

Improvement the performance of IEEE 802.16d (WiMAX) Baseband system with Channel Estimation, Equalization and Timing synchronization under different channel models

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Abstract—Advancements in wireless broadband and mobile communication have provided many features to its subscribers, such as high-speed data connectivity and good voice quality and video application services for economical rates. WiMAX is one of the wireless broadband access technologies which provide broadband and IP connectivity to last mile access. It is based on IEEE 802.16 standard wireless MAN. The WiMAX physical layer is based on OFDM technology that provides very good spectral efficiency and resistance to multipath propagation. This paper presents the model for simulating WiMAX physical layer in Simulink and studying the performance of the system in different channel conditions (AWGN, Rayleigh and Rician fading channel) with channel estimation, equalization (ZFE) and timing synchronization. System performance is evaluated using BER versus Eb/No curves, for comparing the results.

Index Terms—WiMAX, IEEE 802.16, MAN, OFDM, AWGN, ZFE, BER, Eb/No, Synchronization.

1 INTRODUCTION

Wireless Broadband demand has been growth rapidly due to it provides faster web surfing, quicker download files, real-time audio and video streaming, multimedia conferencing and interactive gaming. Consequently, in order to satisfy market, needs new standards. A possible solution is the worldwide interoperability for microwave access (WiMAX) based on IEEE 802.16 standard. It is one of the latest technologies that provide high speed broadband access with large coverage area. WiMAX is the alternative to digital subscriber line (DSL), which deliver broadband over twisted pair telephone wires, and cable modem technology that delivers over coaxial cable TV plant [1]. IEEE 802.16 (WiMAX) is a promising wireless technology for last mile access due to the fact that provide high data rate communications up to 75 Mbps in metropolitan area network (MAN), with a maximum range of approximately 50Km for single hob architecture in the presence of line of sight (LOS) and 25Km for non-line of sight (NLOS) connectivity [2]. Also it supports bandwidth management via centralized bandwidth scheduling in both uplink and downlink directions [3]. WiMAX like cellular system, it offers the three communication modes, namely, point-to-point (p2p), point-to-multipoint (p2mp) and multipoint-to-multipoint (mesh) mode. These modes are similar to the communication between towers, tower with multiusers, and Ad hoc network, respectively.

IEEE 802.16d standard defines two preambles structure to work out the synchronous problem [2]. One is the long preamble and is applicable to network in the downlink, the

other is short preamble and is applicable to network in the uplink. The first symbol consists of four repetitions of 64 sample fragment preceded by cyclic prefix (CP), the second symbol consists of two repetitions of 128 sample fragment preceded by a CP in the time domain. In this paper, we will focus on symbol synchronization algorithm about the network in the downlink, so it mainly refers to long preamble.

There are many papers study the WiMAX, but without synchronization (Synch) or channel estimation (Ch. Est) and equalization (Equ). Most of them concentrated on one modulation and coding scheme. [4] has simulated the channel estimation and equalization for WiMAX physical layer in Simulink without timing synchronization and for QPSK modulation under AWGN channel, while [5] studied WiMAX based OFDM system in Simulink with frame synchronization but without channel estimation and equalization for 16 QAM modulation. In [6] has simulated WiMAX physical layer under adaptive modulation techniques using Simulink without channel estimation, equalization and synchronization, the performance of physical layer was evaluated, it was found that : When channel conditions are poor, energy efficient schemes such as BPSK or QPSK were used and as the channel improves, 16 QAM or 64 QAM was used. [7] has presented the WiMAX 802.16e physical layer using digital modulation techniques and coding rates, this model has been developed for various modulation schemes such as BPSK, QPSK, 16 QAM, and 64QAM under AWGN and without interpolations (Synch , Ch. Est. , and Equ.).

After this introduction, the next section (2) clarifies the WiMAX standards. Then, section (3) and (4) describe respectively, WiMAX physical layer model and simulation model with results. Finally, section (5) present conclusions and future works.

2 WiMAX STANDARDS

The Institute of Electrical and Electronics Engineers (IEEE) 802 committee, which sets networking standards such as Ethernet (802.3) and Wi-Fi (802.11), has published a set of standards that define WiMAX. IEEE 802.16 is a series of wireless broadband standards written by (IEEE) for WiMAX, which was formed in 1999 to develop wireless broadband[2]. There are two different types of broadband wireless services, one is fixed wireless broadband known as 802.16a that was updated to 802.16-2004 (also known as 802.16d), which is similar to the traditional fixed line broadband access technology like, DSL or cable modem but using wireless as a medium of the transmission.

Some of the important features of 802.16-2004 standards are [1]:

- Designed to provide fixed NLOS broadband services to fixed and nomadic users.
- Support 256 Orthogonal Frequency Division Multiplexing (OFDM) physical layer with 64 Quadrature Amplitude Modulation (64 QAM), 16 QAM, QAM and QPSK modulation techniques.
- Support for Advance antenna and Adaptive coding techniques.
- Facilitates the use of point to multi-point topology.
- Low latency for delay sensitive services, thus improving QoS parameters.
- Support for both; Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD).

The other type of broadband wireless is mobile broadband, known as IEEE 802.16-2005 (also known as IEEE 802.16e) which has additional functionality of portability and mobility. Some features of IEEE 802.16e are [8]:

- It improves NLOS coverage, by utilizing advanced antenna diversity schemes, such as adaptive antenna system (AAS) and multiple input multiple output (MIMO) technology.
 - Increasing system gain and improving indoor penetration by multiple subcarriers to different users, this process called sub channelization.
 - It's based on OFDM/OFDMA technology.
- For these feature, many parameters can be improved like, coverage, power consumption, frequency reuse and Bandwidth efficiency.

3 WiMAX PHYSICAL LAYER MODEL

The physical layer of WiMAX is based on IEEE 802.16 standard, which was designed with much influence from Wi-Fi, especially IEEE 802.11a. The two technologies are different due to the inherent difference in their purpose and applications. The role of the physical layer is to encode the binary digits that received from upper layer into signals, which can be transmitted and received across the communication media. The WiMAX physical layer is based on OFDM technique, which used to enable high speed data, video, and multimedia communications, and it's used by a variety of commercial broadband systems. Figure 1 shows the physical layer model, which consists of many blocks listed below:

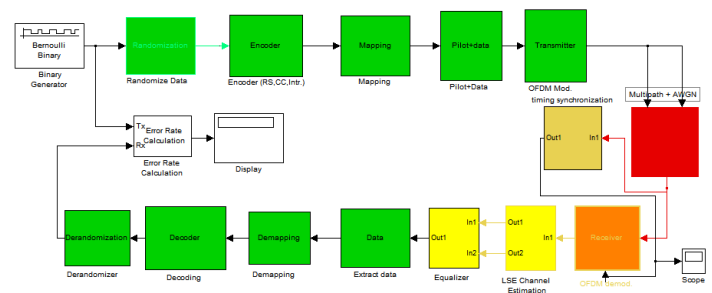


Figure 1. Physical Layer Model

3.1 Randomization/De-randomization

It performs randomization of input data on each burst on each allocation to avoid long sequence of continuous ones or zeros. This process is implemented with a pseudo random binary sequence (PRBS) generator, which uses 15 stage shift register for a generator polynomial of $X^6 + X^3 + 1$ with XOR gate in feedback configuration [2].

At the receiver end, de-randomization is the last step, for recovers original data bits. Figure 2, illustrates randomization/de-randomization process.

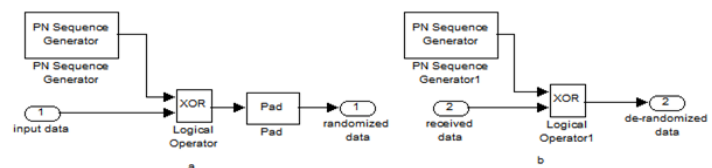


Figure 2. Shows a)Randomization b)De-randomization process

3.2 Reed-Solomon Encoder/Decoder

The randomizer bits are then fed to the Reed Solomon encoder, which is an error-correction coding technique. Input data is over-sampled and parity symbols are calculated which are then appended with original data. In this way redundant bits are added to the actual message which provides immunity against severe channel conditions. the encoder takes k bytes of information and adds parity bytes to obtain a codeword of n bytes.

A Reed Solomon code is represented in the form RS (n, k), where

$$n = 2^m - 1 \quad (1)$$

$$k = 2^m - 1 - 2t \quad (2)$$

Here, m is the number of bits per symbol, k is the number of input data symbol (to be encoded), n is the total number of symbol (data + parity) in the RS codeword and t is the maximum number of data samples that can be corrected [9]. At the receiver Reed Solomon coded samples are decoded by removing parity symbol.

3.3 Convolutional Encoder/Decoder

After the RS encoding process, data bits are further encoded by a binary CC, which has a native rate of 1/2 and a constraint length of 7. The generator polynomials used to derive its two output code bits, denoted X and Y, are specified in the following expressions: G1 = 171 octal for X, and G2 = 133 octal for Y.

3.4 Puncturing / De-puncturing

Puncturing is the process of systematically deleting bits from the output stream of a low-rate encoder in order to reduce the amount of data to be transmitted, thus forming a high-rate code. The process of puncturing is used to create the variable coding rates needed to provide various error protection levels to the users of the system.

3.5 Matrix Interleave and General Block Interleave

It is used to mitigate the effect of burst errors. When too many errors exist in one codeword due to burst error, the decoding of a codeword cannot be done correctly. Thus, to reduce the effect of burst error, the bits in one codeword are interleaved before transmitted. When interleaving occurs, the place of bits will change, which means, that burst error cannot disturb a huge part of one codeword. Figure 3, illustrates the process of interleaving at; a) Transmitter and b) Receiver. It can be seen, that is some errors at the receiver due to the noise, but by decoding we can correct them.

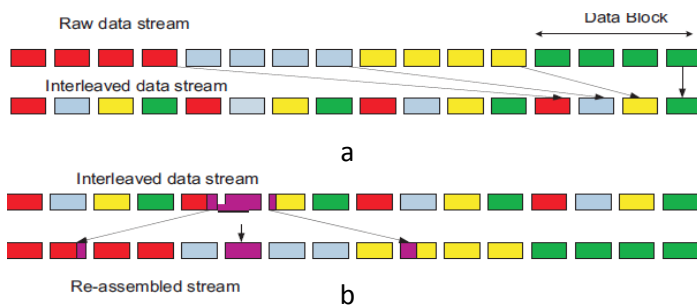


Figure 3. A and b shows transmitted, received bits, respectively.

3.6 Mapping

The IEEE 802.16d standard, defines four signal constellation; QPSK, QAM, 16QAM, and 64QAM, which convert the coded bits into complex number according to Gray-coded constellation mappings.

3.7 Orthogonal Frequency Division Multiplexing

OFDM is a multi-carrier transmission technique, which divide the available spectrum into many carriers, each one being modulated by a low rate data stream. OFDM states that the IFFT of magnitude N, applied on N symbols, realizes on OFDM signal, where each symbol is transmitted on one of the N orthogonal frequencies [10].

The IFFT takes frequency domain spectrum X(k) to get a time domain complex OFDM symbol, which is represented as

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) e^{j \frac{2\pi n k n}{N}}, n = 0, 1, \dots, N-1 \quad (3)$$

Where X(k) denotes the data symbol in subcarrier k, and x(n) is the nth sample of OFDM symbol. After IFFT module, a cyclic prefix is used to mitigate the effect of inter symbol interference (ISI), which is presented due to the multipath propagation. A selector block is applied to insert the last 64 sub-carriers into the beginning of the OFDM symbol.

An OFDM symbol is made up of three types;

- 192 Data subcarriers with indices: -100 ... -1 and +1 ... +100 (except at pilot positions).

- 8 Pilot subcarriers with indices: -88, -63, -38, -13, +13, +38, +63, and +88.

- 56 Null subcarriers with indices: DC carrier at 0, -128 ... 101 for lower guard, and upper guard from +101 ... +127.

3.8 Channel Model

The transmission medium faces two major problems in WiMAX communication system. These problems are: the AWGN noise, Rayleigh and Rician fading. The first, affect on the transmitted signal in a uniform continuous frequency spectrum, the Rayleigh affect on the received signal when NLOS path between transmitter and receiver occur, this caused the received signal equal the sum of all the reflected and scattered waves. The last fading affect also on the received signal when LOS as well as NLOS occurs.

3.9 Timing Synchronization

A misalignment between the sent symbol and the demodulated symbol can introduce ISI (timing error). This error can deteriorate modulation performance. To face this problem, we used long preamble structure.

The auto and cross correlation will be used for frame synchronization [11]. The auto correlation relies on product between the conjugate of samples from first half and the

corresponding samples from the second half, so that the products of each of these pairs of samples will have approximately the same phase and hence the magnitude of the sum will be peaked. If L is the number of complex samples in one half of long preamble which is 128 sample, then P(n) and R(n) are calculated as

$$P(n) = \sum_{m=0}^{L-1} y^*(n+m)y(n+m+L) \quad (4)$$

$$R(n) = \sum_{m=0}^{L-1} |y(n+m+L)|^2 \quad (5)$$

Where P(n) is the sum of the pairs of products, R(n) is the received energy for the second half of long preamble, y is the received signal, n is the timing index, and the timing metric is

$$M1(n) = \frac{|P(n)|^2}{(R(n))^2} \quad (6)$$

Figure 4, shows the timing metric for free noise, where the plateau is clearly obvious and completely flat, this is the ideal state of synchronizer in which any point within the plateau can be chosen to start the data symbol. It can be seen from figure 4, the plateau is not obtained due to noise variation for very low SNR .

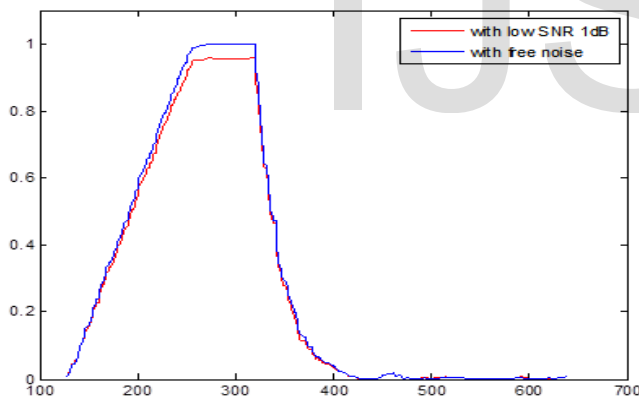


Figure 4. Timing metric M1(n) for auto correlation for 1 frame.

Thus, the timing metric will be modified using cross correlation and it is given by

$$M2(n) = \frac{|P(n)|^2}{(R(n))^2} \quad (7)$$

$$P(n) = \left| \sum_{m=0}^{L-1} y^*(n+m)P(m) \right| \left| \sum_{m=0}^{L-1} y^*(n+m+2L)P(m) \right| \quad (8)$$

$$R(n) = \left(\sum_{m=0}^{L-1} |y^*(n+m)|^2 \right) \left(\sum_{m=0}^{L-1} |P(m)|^2 \right) \quad (9)$$

Figure 5, shows the cross correlation method which solved the peak value platform, but there are some secondary peaks in the side of main peaks as shown for four frames.

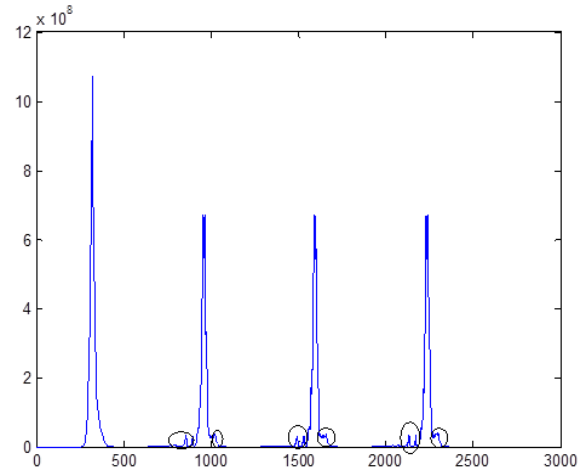


Figure 5. timing metric M2(n) for cross correlation for 4 frames

So, a modified method uses the difference sequence of the receiver and the difference sequence of the preamble shown in figure 6, to overcome the peaks in the sides of the main peak.

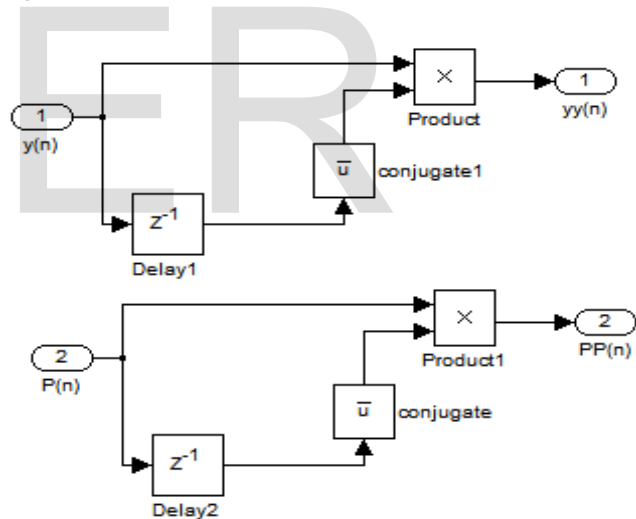


Figure 6. shows difference sequence of y(n) and p(n)

The product between the outputs of cross correlation and sequence difference will give peaks that clearly obvious as shown in figure 7.

$$M3(n) = \frac{|P(n)|^2}{(R(n))^2} \quad (10)$$

$$P(n) = \left| \sum_{m=0}^{L-1} yy^*(n+m)PP(m) \right| *$$

$$\left| \sum_{m=0}^{L-1} yy^*(n+m+2L)PP(m) \right| \quad (11)$$

$$R(n) = \left(\sum_{m=0}^{L-1} |yy^*(n+m)|^2 \right) \left(\sum_{m=0}^{L-1} |PP(m)|^2 \right) \quad (12)$$

$$M4(n) = M2(n) \times M3(n) \quad (13)$$

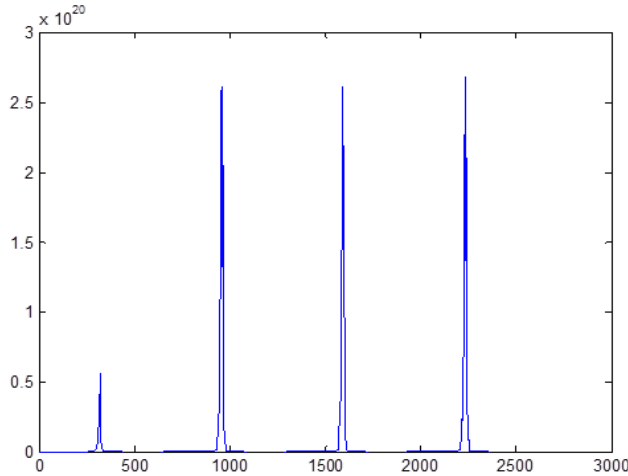


Figure 7. timing metric M4(n)

3.10 Channel Estimation

The received signal is usually distorted by the channel environment. In order to recover the transmitted bits, the channel effect must be estimated and compensated within the receiver [12]. A training symbols is one method to find channel frequency response (CFR) and it is must be known to both transmitter and receiver, after that various interpolation techniques employed to estimate the channel response for the subcarriers.

training symbols, provide a good performance, the least square error (LSE) and minimum mean square error (MMSE) techniques are widely used for channel estimation when training symbols are available [10][12]. A better approach for channel estimation is (LSE) for its simple structure and provide a small bit BER through multipath effect, but it is susceptible to low SNR for AWGN effect.

For deriving estimation CFR, we assume all subcarrier are orthogonal, thus a training symbols for N subcarrier can be represented by a diagonal matrix:

$$X = \begin{bmatrix} x[0] & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & x[N-1] \end{bmatrix} \quad (14)$$

Where X(k) denotes a training tone at the kth subcarrier, k=1, 2, ..., N-1. The channel gain is H(k) for each subcarrier, and thus, the received training signal Y(k) can be represented as

$$Y = \begin{bmatrix} Y[0] \\ Y[1] \\ \vdots \\ Y[N-1] \end{bmatrix} = \begin{bmatrix} x[0] & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & x[N-1] \end{bmatrix} \cdot \begin{bmatrix} H[0] \\ H[1] \\ \vdots \\ H[N-1] \end{bmatrix} + \begin{bmatrix} Z[0] \\ Z[1] \\ \vdots \\ Z[N-1] \end{bmatrix} \quad (15)$$

$$Y = XH + Z \quad (16)$$

Where;

Y_P = [Y₀ Y₁ ... Y_{Np-1}]^T is the received training

X_P = [X₀ X₁ ... X_{Np-1}]^T is the transmitted training

H_P = [H₀ H₁ ... H_{Np-1}]^T is the CFR and

Z_P = [Z₀ Z₁ ... Z_{Np-1}]^T the noise

Let \hat{H}_p denote the estimate of the channel H_p and the error equal to J(\hat{H}_p), so that:

$$J(\hat{H}_p) = \|Y_p - X_p \hat{H}_p\|^2$$

Minimizing the expected error $E\|Y_p - X_p \hat{H}_p\|^2$ by sitting the first derivative equal to zero.

$$\frac{\partial J(\hat{H}_p)}{\partial (\hat{H}_p)} = 0 \quad (17)$$

Which gives the solution to the LS channel estimation:

$$\hat{H}_{LS} = (X_p^H X_p)^{-1} X_p^H Y_p \quad (18)$$

To restore the transmitted signal, a zero forcing equalizer (ZFE) is used, that applies the inverse of the CFR that was estimated by LSE. Figure 8, illustrate a ZFE, which gives a flat frequency response by combination the channel and ZFE output response [13].

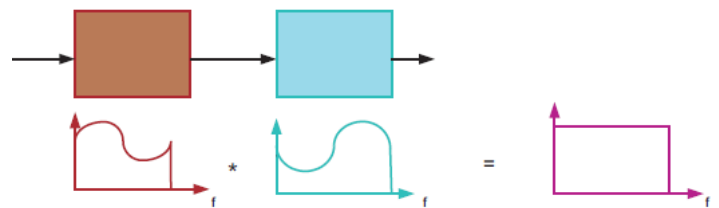


Figure 8. Zero forcing equalizer

4 SIMULATION MODEL AND RESULTS

In this paper a simulation model had been implemented by using Simulink in matlab 7.14.0.739 (R2012a) version running

on windows 7. The model and simulation goals is to studying the WiMAX model and exploit the system performance analysis for different system specifications listed in table 1.

Table 1

System Parameters and Specification

Parameters	Specification
FFT size	256
Constellation	QPSK,QAM,16QAM,and 64QAM
Code rate	2/3 ,5/6
Bandwidth	20MHz
No. of used subcarriers (data +pilot)	192+8
Guard band	56
Channel model	AWGN , Rayleigh, and Rician multipath
No. of multipath	4 (0, 0.3, 0.8, 1.5)e-6sec.
Cyclic prefix	64
Ch. Est. and Equ.	LSE +ZFE
Timing Synch.	Auto, cross and difference sequence -correlation
Data rate(Rb) (QPSK,QAM, 16QAM,and 64QAM)	32, 32, 64, and 96Mbps Respectively
Preamble	Long preamble (64+128+128)

The AWGN and multipath channel models were used as a testing environment. Comparing the performance of the model, by measuring bit error rate (BER) versus bit energy to noise power spectral density ratio (Eb/No) for AWGN and multipath delay with different modulation schemes and coding rate under channel estimation with equalization, and timing synchronization.

Data rate for this system can be calculated as follows [14]:

$$\Delta f = \frac{\text{B.W}}{\text{No. of FFT subcarriers}} = \frac{20\text{MHz}}{256} = 0.078\text{MHz}$$

Where Δf is the subcarrier frequency spacing.

FFT subcarrier period T_{IFFT} is

$$T_{IFFT} = \frac{1}{\Delta f} = 12.8\mu\text{s}$$

TG is the guard interval $=\frac{12.8}{4} = 3.2\mu\text{s}$

OFDM Symbol $=T_{IFFT} + T_G = 12.8 + 3.2 = 16\mu\text{s}$

Then the data rate Rb is

$$R_b = \frac{\log_2(\text{Constellation point}) \times (\text{No. of IFFT subcarriers})}{\text{OFDM symbol interval}}$$

The BER performance of WiMAX physical layer through AWGN channel, Rayleigh and Rician fading channels shown in figure 9, figure 10 and figure 11 respectively, for different modulation schemes (QPSK, QAM, 16QAM and 64QAM) with estimation, equalization and timing synchronization.

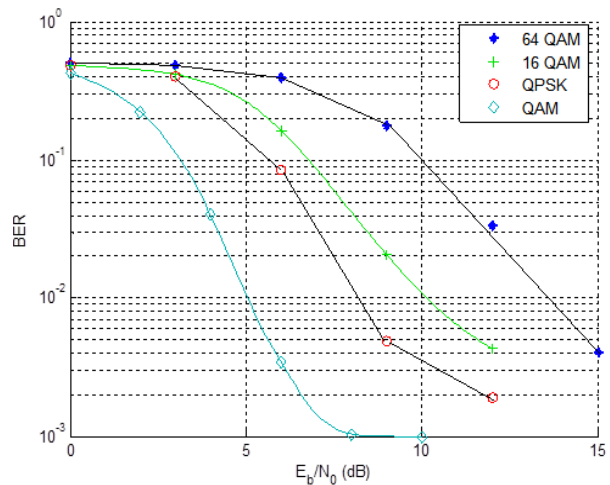


Figure 9. AWGN Ch. with Est, Equ, and Synch

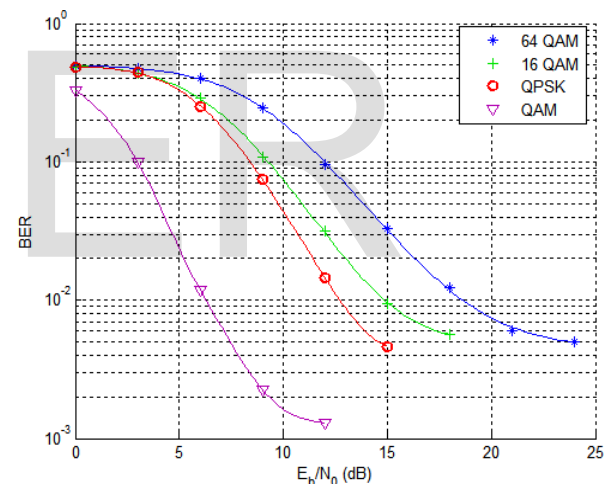


Figure 10. Rayleigh Ch. with Est, Equ, and Synch

Higher order modulation enable higher data rates, but with the higher number of constellation points, the Euclidian distance is reduced. Smaller distance causes heavy noise sensitivity and requiring higher (Eb/No) obtaining the same BER.

From figures 9, 10 and 11, it can be seen that, the AWGN channel has lower BER than Rayleigh and Rician fading channel. QAM modulation is good for the model to work well as we saw, it has lower BER with lower Eb/No.

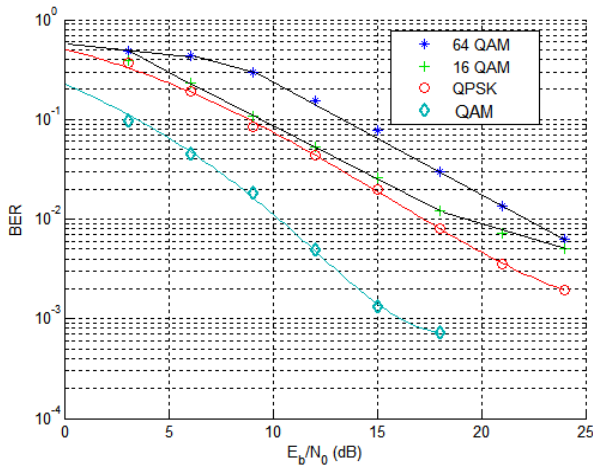


Figure 11. Rician Ch. with Est, Equ, and Synch

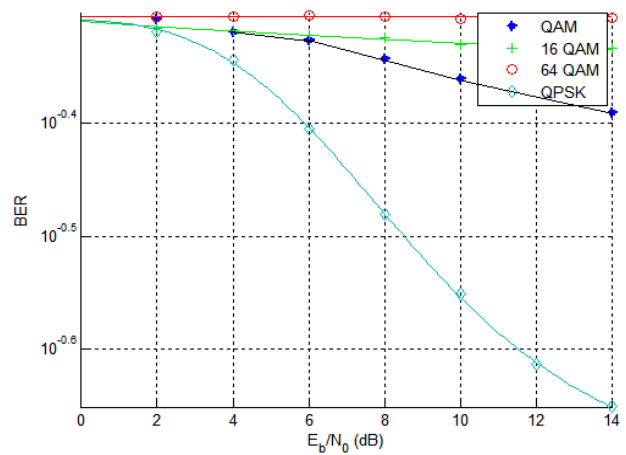


Figure 13. Fading Ch. Without (Est, Equ, and Synch)

Figure 12 and figure 13, illustrates the AWGN channel and fading channel (Rayleigh and Rician) without estimation, equalization and synchronization, its observed that the AWGN channel work well than figure 9 with (Est, Equ, and Synch.) but figure 13 (fading channel) do not work without (Est, Equ, and Synch) as its shown.

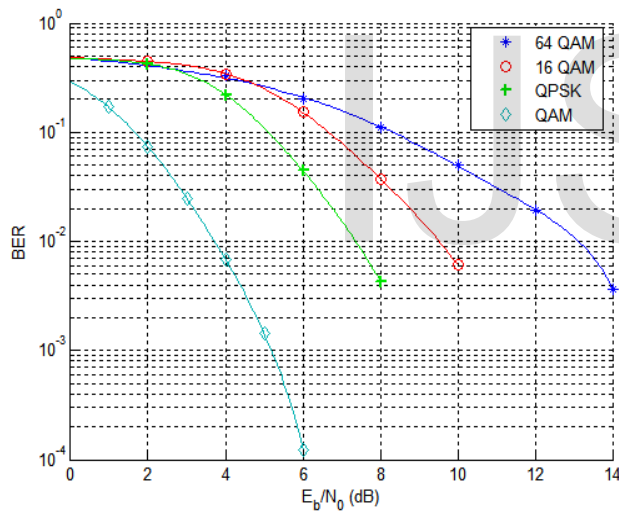


Figure 12. AWGN Ch. Without (Est, Equ, and Synch)

5 CONCLUSION AND FUTURE WORKS

This paper introduces the standard IEEE 802.16d-based WiMAX downlink model, its became clear that all channels parameters must be provided for appropriate simulation. According to the simulation results, we can conclude that the low complexity channel estimation (LSE) method, gives good results in fading channels (Rayleigh and Rician) but its susceptible in low E_b/N_0 AWGN channel. However, WiMAX system works well for a variety of modulation schemes, but under certain E_b/N_0 constraints that are addressed in this paper.

For future, improvement in data transmission and resistance to fading channel requires accurate timing / frequency synchronization and adaptive channel estimation with multi-input multi-output (MIMO) technology.

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