error occurs within one second in transmitted signal then we called Bit Error Rate (BER) [6]. In another sentence Bit Error rate is one type of parameter which used to access the system that can transmit digital signal from one end to other end. We can define BER as equation (6),

$$BER = \frac{Error\ Number}{Total\ Number\ of\ bits\ sent} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

b) **Eb/No:**Energy per bit to noise power spectral density ratio is important role especially in simulation. Whenever we are simulating and comparing the Bit Error rate (BER) performance of adaptive modulation technique is very necessary Eb/No. The normalized form of Eb/No is Signal-to- Noise Ratio (SNR). In telecommunication, Signal-to-Noise ratio is the form of power ratio between a signal and background noise given as equation (7),

$$SNR = \frac{P_{signal}}{P_{Noise}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Here P is mean power.

c) **BER VsEb/No:** BER is defined as the probability of error (P_e). On the other hand SNR has three variables like,

 i. The error function (erf)
 ii. The energy per bit (Eb)
 iii. The noise power spectral density (No)

Every modulation scheme has its own value for the erf. Hence each modulation scheme performs in different manner due to the presence of background noise. For instance, the higher modulation scheme (64-QAM) is not robust but it carries higher data rate. On the contrary, the lower modulation scheme (BPSK) is more robust but carries lower data rate. The Eb is a measure of energy with the unit of Joules. Noise power spectral density (No) is power per hertz with the unit of Joules per second. So, it is clear that the dimension of SNR is cancelled out. So we can agree on that point that, the probability of error is proportional to Eb/No.

d) **Physical layer performance results:** The basic goal of this paper is to analyse the performance of WiMAX OFDM physical layer based on the simulation results. In order to analyse, firstly we focused on the scattering points. Secondly, we investigated the BER vs SNR plot by using AWGN channel and finally, we investigated Probability of Error Rate.

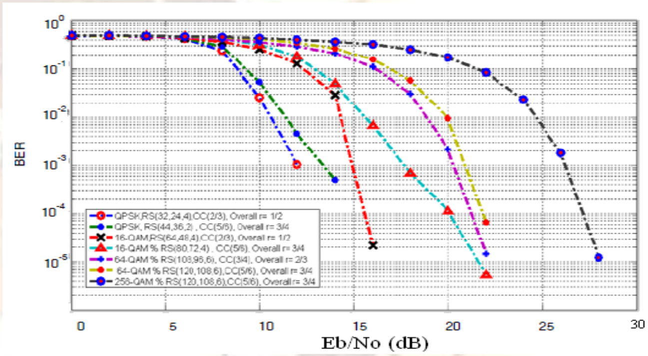

Figure 10: BER vs. Eb/No for different modulation schemes

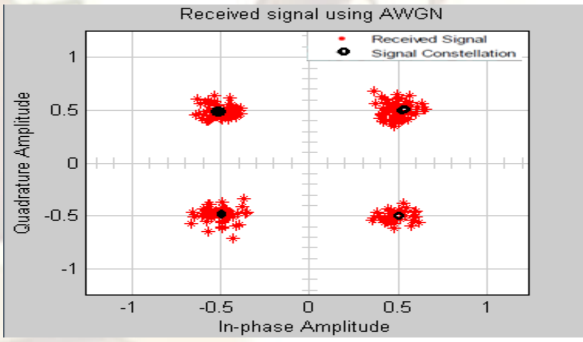

Figure 11: QPSK constellation

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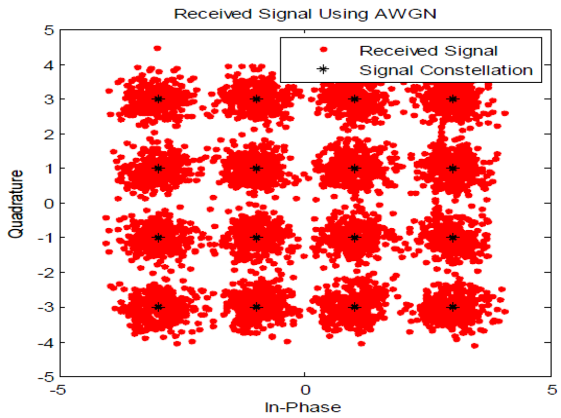

Figure 12: 16-QAM constellation

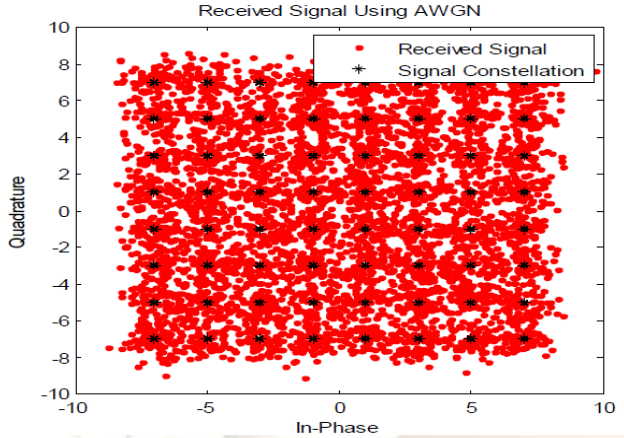

Figure 13: 64-QAM constellation

It can be seen from the above figure 10 that the lower modulation and coding scheme provides better performance with less Eb/No. This can be easily visualized if we look at their constellation mapping shown in figures 11-13: 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 Eb/No, adaptive modulation schemes can be used to attain highest transmission speed with a target BER.

V. CONCLUSION

Wireless technologies are currently limited to some restricted services, but by offering high mobility, high data rate and high QoS wireless technologies will offer new alternatives. Offering a trade-off between coverage, data rate, and mobility with generic air interface architecture is the primary goal of the next generation of wireless systems (4G). In this context, WiMAX appears to fulfill cited requirements, providing vehicular mobility and high service areas and data rates. WiMAX Physical layer is based on OFDM techniques with employing adaptive technologies such as different combinations of channel coding and modulation together with power control, we can conclude the performance of WiMAX as, BPSK is more power efficient and needs less bandwidth. During all simulations we got, BPSK has the lowest BER and 64-QAM has the highest BER than other modulation techniques.

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