Performance Evaluation of WiMAX Network with AMC and MCCDMA for Mobile Environments

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Abstract

The WiMAX forum is based on 802.16d/e Orthogonal Frequency Division Multiplexing (OFDM) based adaptive Physical Layer (PHY) layer. In this paper, the performance of WiMAX PHY layer is investigated for two PHY layer modifications, link adaption algorithm (Adaptive Modulation and coding, AMC) and MCCDMA (hybrid OFDM system with multiple access technology, Code Division Multiple Access) to provide high suppression against multipath fading , provide high bandwidth efficiency, high throughput with high data rates for mobile environments. The results obtained for these modifications show that these mechanisms enhance the performance of the PHY layer in mobile environments with lower BER and high spectral efficiency.

Keywords: *WiMAX, IEEE 802.16, OFDM, MCCDMA, AMC*

1. Introduction

Worldwide Interoperability for Microwave Access (WiMAX) is an emerging global broadband wireless system based on IEEE 802.16 standard. It is a new wireless OFDM-based technology that provides high quality broadband services long distances based on IEEE.802.16 wireless (Metropolitan Area Network) MAN air interface standard to fixed, portable and mobile users [1, 2] . WiMAX promises to combine high data rate services with wide area coverage (in frequency range of 10 – 66 GHz (Line of sight) and 2 -11 GHz (Non Line of Sight)) and large user densities with a variety of Quality of Service (QoS) requirements. WiMAX can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed station and 3 to 10 miles (5-15 km) for mobile stations with theoretical data rats between 1.5 and 75 Mbps per channel. The new standards for WiMAX are being developed for expanding the mobility further with enhanced coverage, performance and higher data rates (of the order of 100 Mb/s) in a WiMAX Network. The WiMAX standard air interface includes the definition of both the medium access control (MAC) and the physical (PHY) layers for the subscriber station and base station while the access network operability is defined by the WiMAX Forum, an organization consisting of operators and component and equipment manufacturers [5].

As the primary function of WiMAX PHY layer is the actual physical transportation of data. The main performance becomes more challenging when mobile environments are encountered in wireless channel. In order to achieve maximum performance at low BER, high data rate transmission (both in fixed and mobile environments) and high spectral efficiency with variety of QoS needs IEEE 802.16d/e standard supports variety of PHY layer mechanisms with a variety of features. The flexibility of the PHY enables the system designers to tailor their system according to their requirements. Some of the innovative adaptations in WiMAX PHY layer is the use of OFDM (Orthogonal Frequency Division Multiplexing) and Orthogonal Frequency Division Multiple Access (OFDMA) [6] for fixed (256- point FFT) and mobile communications (128 bits to 2,048 point FFT). These features are further outlined by IEEE 802.16 d/e standard as enhancement techniques for its PHY layer improvement in mobile environments, these techniques include: AMC to provide adaptive PHY layer profile [9]; combination of OFDM/OFDMA with MIMO [10, 11], diversity techniques and advance OFDM systems [12] MCCDMA to provide spectral efficiency and turbo encoding to provide more robustness error correction technique.

In this paper the behavior of IEEE 802.16 standard based PHY layer for fixed and mobile WiMAX system is analyzed for two adaptions, AMC and MCCDMA at the WiMAX PHY layer. The investigations are carried out on improvement in the bit error rate (BER) performance and spectral efficiency on the PHY layer with introduction of AMC and advanced CDMA-OFDM system in the PHY layer profile for both the fixed and mobile environments.

Following this introduction, a brief review of related work is presented next. Section 3 describes PHY model developed for the analysis. Section 4 describes the proposed MCCDMA based PHY layer. Explanation of the results obtained via simulation of various scenarios is done in Section 5 and finally conclusion of work done is presented in section 6.

2. Related Work

Improvement of PHY layer of WiMAX is one of the various areas of research that is just getting started with 802.16 on developing its performance in variable environments. The performance of WiMAX compatible systems, from a physical-layer perspective had been analyzed by [7–13] and spatial multiplexing (increase the data rate); Hybrid ARQ (Automatic repeat request), interference cancellation and adaptive sub carrier power allocation (increase the range and robustness) had been proposed as the four major techniques to increase the throughput and robustness of future WiMAX systems. The finite-length queuing and AMC were combined by [14] and the QoS performance was found to be improved in terms of the reduced packet loss rate, increased average throughput, and the average spectral efficiency (ASE) of AMC by. A cross layer design was also proposed and implemented at the data link layer to minimize the packet loss rate and to maximize the average throughput at physical layer. Some researchers also expanded their work on the existing modulation schemes while some inclined on developing a simulation model of the WiMAX PHY layer to study its behavior and suggest few enhancements on various aspects of it. A novel interleaving approach for multi-quality transmission that can effectively combat different burst errors caused by phase noise and multipath fading without deteriorating the channel capacity was proposed [15]. A top level WiMAX simulink model was developed [16] to focus on channel estimation with different interpolation approaches for fixed/mobile OFDM systems. An impact of Doppler shift on the relative performance between the different channel estimators and interpolation approaches was also observed. The performance of the WiMAX under different data rates, coding schemes and channel conditions has also been evaluated by [17] based on standards from IEEE.

The other advanced features of PHY layer include the channel estimation schemes, advanced antenna systems, transmit diversity and MIMO based systems to support mobility extensions to the physical layer. Lower Density Packed Codes (LDPC) and different equalization techniques were proposed [18] to improve the WiMAX system performance. Further verification was done with the improvement in Bit Error Rate (BER) performance by taking into account the channel behavior in terms of capability to switch the order of the modulation and the coding rate to better match the channel conditions with respect to statistical Modulation and Coding Scheme (MCS) selection techniques [19]. The impact of using adaptive modulation and coding on the overall performance of the system and Erlang capacity of a WiMAX system was also presented [20]. A method to choose the best admission control and modulation scheme that extended the Erlang capacity region with increased capacity of the system was formulated. A new combining scheme had also been proposed for multiple-input multiple-output (MIMO) systems with hybrid automatic-repeat-request (HARQ) to achieve optimal decoding performance with low memory requirement and reduced complexity as compared to other optimal combining schemes [21].

The literature also reports the emergence of new hybrid OFDM system with multiple access technology CDMA known as MCCDMA to provide high suppression against multipath fading, high bandwidth efficiency and high throughput with high data rates i.e. delivering the benefits of both OFDM and CDMA. The work also includes the contributions of [22] which compared the performance of both Direct Sequence (DS-CDMA) and MCCDMA systems in frequency selective Rayleigh faded channels. It also found that MCCDMA proved to be an effective technique in these environments with little complexity in the receiver system.

Furthermore implementation of these optional schemes in IEEE 802.16d/e based PHY layer standard are the keen research areas that are being explored are to improve the WiMAX performance. In the present work we intend to implement two schemes, AMC and MCCDMA, at the PHY layer of the Base Station (BS) of WiMAX Systems and observe the performance improvements in terms of BER and spectral efficiency for different applications.

3. Adaptive PHY Layer Profile

WiMAX PHY layer supports features to provide adaptive PHY profile with the ability to switch the Radio Link Control (RLC) to a more robust and efficient PHY technology (burst profile including the UL (Uplink) or DL (Down Link) [13], Modulation type, Forward Error Correction (FEC, preamble length, guard time), adaptive antenna systems and advance OFDM systems. depending on channel conditions. WiMAX supports link adaptation techniques known as adaptive modulation and coding in which the modulation scheme changes depending on channel conditions. Using adaptive modulation scheme, WiMAX system can switch to the highest order modulation depending on the channel conditions. As the signal-to-noise ratio (SNR) is very good near the BS, so higher order modulation scheme is used in this area to increase the throughput. While for the areas where the SNR is poor the system switches to the lower order modulation scheme to maintain the connection quality and link stability with increased throughput, Figure 1.

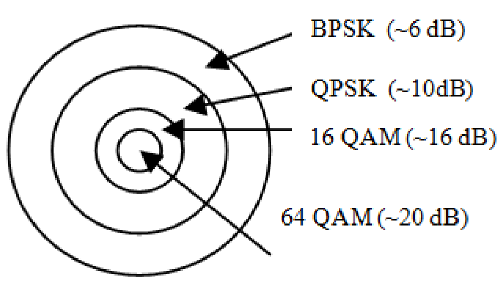

Figure 1. Adaptive Modulation Radii

The supported modulations are BPSK, QPSK, 16- QAM and 64-QAM. AMC technique helps to reduce the time selective fading, increases the range that a higher modulation scheme can be used over [7].

Table 1. OFDM/OFDMA Parameters used in WiMAX

Parameter	Fixed WiMAX (OFDM PHY)	Mobile WiMAX Scalable OFDMA-PHY			
FFT Size	256	128	512	1024	2048
Number of subcarriers	192	72	360	720	1440
Cyclic Prefix	1/32, 1/16, 1/8, 1/4				
Channel bandwidth (MHZ)	3.5	1.25	5	10	20

4. Proposed MC-CDMA Based PHY layer Profile

The combination of both OFDM and CDMA scheme refers to OFDM-CDMA or MC-CDMA with benefits of both OFDM and CDMA. MC-CDMA has emerged as a very promising spectral efficient technique, specifically for the downlink of the future cellular mobile radio for achieving high data rates and enhanced robustness against frequency selective fading. In contrast to DS-CDMA, MC-CDMA assigns a subset of orthogonal codes to each user allowing the information symbols to be spread on many sub carriers in either the frequency or time domain instead of using only one carrier. Thus, a MC-CDMA system mitigates the inter-chip interference, provides flexibility inherent in terms of system design that allows better spectrum utilization, providing frequency diversity with a relatively simple receiver structure compared to DS-CDMA [22]. Multiplexing is done by CDMA while the selection of the signal waveforms carried by OFDM. Wherein the OFDM scheme transmits different symbols, MC-CDMA scheme transmits the same symbol in parallel through several sub carriers. Signals to different users are added linearly onto a multiplex of Multi-Carrier CDMA signals, meaning that different users are transmitting at the same set of sub-carriers but with spreading codes that are orthogonal to the codes of other users. Each user data is first serial to parallel converted and is spread using a given high rate spreading code in the frequency domain, Figure 2 (a). All data corresponding to the total number of sub carriers is then IFFT modulated in base band and converted back into serial data. Then, a cyclic prefix is inserted between the symbols to combat the inter-symbol interference (ISI) and the inter-carrier interference (ICI) caused by multipath fading. Finally, the signal is digital to analog converted and up converted for transmission. At the receiver side, the CP is removed and signal is demodulated by FFT and then de spread. To reduce the effect of the fading and the interference different estimation and equalization techniques can be used, Figure 2 (b).

Based on the above features of MC-CDMA, we propose to model the IEEE 802.16 PHY layer of WiMAX with advance OFDM systems by combining the OFDM with CDMA (MC CDMA), Figure 3.

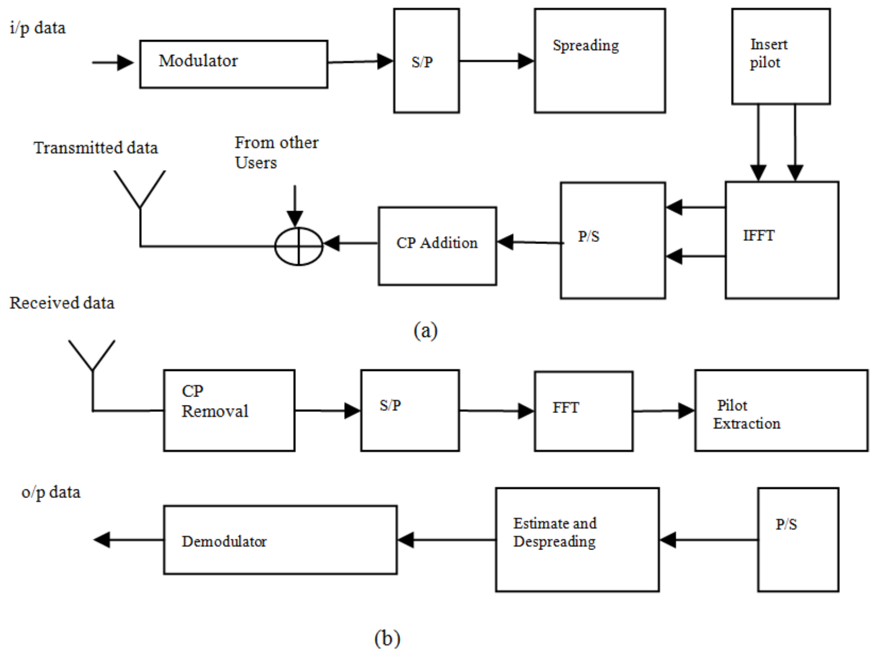

Figure 2. (a) MCCDMA Transmitter (b) MCCDMA Receiver

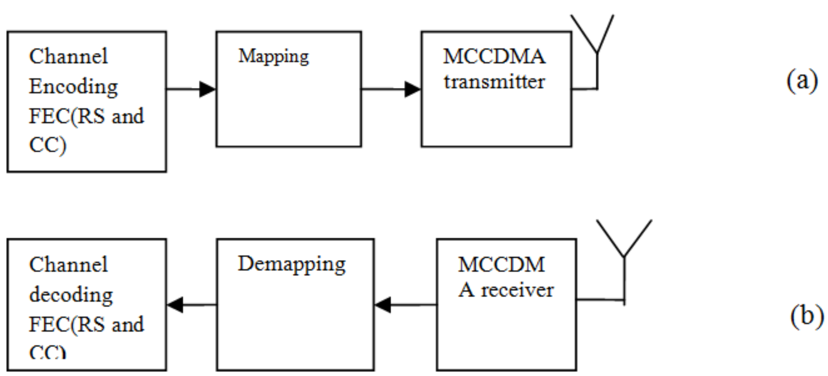

Figure 3. Proposed IEEE 802.16 PHY Layer of WiMAX (a) Transmitter (b) Receiver

5. Modeling and Simulation

Three scenarios have been developed for modeling and simulation. In Scenario 1, PHY layer model is developed from the standard documents with Matlab R2007a [22, 23, 16] and analyzed for adaptive profile. In scenario 2, the performance of the proposed MCCDMA system is investigated with system shown in Figure 2 and is further implemented with IEEE 802.16 d/e PHY layer in scenario III, Figure 3. The wireless channels modeled are in accordance with ITU- A vehicular and ITU B pedestrian models so as to incorporate different terrain scenarios and mobility types with path loss (including shadowing) multipath delay spreads, fading characteristics, doppler spread, co channel and adjacent channel interference. The various parameters that are used for schematic evaluation are summarized in Table 2.

Table 2. Parameters for Simulation Scenario 1

Parameter	Value
Modulation scheme	BPSK ½; QPSK ½;16 QAM ½
Channel model	ITU vehicular A for mobile user and ITU pedestrian B for fixed user
CP length	1/8 and 1/16
Channel Bandwidth	5 MHz
No. of users and speed of user	1; 30 and 100 km/h (for mobile) and 0 km/h (for fixed)

Depending on orthogonally, correlation properties, implementation complexity and peak-to-average power ratio (PAPR) a number of spreading codes exist. In our model we have used Orthogonal Walsh-Hadamard codes. Orthogonal Walsh–Hadamard codes are simple codes and are generated recursively by using the following Hadamard matrix generation (eqn.1),

$$C_L = \begin{bmatrix} C_{L/2} & C_{L/2} \\ C_{L/2} & C_{-L/2} \end{bmatrix}, \ \forall L = 2^n, n \geq 1, C_1 = 1 \quad \ldots(1)$$

Here L denotes the maximum number of orthogonal codes and hence the maximum number of active users. The rows in the Hadamard matrix are the Walsh-Hadamard sequences, which have the property that they are all orthogonal to each other. Further orthogonal spreading can also be achieved by Walsh-Hadamard sequences, where the users are distinguished by assigning them different Walsh-Hadamard sequences.

6. Results and Analysis

Three scenarios had been modeled to investigate the performance of WiMAX PHY layer with adaptive modulation techniques and MCCDMA. The Bit Error Rate (BER) curves are used to measure the performance of the WiMAX system for different adaptive modulation techniques available in the standard with varying parameters (FEC and channel conditions) and the proposed MC-CDMA technique to characterize performance of the WiMAX system.

6.1 Scenario 1

This scenario compares the performance of various mandatory modulation and coding schemes specified in the IEEE 802.16 standard for fixed WiMAX, Figure 4. It is observed that lower modulation coding rates provide better performance at low Eb/No values which results from the larger distance between the adjacent points in the constellation maps as compared to higher modulation and coding rates. Furthermore, in terms of spectrum utilization it is observed that 64 QAM ½ requires a higher bandwidth but provides higher data rates than all the other schemes. The spectral efficiency, Figure 5, compares the channel capacity and provides switching points for various adaptive modulation coding schemes for the system, Table 3.

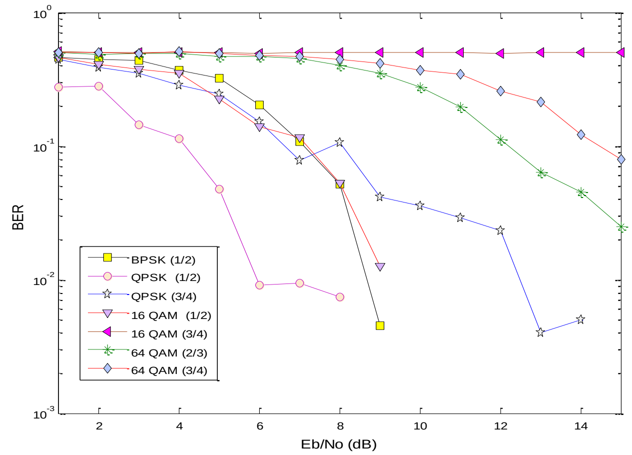

Figure 4. BER Performance Curves for Different Modulation Techniques for WiMAX System for Mobile User (ITU A)

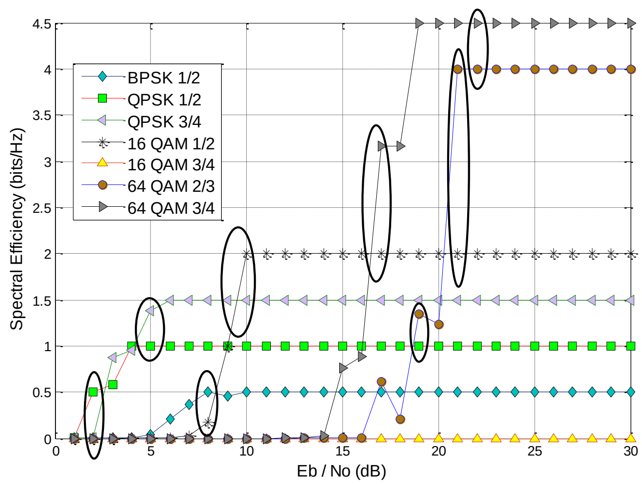

Figure 5. Spectral Efficiency of Different Modulation and Coding Profile for Mobile User with WiMAX System (CP=1/16 and BW=5 MHZ)

Table 3. Different Switching Points for AMC

SNR (dB)	Switching
5	BPSK to QPSK
8	QPSK to 16 QAM
16	16 QAM to 64 QAM

Thus the appropriate switching is based on the criterion that gives the highest spectral efficiency at each scheduling instant. The simulation is then carried out for WiMAX PHY layer (IEEE 802.16e standard for mobile WiMAX) for mobile user at two different speeds of 30km/h and 100km/h, Figure 6.

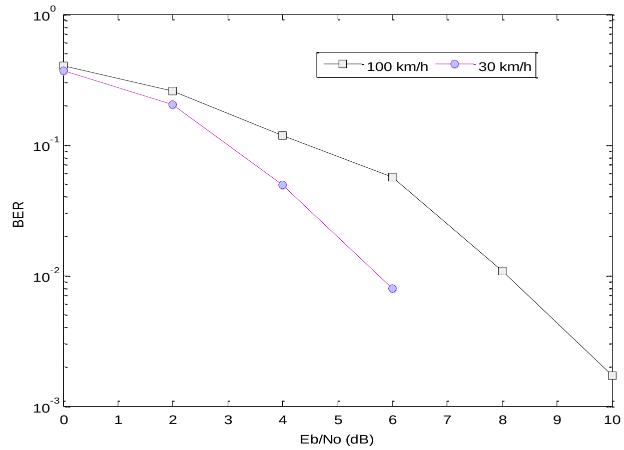

Figure 6. BER Performance for WiMAX Mobile User with Different Velocities for a QPSK ½ System

Degradation in the system performance is observed with increase in velocity. This mainly results because of the increased fading effect of the channel and doppler spread due to change in user velocity.

6.2 Scenario 2

The performance of MCCDMA system is investigated with the parameters listed in Table 3. Figure 7 shows the performance of MCCDMA system in Rayleigh faded and AWGN channel. A better performance in terms of BER and channel capacity is observed for a MCCDMA system when compared with OFDM BPSK ½ system for ITU vehicular channel model thus indicating a better performance for mobile environments. A gain of 6 dB and 10 dB is obtained at BER of 10^{-2} and 10^{-3}, Figure 8.

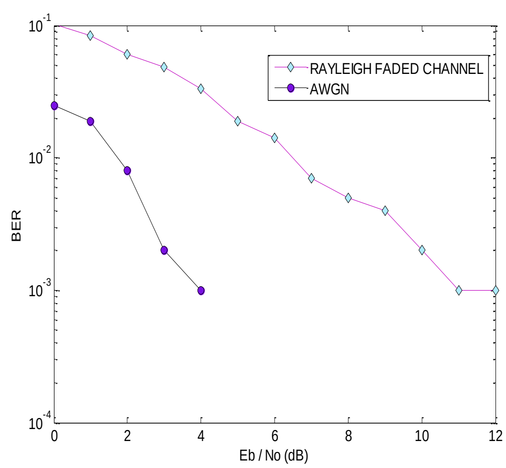

Figure 7. MCCDMA in Rayleigh and AWGN Channel

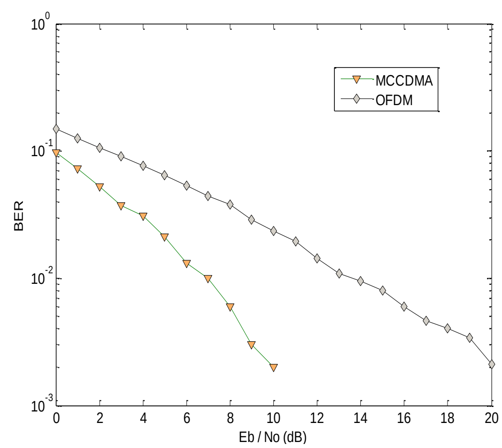

Figure 8. BER Performance of MCCDMA and OFDM for a BPSK ½ System

Figure 9 shows a high throughput (high data rates) achievable by a MCCDMA with high spectral utilization when compared with OFDM system.

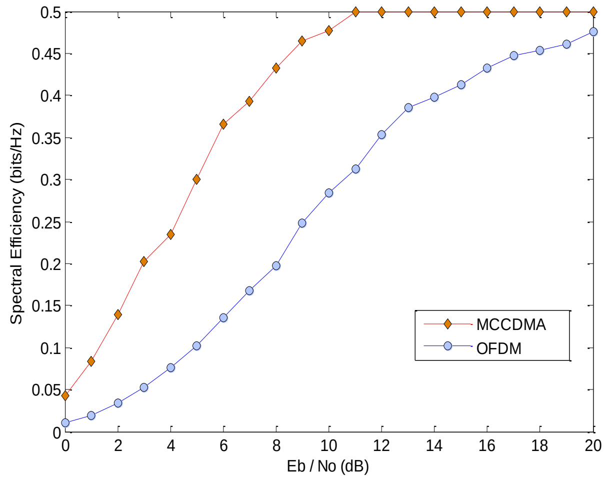

Figure 9. Spectral Efficiency of MCCDMA vs. OFDM

6.3 Scenario 3

With results obtained from the above scenario, the WiMAX PHY Layer is then implemented and simulated with MCCDMA, Figure 3. Orthogonal Walsh-Hadamard codes have been used as spreading codes which are generated recursively by using the following Hadamard matrix generation. The further parameters used are listed in Table 4.

Table 4. Parameters for Simulation of Scenario 3

Parameter			Value		
Modulation scheme			BPSK ½;		
Channel model			ITU vehicular A for mobile user		
CP length	Spreading length	Codes	1/8	8	Walsh codes
Channel Bandwidth			5 MHz		

Figure 10 compares the performance of the OFDM based PHY layer of WiMAX with MCCDMA based PHY layer. A performance improvement of 8dB for BPSK ½ and 4dB for QPSK ½ system at BER of 10^{-2} is obtained for a MCCDMA based PHY layer for a mobile user environment, thus giving a better performance in multipath conditions.

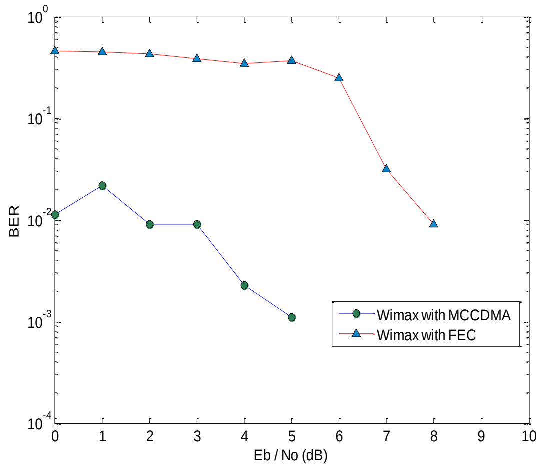

Figure 10. BER Performance of WiMAX with MCCDMA and OFDM (BPSK ½ System)

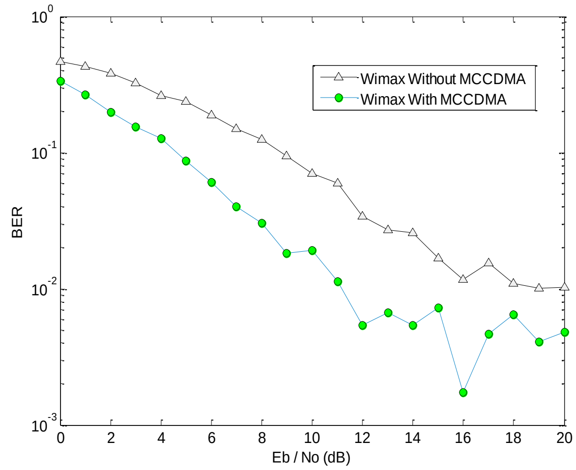

Figure 11. BER Performance of WiMAX with MCCDMA and OFDM (QPSK ½ System)

7. Conclusion

The performance of IEEE 802.16d/e based PHY layer is investigated by implementing its two improvements: AMC and MCCDMA in both the fixed and mobile environments. The results for AMC show that performance of WiMAX system can be optimized to a higher throughput and lower BER based on the channel conditions with lower modulation scheme for the increased range while switching to higher modulation schemes for the range closer to the base station. Further, results for mobile users show that the fading environments, mobile environments, severely degrade the performance of the system. The proposed combination of OFDM and CDMA, MC-CDMA, provided a better BER performance, high bandwidth efficiency and higher throughput in fading environments encountered by mobile users. The BER performance of WiMAX OFDM based PHY layer is hence improved with MCCDMA in PHY layer.

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