Analysis of WIMAX Physical Layer using Spatial Diversity under Different Fading Channels

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ABSTRACT
WiMAX is basically described as the IEEE 802.16 standard for Broadband Wireless Access (BWA) that was developed to provide high transmission data rates over larger areas and also to those areas users where broadband coverage is not available. MIMO systems are also of major interest in the field of wireless communication as it allows data to be sent and received over different antennas. WiMAX-MIMO systems are mainly developed to increase the performance of simple WiMAX system. This paper analyzes WiMAX-MIMO systems under different modulations with different CC code rates for different fading channels (Rician and Nakagami channel). Spatial Diversity technique of MIMO system is used for the simulation purpose. Signal-to Noise Ratio (SNR) vs Bit Error Rate (BER) plots are analyzed for this purpose.

Keywords
BWA, WiMAX, MIMO, SNR, BER, FEC, CC, PHY

1. INTRODUCTION
WiMAX protocol is basically the commercialization of the IEEE 802.16 standard that provides high speed internet access to its users. This standard is also known as Wireless MAN because it can be employed in metropolitan area networks. WiMAX is a Wireless MAN (WAN) technology as it fits between WLANs and wireless wide area networks (WANs). It has been developed to provide cost effective, high-quality and reliable data transmission that helps in achieving the required data rates for using the internet. WiMAX can be employed in those areas where wired broadband services cannot play an efficient role and hence provides economic solution for broadband access thus reducing cost and making technology more accessible. WiMAX connection can provide internet access up to 30 miles (50 km) of distance at transmission data rates of up to 75 Mbps. The IEEE 802.16e air interface standard [1] for WiMAX is based on orthogonal frequency-division multiplexing (OFDM) technology, which has been regarded as an efficient method to combat the inter-symbol interference (ISI).

The first version of the IEEE 802.16 standard operated in the 10–66GHz frequency band and required line-of-sight (LOS) between the transmitter and the receiver called Fixed WiMAX [2]. Most of the technologies rely on these high frequencies as they require more available bandwidth and has less risk of interference. But at such high frequencies, signals are unable to diffract around obstacles, hence there was a need to develop the technology at lower frequencies. Thus the standard was extended through different PHY specification at 2-11 GHz frequency band enabling non line of sight (NLOS) connections i.e. no direct connection between the transmitter and the receiver called as Mobile WiMAX, which require techniques that can efficiently mitigate the problem of fading and multipath propagation [3].

MIMO technology was developed that provided attracted attention in the field of wireless communications, as it offers significant increase in data transmission throughput and link range without requirement of any additional bandwidth or transmit power. It includes various techniques thus providing diversity as well as multiplexing gain. It generally refers to the use of multiple antennas both at the transmitter and receiver to improve the performance of the simple communication system. A MIMO system takes advantage of the spatial diversity that can be obtained by placing spatially separated antennas in a dense multipath scattering environment. MIMO systems may be implemented in a number of different ways to obtain either a diversity gain to combat signal fading or to obtain a capacity gain [4] with the help of its different techniques.

The paper is organized as follows: WiMAX Physical layer specifications are described in section II. WiMAX model of its Physical layer is explained in detail in section III. An overview of the MIMO systems is presented in Section IV. MIMO system techniques are provided in section IV. A detailed explanation of WiMAX-MIMO systems are studied in section V. Results and simulations are analyzed in section VI. At the end final conclusion drawn from the results is given in section VII.

2. WiMAX PHYSICAL LAYER SPECIFICATIONS
The IEEE 802.16 PHY includes mainly three specifications, which are suited to different operational environments. For frequencies from 10 to 66 GHz, the standard recommends the Wireless MAN-SC PHY, where SC means single-carrier modulation. The typical channel bandwidth is 25 MHz or 28 MHz, and the raw data rates can exceed 120 Mb/s.

For frequency band below 11 GHz, two alternatives have been specified: Wireless MAN-OFDM and Wireless MAN-OFDMA. In this frequency range, the wavelength is relatively long, and therefore it is a Non-LOS (NLOS). Hence the impairments like fading and multipath propagation are more prominent in both of these specifications.

2.1 Wireless MAN-SC PHY

This specification operates in 10-66 GHz, supports both TDD and FDD for flexible spectrum usage. Each frame consists of uplink and downlink subframes. The uplink channel is divided into number of time slots that are controlled by the MAC layer in the base station whereas the downlink uses TDM in which information from multiple mobile stations (MS) are multiplexed into one stream. The system structures for the uplink and downlink transmitters are similar for both.

2.2 Wireless MAN-OFDM

OFDM is an efficient version of multicarrier modulation, where the subcarriers are selected such that they all are orthogonal to one another over the symbol duration; thereby eliminating inter-carrier interference. The OFDM PHY is based on OFDM modulation and designed for NLOS environment [5]. In the frequency domain, an OFDM symbol consists of 256 subcarriers. This air interface provides multiple access to different stations through time-division multiple access.

2.3 Wireless MAN-OFDMA

The Wireless MAN-OFDMA PHY is designed for NLOS operation in the frequency bands below 11 GHz for licensed bands. However, the fast Fourier transform (FFT) size of OFDMA PHY can be 128, 512, 1024, or 2048. The OFDMA PHY supports QPSK, 16-QAM, and 64-QAM modulations. This air interface provides multiple access by assigning a subset of the carriers to an individual receiver.

An OFDMA symbols are constructed from data, pilot, and null carriers:

- Data carriers - for data transmission.
- Pilot carriers - the magnitude and phase of these carriers are known to the receiver and they are used for channel estimation.
- Null carriers - prevent leakage of energy into adjacent channels.

3. WiMAX MODEL FOR PHYSICAL LAYER

The adaptive features at the WiMAX Physical layer allow trade-offs between robustness and capacity. This layer has a low level access to the link medium, which is in case of Mobile WiMAX the radio environment. The main task of the physical layer is to process data frames delivered from upper layers to a suitable format for the wireless channel. This task is done by various processing techniques. The block diagram of WiMAX Physical layer system is shown in figure 1 [6]. Now we will explain each of the blocks one by one in detail.

3.1 Randomization

It is the first process carried out in layer after the data packet is received from the higher layers each burst in Downlink and Uplink is randomized. It is basically scrambling of data to generate random sequence. Randomizer operates on a bit by bit basis. The purpose of the scrambled data is to convert long sequences of 0's or 1's in a random sequence to improve coding performance and data integrity [7]. Randomization starts with the original data and calculates the appropriate test statistic on each reordering. It is mainly concerned with the changing of position as well as state of the bits.

3.2 Forward Error Correction (FEC)

The incoming bits from the randomizer are then applied to the FEC encoder. FEC encoding is done on the uplink and downlink bursts of data and consists of a concatenated outer RS code and inner convolutional code. These are used for error detection and error correction and are included in the channel coding.

3.2.1 RS codes

These are concatenated with punctured inner convolutional code. These codes are used for variable block size and error correction capabilities. RS codes corrects block errors. The encoding process for RS encoder is based on Galois field computation to add the redundant bits to the original bit stream. WiMAX is based on GF (2^8) that corresponds to as RS (N = 255, K = 239, T =8)

Where:

N = Number of Bytes after encoding

K = Data Bytes before encoding

T = Number of bytes that can be corrected

3.2.2 Convolution codes (CC)

These CC codes are used to correct the random errors [8] and are easy to implement in comparison to RS codes. These codes introduce redundant bits into the data stream through the use of linear shift memory registers (k). is specified by CC (m, n, k) in which each m-bit information symbol to be encoded id transformed into an n-bit symbol. Hence the code rate can be given by m/n. Higher rates like 2/3 and 3/4, are derived from it by employing "puncturing." Puncturing is a procedure for omitting some of the encoded bits in the transmitter and inserting a dummy "zero" metric into the convolution decoder on the receive side in place of the omitted bits.

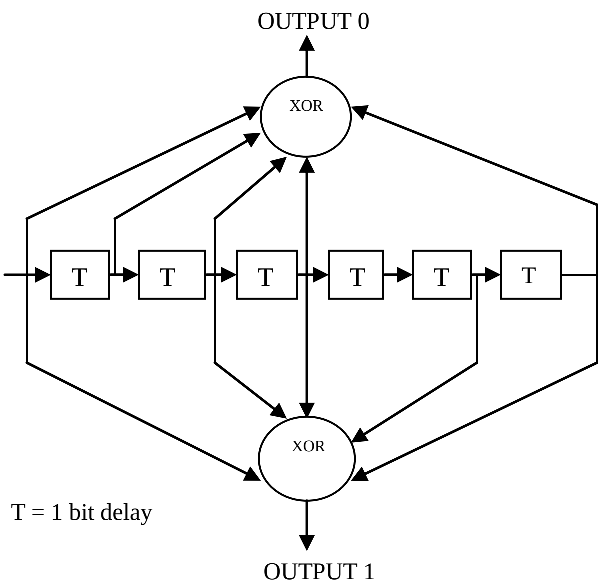


Fig 1. Convolution Encoder

For decoding the encoded sequence, Viterbi algorithm is used at the receiver. Viterbi algorithm is used to decode the channel coded symbols at the receiver of a WiMAX system [9]. It performs maximum likelihood (ML) decoding of the received symbols by attempting to retrace all the state transitions of the encoder in the trellis diagram but the complexity of the viterbi decoder increases with the constraint length.

3.3 Interleaving

Interleaving is a method which is similar to randomization but it is only concerned with the change in only the position of the bits and not the state of the bits. It aims to distribute transmitted bits in time or frequency or both to achieve desirable bit error distribution after demodulation. It is done by spreading the coded symbols in time before transmission. In this, the bits are mapped on to the non-adjacent subcarriers such that the probability of burst errors is reduced. Bursts errors are basically introduced due to multipath distortion. Interleaving are of two types: Block and Convolutional interleaving.

3.3.1 Block Interleaving

Block interleaving operates on one block of bits at a time. The number of bits in the block is called *interleaving depth,* which defines the delay introduced by interleaving. A block interleaver can be described as a matrix to which data is written in columns and read in rows, or vice versa.

3.3.2 Convolutional Interleaving

Convolutional interleaving operates on continuous stream of bits. The interleaver operates by writing the bits into the commutator on the left, and reading bits out from the commutator on the right. The delay elements *D* are clocked after each cycle of the commutators is completed; that is, after the last delay line has been written and read. The main benefit of a convolutional interleaver is that it requires approximately half of the memory required by a block interleaver to achieve the same interleaving depth. This saving can be significant for long interleaver depths.

3.4 Modulation

Modulation is a fundamental component of a digital communication system. It involves mapping of incoming digital information from interleaver into analog form onto a constellation so it can be transmitted over the channel. Various digital modulation techniques used in our analysis that are M-PSK and M-QAM [9] where M is the number of constellation points in the constellation diagram. After modulation process, codewords generated by encoding process are converted into symbols. Inverse process of modulator is called demodulation which is done at the receiver side of Physical layer to recover the transmitted digital information.

3.5 Pilot Insertion

The pilot subcarriers are used for various estimation and synchronization purposes. Pilot carriers are inserted whose magnitude and phase is known to the receiver. Pilots are used to track the residual phase error if present after frequency correction. Without this correction, the constellation points start rotating either +ve/-ve angle. It is very much sensitive at higher constellation.

3.6 Inverse Fast Fourier Transform (IFFT)

It converts the data from frequency domain to time domain data representing OFDM subcarrier because the channel is in time domain. IFFT is useful for OFDM because it generates samples of a waveform with frequency component satisfying orthogonality condition.

Similarly FFT functions opposite to IFFT; it converts the time domain data to frequency domain data as we have to work in the frequency domain [10]. By calculating the outputs simultaneously and taking advantage of the cyclic properties of the multipliers Fast Fourier Transform (FFT) techniques reduce the number of computations to the order of $N \log N$. The FFT is most efficient when N is a power of two. The result of the FFT contains the frequency data and the complex transformed result.

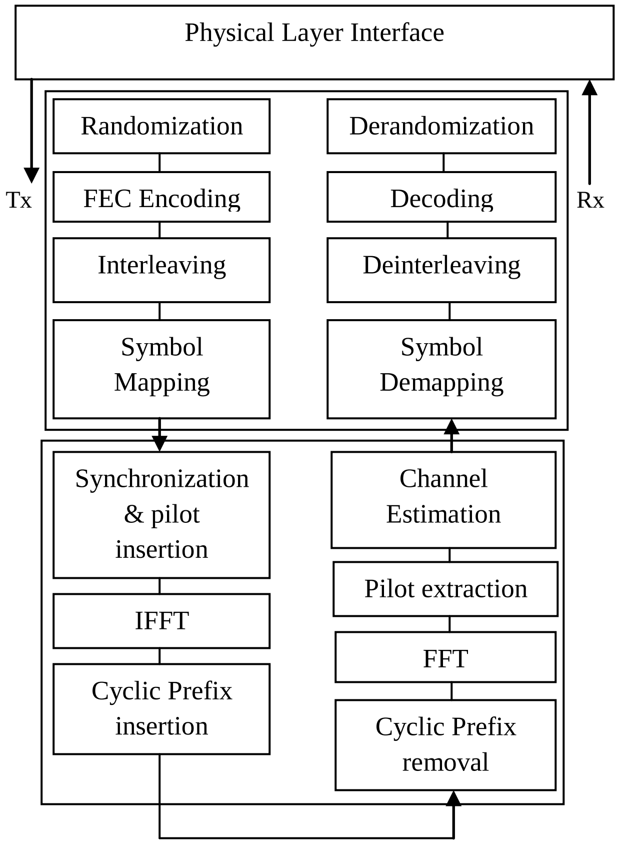


Fig 2. WiMAX Model for Physical Layer

3.7 Cyclic Prefix

One way to prevent IS1 is to create a cyclically extended guard interval [12], where each symbol is preceded by a periodic extension of the signal itself. The frame will contain $N_{total} = L + N$ samples. The cyclic prefix can be 1/4, 1/8, 1/16 or 1/32 of the (useful) symbol length. A discrete time implementation of the Multi Carrier transmitter will use a cyclic prefix to emulate the guard interval from the analog transmission. At the receiver, removing the guard interval becomes equivalent to removing the cyclic prefix, while the effect of the channel transforms into the periodic convolution of the discrete time channel with the IDFT of the data symbols.

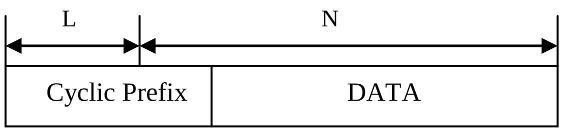


Fig 3. Cyclic Prefix

3.8 Communication Channels

Communication between transmitter and receiver side of WiMAX is done through wireless channels. Wireless transmission uses air or space for its transmission medium.

The received signal is not same as that of the transmitted signal but it is a combination of reflected, diffracted and scattered copies of the transmitted signal. These additional copies of the transmitted signal are called multipath signal components.

In our analysis Rician and Nakagami channels are taken into consideration for the analysis purpose. When there is line of sight, direct path is normally the strongest component goes into deeper fade compared to the multipath components. This kind of signal is approximated by Rician distribution. As the dominating component run into more fade the signal characteristic goes from Rician to Rayleigh distribution.

The Rician distribution is given by:

$$P(r) = (r/\sigma^2)\, exp(-(r^2 + A^2)/2\sigma^2)\, l_0\, (A_r/\sigma^2) \quad ,$$

$$for\ (A \geq 0,\ r \geq 0)$$

where A denotes the peak amplitude of the dominant signal and $I_0[.]$ is the modified Bessel function of the first kind and zero-order.

The Nakagami distribution has been employed as another useful model for characterizing the amplitude of fading channels. Rayleigh fading falls short in describing long-distance fading effects which was corrected by Nakagami by formulating a parametric gamma distribution-based density function. It provides a better explanation to less and more severe conditions than the Rayleigh and Rician model and provides a better fit to the mobile communication channel data. Nakagami fading can be described by the PDF:

$$f_R\ (r) = \left(\frac{2}{\Gamma(m)}\right) \left(\frac{m}{\Omega}\right)^m\ r^{2m-1} e^{\left(\frac{mr^2}{\Omega}\right)}\, u(r)$$

For $m \leq 0.5\ \Omega^2\,/E[(R^2 - \Omega^2)^2]$

Where the parameter Ω and the fading figure m are defined via:

$$\Omega = E\,\{R^2\} \quad , \quad m = \frac{\Omega^2}{E[(R^2 - \Omega^2)^2]}$$

And *r[n]* is the standard Gamma function defined via:

$$\Gamma[n] = \int_0^\infty e^{(-x)}\, x^{n-1}\, dx$$

3.9 Receiver Side

At the receiving side, a reverse process (including deinterleaving and decoding) is executed to obtain the original data bits. As the deinterleaving process only changes the order of received data, the error probability is intact.

4. MULTI INPUT MULTI OUTPUT (MIMO) SYSTEMS

Multiple Input Multiple Output (MIMO) has been the most promising technology to improve the performance of a wireless link. MIMO transmission system is the recent and the most promising approach which is currently practiced for high-rate wireless communication. MIMO refers to a radio link with multiple transmitting and multiple receiving antennas plus adaptive signal processing. The advantage of MIMO system is to benefit the users with multipath propagation. MIMO improves the capacity and combats fading by different diversity techniques.

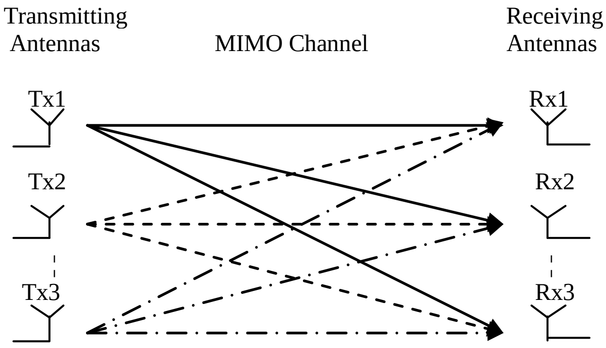


Fig 4. Block Diagram of MIMO system with M Transmitters and N Receivers

Wireless systems using MIMO can significantly improve the spectral efficiency of a system. It is a wireless technology that uses multiple transmitters and receivers to transfer more data at the same time. [12]. MIMO technology exploits multipath behavior instead of mitigating it by using multiple transmitters and receivers with an added spatial dimension to increase performance and range of the system. MIMO allows multiple antennas to send and receive multiple spatial streams at the same time.

5. MIMO TECHNIQUES

MIMO system includes different techniques that improve the performance of the system. MIMO systems can be implemented in different ways in order to attain a diversity gain to combat signal fading or a capacity gain.

5.1 Spatial Diversity

Diversity is a technique of transmitting multiple copies of the same signal [13]. This technique requires a number of signal transmission paths known as diversity branches and each branch carries the same information with approximately uncorrelated or dissimilar multipath fading characteristics. Diversity technique requires combining circuitry so that to combine the signals from each diversity branch or to select only the best signal out of different received signals. The signal is a coded using technique called space-time coding [14]. Diversity techniques are basically used to reduce the effects of multipath fading and improve the reliability of transmission without sacrificing the bandwidth and without increasing the transmitted power of the signal by transmitting same information on different independent.

The basic idea behind the diversity technique is that, if two or more independent samples of a signal are taken, these samples fades in an uncorrelated manner such that some are less attenuated while the others are severely attenuated due to multipath propagation phenomenon. This technique requires multiple replicas of the transmitted signals at the receiver such that all the signals carry same information but with small correlation in fading statistics. Diversity methods [15] improves the robustness of the communication system in terms of BER by exploiting the multiple paths between transmit and receive antennas. In this paper, Spatial diversity STBC 3X3 technique is taken onto consideration for analyzing the system for different fading channels.

5.2 Spatial Multiplexing

The basic concept of spatial multiplexing is to divide (multiplex) and transmit a data stream into several branches and transmit via several (independent) channels in space and different bits are transmitted via different antennas. One of the key advantages of MIMO spatial multiplexing is the fact that it is able to provide additional data capacity thus providing capacity gain. MIMO spatial multiplexing achieves this by utilizing the multiple paths and effectively using them as additional "channels" to carry data such that receiver receives multiple data at the same time. The tenet in spatial multiplexing is to transmit different symbols from each antenna and the receiver discriminates these symbols by taking advantage of the fact that, due to spatial selectivity, each transmit antenna has a different spatial signature at the receiver. This allows an increased number of information symbols per MIMO symbol; depending on the particular transmission technique used. In any case for MIMO spatial multiplexing, the number of receiving antennas must be equal to or greater than the number of transmit antennas such that data can be transmitted over different antennas. This technique includes layered approach that increases the capacity of the system. One such technique is V-BLAST [16].

5.3 Beamforming

Beamforming exploits the knowledge of the channel at the transmitter end of the MIMO system. It mainly decomposes the channel coefficient matrix using SVD and uses these decomposed unitary matrices as pre as well as post filters at the transmitter and the receiver side to achieve near capacity. This technique provides gain in between diversity and capacity gain. In single-layer beamforming, same signal is emitted from each of the transmitting antennas with appropriate phase and gain weighting such that the signal power is maximized at the receiver input. The benefits of beamforming are to increase the received signal gain, by making signals emitted from different antennas add up constructively, and to reduce the multipath fading effect [17]. Beamforming involves directing the signal in the desired direction such that the signal going in the desired direction is increased and signal going in the other directions is reduced. In beamforming, the same signal is emitted from each of the transmit antennas with appropriate phase (and sometimes gain) weighting such that the signal power is maximized at the receiver input.

6. WiMAX-MIMO SYSTEMS

WiMAX-MIMO systems are basically developed to get the benefits of both WiMAX protocol as well as the MIMO systems such that high speed broadband internet access can be provided to the users [18]. This paper involves combining WiMAX protocol with the spatial diversity technique of MIMO systems such that diversity gain can be obtained.

Diversity gain can be obtained by transmitting same information over different antennas involved at the transmitter side of MIMO systems. MIMO systems take advantage of spatial diversity by placing spatially separated antennas in dense multipath scattering environment. This provides received signal as the combination of various transmitting signal [19]. The WiMAX-MIMO system block diagram is given in figure 5.

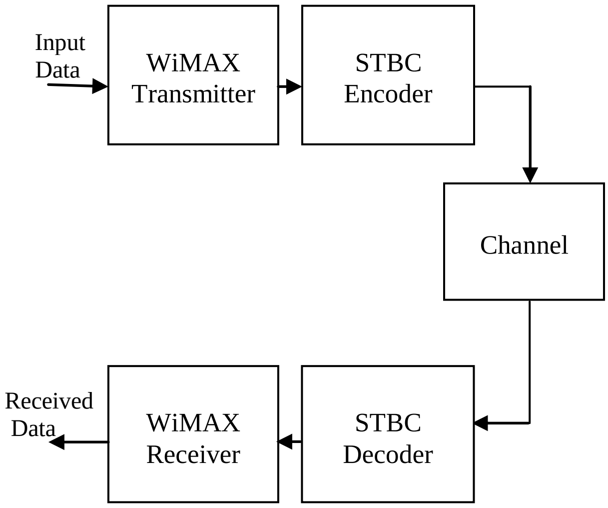


Fig 5. WiMAX-MIMO System

Combining both the systems WiMAX and MIMO technology provides high data rate transmission thus improving the performance of WiMAX-MIMO system in comparison to simple WiMAX system. This system provides better BER and SNR performance in comparison to simple WiMAX without the use of MIMO systems. Spatial diversity can be done in many ways to obtain diversity gain to combat signal fading. WiMAX standard is combined with the MIMO system by employing STBC Encoder and Decoder at the transmitter and receiver side of the WiMAX PHY layer before and after the channel respectively as shown in the block diagram.

This paper analyze the spatial diversity technique of MIMO systems with WiMAX protocol in order to achieve higher data rates by lowering the Bit Error Rate of the system for lower value of SNR to achieve better performance and results. Results are obtained for the Rician and Nakagami channel.

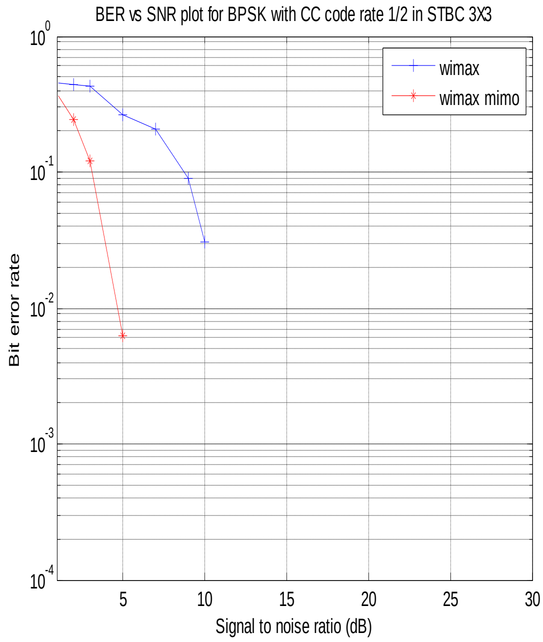
7. RESULTS AND SIMULATIONS

This paper analyzes the behavior of WiMAX-MIMO systems under different modulation schemes with different CC code rates for different fading channels i.e. Rician and Nakagami channels. Results are shown in the form of SNR vs BER plots. The simulations are done for Spatial diversity STBC 3X3 i.e. 3 antennas present at the transmitter and the receiver side so that there is improved performance of the WiMAX-MIMO systems compared to simple WiMAX standard.

Firstly WiMAX physical layer has been simulated and then it is combined with the STBC 3X3 technique of MIMO systems for the analysis of the WiMAX-MIMO system. The simulation is done using different lower and higher modulation schemes under different CC code rates that enhances the overall performance of the WiMAX-MIMO system.

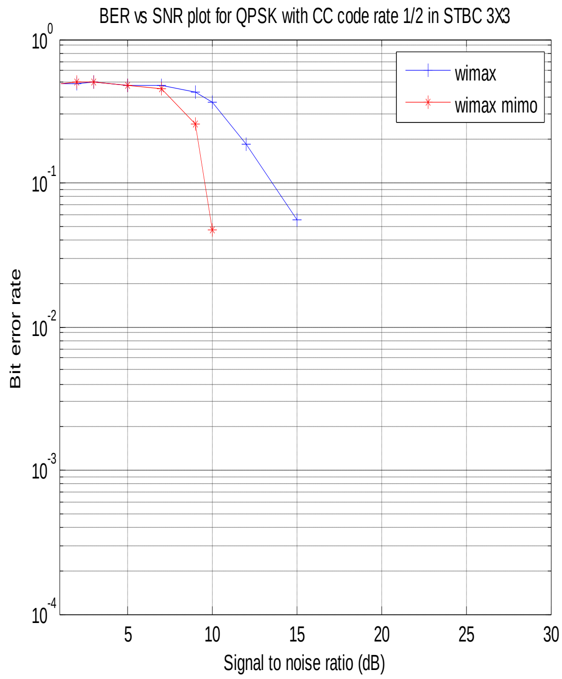
7.1 BER Analysis for Rician Channel

In this section BER analysis of WiMAX-MIMO system with Spatial Diversity is done for different Modulations over Rician fading channel.



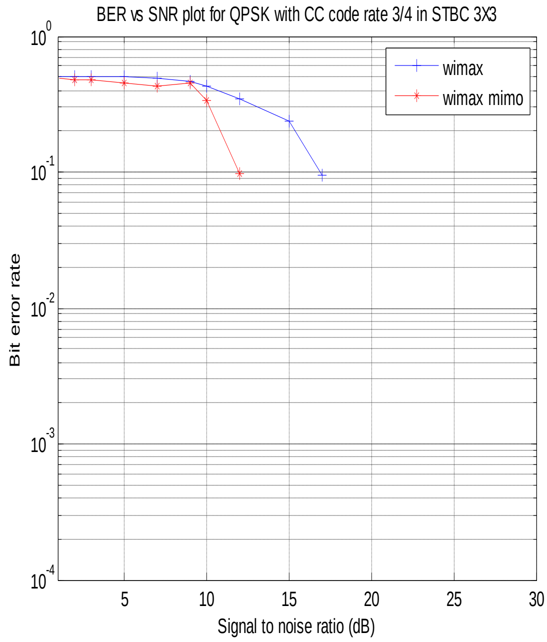
(a) BPSK with CC code rate 1/2

In this graph we are able to acheive 5dB improvement in SNR is shown when we employ Spatial Diversity technique of MIMO in WiMAX in the presence of Rician channel.



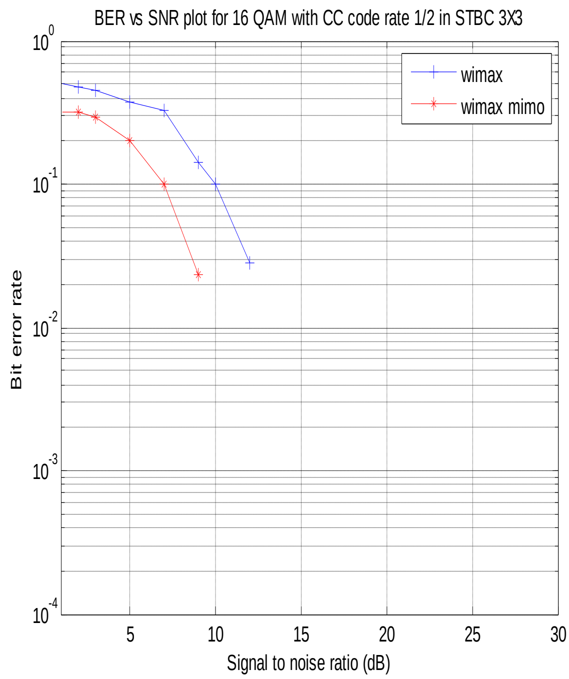
(b) QPSK with CC code rate 1/2

QPSK modulation with CC code rate 1/2 provides 5dB improvement in SNR when combining WiMAX with MIMO Spatial Diversity technique. Rician channel is used for the analysis purpose.



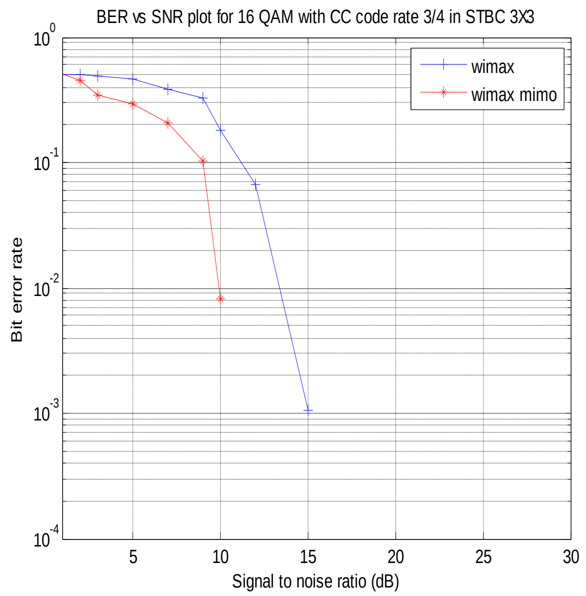
(c) QPSK with CC code rate 3/4

Using QPSK modulation with CC code rate of 3/4, SNR improvement of 5dB can be seen in WiMAX-MIMO system compared to simple WiMAX standard.



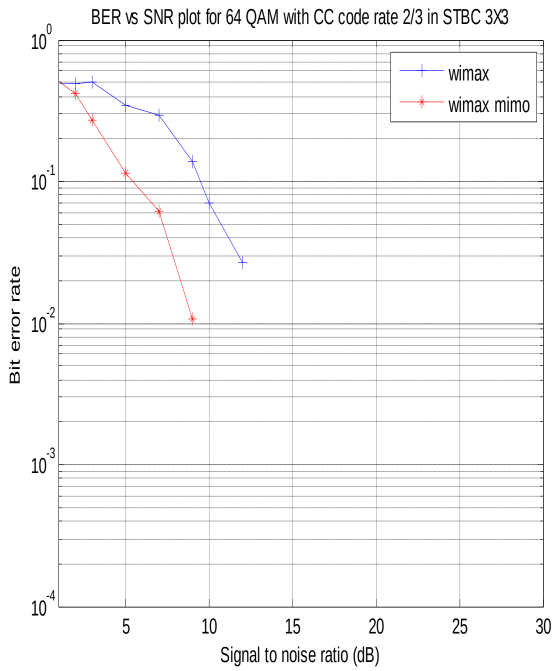
(d) 16QAM with CC code rate 1/2

As we can seen from the graph, SNR improvement of 3dB is there using WiMAX protocol with Spatial Diversity technique of MIMO technology in the presence of Rician channel. Performance of simple WiMAX is improved using MIMO.



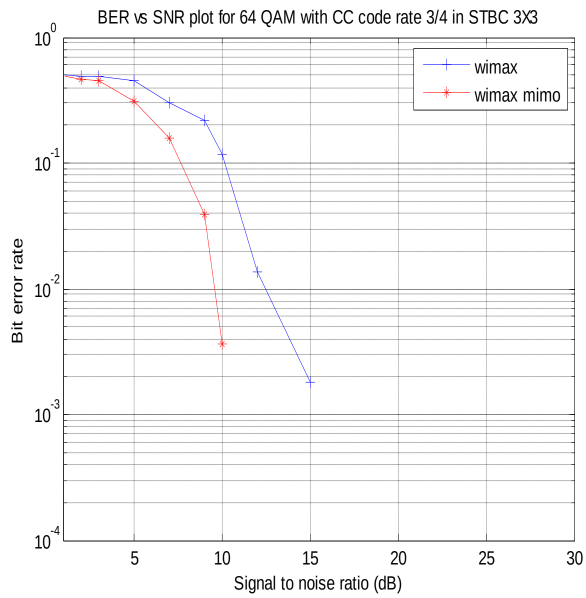
(e) 16 QAM with CC code rate 3/4

Again as we can see there is an improvement of 5dB in the SNR value using Rician channel with the combination of WiMAX standard with the MIMO technology.



(f) 64 QAM with CC code rate 2/3

SNR improvement of 3dB incase of 64QAM modulation with CC code rate 2/3 can be seen when we use WiMAX protocol with the STBC 3X3 technique of MIMO in the presence of Rician channel.



(g) 64 QAM with CC code rate 3/4

This graph shows an SNR improvement of 5dB using WiMAX-MIMO system in the presence of Rician channel.

Fig 6. BER vs SNR plots for Rician channel a) BPSK code rate 1/2 b) QPSK code rate 1/2 c) QPSK code rate 3/4 d) 16 QAM code rate 1/2 e) 16 QAM code rate 3/4 (f) 64 QAM code rate 2/3 (g) 64 QAM code rate 3/4

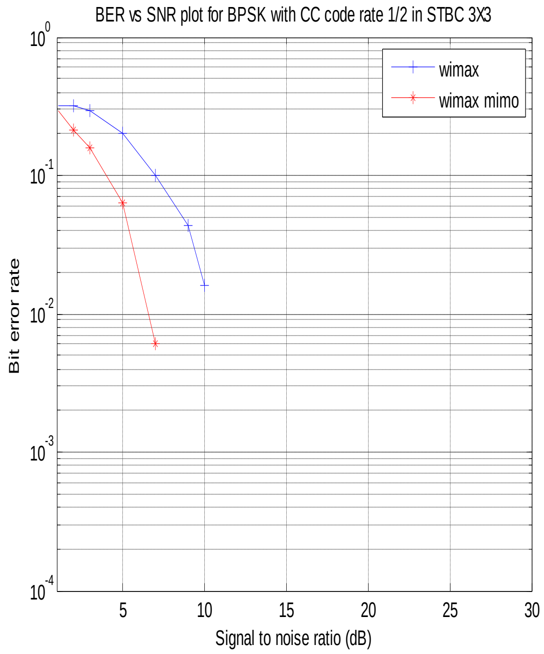
The performance of WiMAX-MIMO system with different modulations and different CC code rates have been presented in the form of BER vs SNR plots over Rician channel in Figure 6 (a)–(g). Each graph shows an improvement in the SNR value using spatial diversity STBC 3X3 technique of MIMO system.

Table 1: SNR improvement in Rician channel by using Spatial Diversity in WiMAX

MODULATION	SNR Improvement using Rician channel (dB)
BPSK code rate 1/2	5dB
QPSK code rate 1/2	5dB
QPSK code rate 3/4	5dB
16 QAM code rate 1/2	3dB
16 QAM code rate 3/4	5dB
64QAM code rate 2/3	3dB
64QAM code rate 3/4	5dB

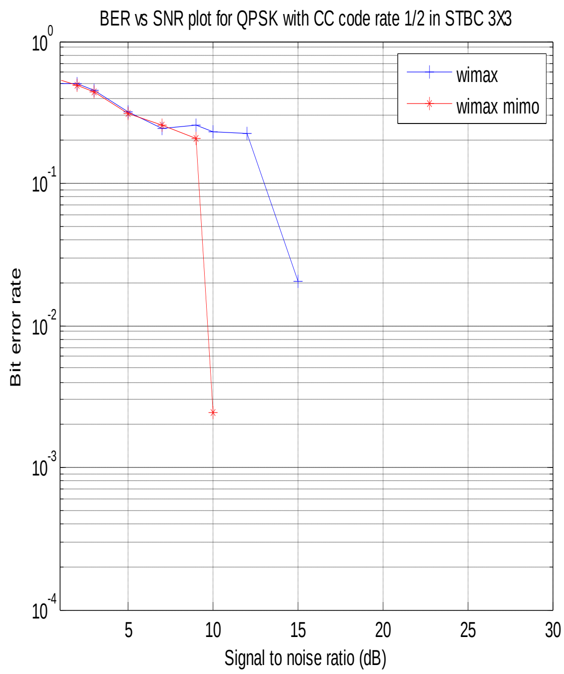
7.2 BER Analysis for Nakagami channel

In this section BER analysis of WiMAX-MIMO system with Spatial Diversity STBC 3X3 is done for different Modulations over Nakagami fading channel.



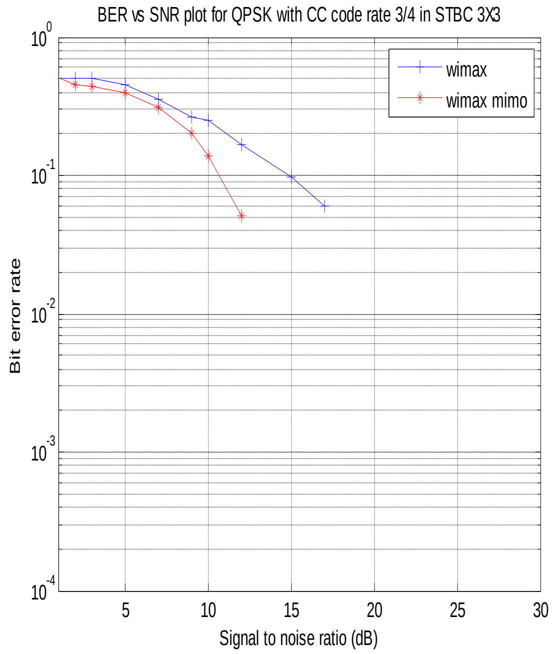
(a) BPSK with CC code rate 1/2

We are able to acheive 3dB improvement in SNR when we employ Spatial Diversity STBC 3X3 technique of MIMO system in WiMAX in the presence of Nakagami channel.



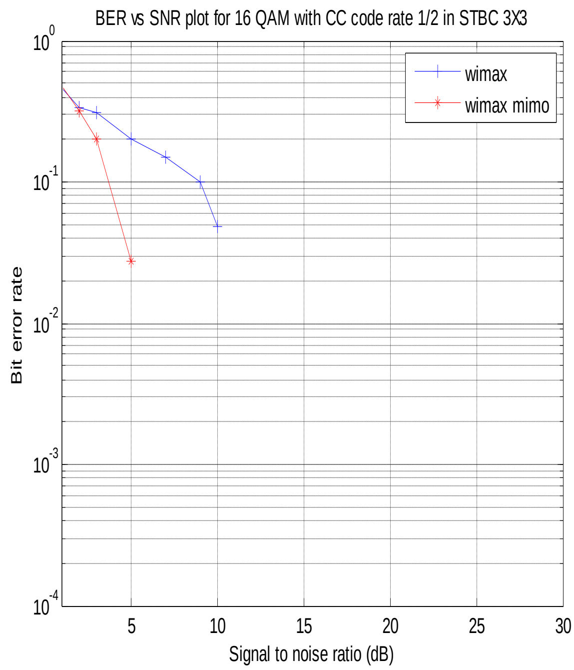
(b) QPSK with CC code rate 1/2

QPSK modulation with CC code rate of 1/2 provides 5dB improvement in SNR when combining WiMAX with MIMO Spatial Diversity technique. For the analysis purpose, Nakagami channel is used.



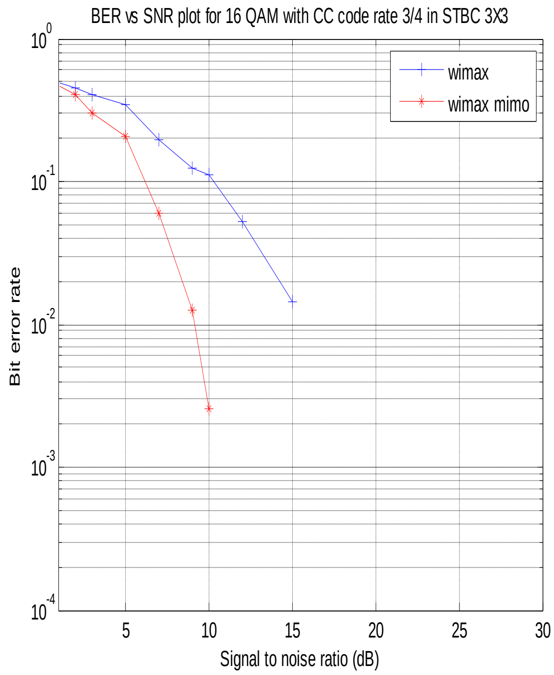
(c) QPSK with CC code rate 3/4

Using QPSK modulation with CC code rate of 3/4, SNR improvement of 5dB can be seen in WiMAX-MIMO system when it is compared to simple WiMAX standard.



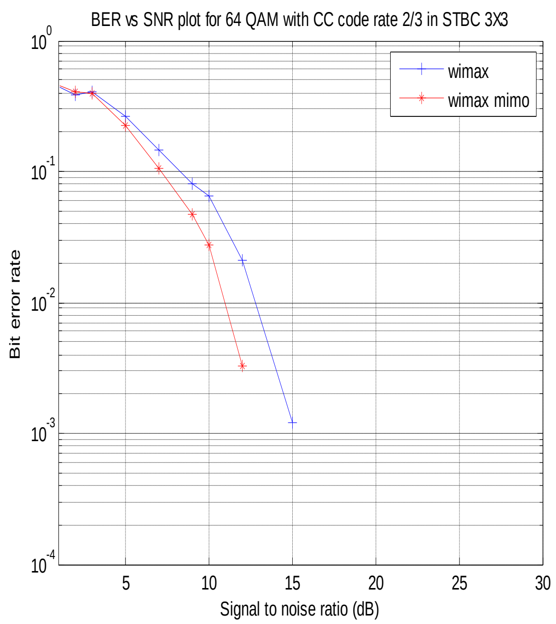
(d) 16QAM with CC code rate 1/2

SNR improvement of 5dB can be seen using WiMAX protocol with Spatial Diversity technique of MIMO technology in the presence of Nakagami channel.



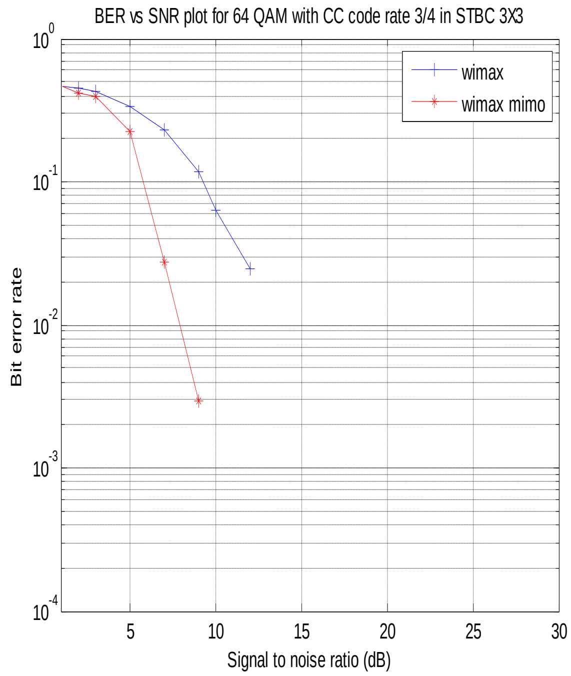
(e) 16 QAM with CC code rate 3/4

Again as we can see that there is an improvement of 5dB in the SNR value using Nakagami channel with the combination of WiMAX standard with the MIMO technology using 16 QAM modulation with CC code rate 3/4.



(f) 64 QAM with CC code rate 2/3

SNR improvement of 3dB is observed incase of 64QAM modulation with CC code rate 2/3 using WiMAX protocol with the STBC 3X3 technique of MIMO in the presence of Nakagami channel.



(g) 64 QAM with CC code rate 3/4

This graph shows an SNR improvement of 3dB in WiMAX-MIMO system in the presence of Nakagami channel using 64QAM modulation with CC code rate of 3/4.

Fig 7. BER vs SNR plots for Nakagami channel
a) BPSK code rate 1/2 b) QPSK code rate 1/2
c) QPSK code rate 3/4 d) 16 QAM code rate 1/2
e) 16 QAM code rate 3/4 (f) 64 QAM code rate 2/3
(g) 64 QAM code rate 3/4

The performance of WiMAX-MIMO system with different modulations and different CC code rates have been presented in the form of BER vs SNR plots over Nakagami channel in Figure 7 (a)–(g). Each graph shows an improvement in the SNR value using spatial diversity STBC 3X3 technique of MIMO system which is given in the following table.

Table 2: SNR improvement in Nakagami channel by using Spatial Diversity in WiMAX

MODULATION	SNR Improvement using Nakagami channel (dB)
BPSK code rate 1/2	3dB
QPSK code rate 1/2	5dB
QPSK code rate 3/4	5dB
16 QAM code rate 1/2	5dB
16 QAM code rate 3/4	5dB
64QAM code rate 2/3	3dB
64QAM code rate 3/4	3dB

8. CONCLUSION

In this paper effect of employing MIMO spatial diversity STBC 3X3 in 802.16e PHY layer has been simulated and the improvement is shown in the form of SNR value. Rician and Nakagami fading channels have been taken into account for the analysis of WiMAX-MIMO system. Simulations show that there is improvement in the SNR value as compared to simple WiMAX in case of both of the fading channels. Results of both the channels have shown that BER value approaches to zero for a lower value of SNR when we employ MIMO system in WiMAX for different modulations and different CC code rates. This shows that employing MIMO systems in WiMAX protocol improves the overall performance of the system

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