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Performance of Alamouti Space Time Coding in Fading Channels for IEEE 802.16e Protocol

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Abstract - In this paper, a general Alamouti space time block code structure is proposed for multiple-input multiple-output–orthogonal frequency-division multiplexing (MIMO-OFDM) in WiMAX systems for 2 X N_R antenna configurations. The signal detection technology used in this paper for MIMO-OFDM system is Zero-Forcing Equalization (linear detection technique). The analysis of Signal to Noise Ratio (SNR) vs Bit Error Rate (BER) for MIMO in WiMAX system has been done. For this purpose modulation technique QPSK has been considered for different convolution-codes (CC)-rates. Also Reed-Solomon (RS) codes have been implemented along with CC codes. Comparisons between ideal channel, Additive White Gaussian Noise (AWGN) and practical fading channel, Rayleigh channel has been done. Also the comparison is provided on the basis of SNR vs BER graph for different antenna configurations.

Index Terms: - WiMAX, OFDM, MIMO, Alamouti Space Time Coding, Zero Forcing Equalisation, BER(Bit Error Rate), FEC

1. INTRODUCTION

Among the emerging technologies for broadband wireless access, IEEE 802.16e is one of the most promising and attractive candidates. However, it also presents very challenging aspects in terms of radio resource management which intentionally left open to implementers [1]. The IEEE
802.16e air interface standard [2] is based on orthogonal frequency-division multiplexing (OFDM), which has been regarded as an efficient way to combat the inter-symbol interference (ISI) for its excellent performance over frequency selective channels for broadband wireless networks. Multi-Input Multi-Output (MIMO) technology has also been recognized as a key approach for achieving a dramatic increase in the capacity of wireless communication systems [3].

In particular, the use of OFDM technology combined with MIMO is an attractive solution for future broadband wireless systems that require reliable and high-rate data transmission. The inherent structure of MIMO-OFDM allows the use of dynamic resource allocation of subcarriers, bits, power and antennas which will improve the system performance remarkably.

Currently, Worldwide Interoperability for Microwave Access (WiMAX) has received much attention. It is based on the IEEE 802.16e standard and can be classified into Fixed WiMAX [4] and Mobile WiMAX . October 2007, wireless broadband technology, WiMAX, was formally adopted to be one of the 3G standards by International Telecommunication Union (ITU), which is a milestone in the development of WiMAX. For 802.16e MAC & PHY layers has been defined, but for present work only PHY has been taken into consideration. PHY layer for mobile WiMAX (IEEE-802.16e) has scalable FFT size128-2048 point FFT with OFDMA, Range is from 1.6 to 5 Km. at 5Mbps in 5MHz. channel BW, it supports 100Km/hr speed.

2. WiMAX MODEL FOR PHYSICAL LAYER

The block diagram for Wi-MAX system (standard: 802.16e) is shown in figure 1 [5]. Now we will take each block one by one in detail and in present paper simulation has been done for each block separately.

➢ Randomization 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

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generate random sequence to improve coding performance.

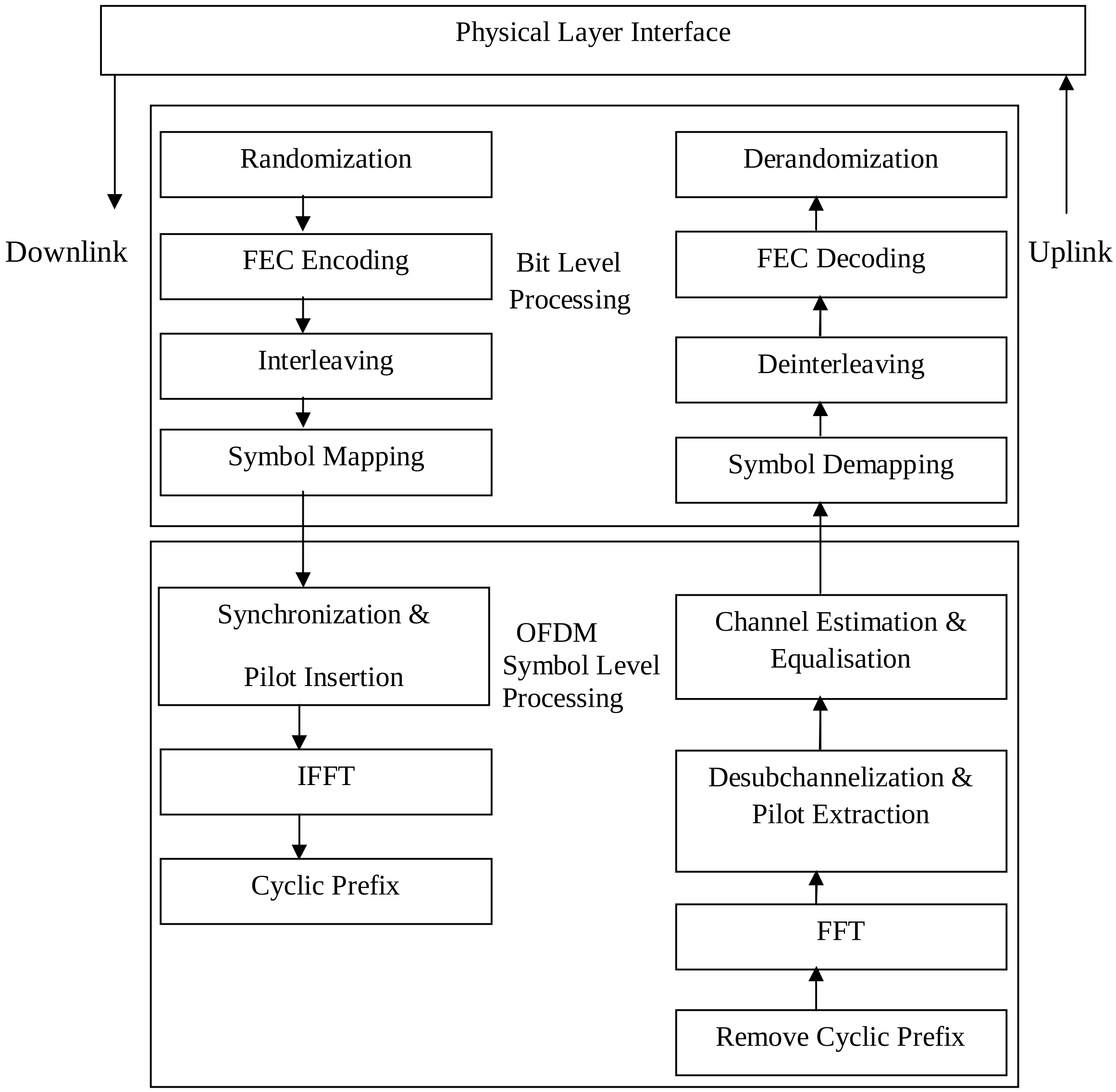

Figure 1:- WiMAX Model for Physical layer (802.16)

➢ In Forward Error Correction (FEC) there are number of coding system like RS codes, convolution codes Turbo codes etc. But in the present paper only RS codes and convolution codes has been taken for simulation.

RS codes basically add redundancy to the data .this redundancy improves Blocks error. RS-encoder is based on Galois field computation to add the redundancy bits. Wi-MAX 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

In this coding two polynomials are required namely code generator polynomial g(x)and field generator polynomial p(x) .For Wi-MAX system

Code generator polynomial

$$G(x) = (x + k^0)(x + k^1)(x + k^2) \ldots\ldots \ldots\ldots (x + k^{2T-1}) \quad (1)$$

Field generator polynomial

$$P(x) = x^8 + x^4 + x^3 + x^2 + 1 \quad (2)$$

Convolutional codes are commonly specified by three parameters n, k, m. Where n is the number of output bits, k is the number of input bits and m is the number of memory registers. Encoder for a convolutional code accepts k-bit blocks of information sequence and produces an encoded sequence (codeword) of n-bit blocks. However, each encoded block depends not only on the corresponding k-bit message block at the same time unit, but also on M previous blocks. Hence, the encoder has a memory length of m. Encoder operates on the incoming message sequence continuously in a serial manner.

The quantity k/n called the code rate, is a measure of code's efficiency. Other important parameter of convolutional code is the constraint length of the code and is defined by L= k*(m– 1) The constraint length L represents the number of bits in the encoder memory that affect the generation of the n output bits. The error correction capacity is related with this value. The number of bits' combinations in the registers is called the states of the code and are defined by number of states Ns = 2L, where L is the constraint length of the code.

➢ Interleaving aims to distribute transmitted bits in time or frequency or both to achieve desirable bit error distribution after demodulation. What constitutes a desirable error distribution depends on the used FEC code. What kind of interleaving pattern is needed depends on the channel characteristics. If the system operates in purely AWGN environment, no interleaving is needed, because the error distribution cannot be changed by relocating the bits.

➢ Communication channels are divided into *fast* and *slow* fading channels. A channel is fast fading if the impulse response changes approximately at the symbol rate of the communication system, whereas a slow fading channel stays unchanged for several symbols.

➢ Modulation and channel coding are fundamental components of a digital communication system. Modulation is the process of mapping the digital information to analog form so it can be transmitted over the channel. Consequently every digital communication system has a *modulator* that performs this task. Closely related to modulation is the inverse process, called *demodulation,* done by the receiver to recover the transmitted digital information. The design of optimal demodulators is called *detection* theory. Different coherent mapping used are BPSK, QPSK and M-QAM .However there is trade-off between, different Mapping tech and spectral efficiency. In present paper all mappings are used for simulation purpose.

➢ Pilot insertion is used for channel estimation & synchronization purpose.

➢ An inverse Fourier transform converts the frequency domain data input to time domain representing OFDM Subcarrier. IFFT is useful for OFDM because it generates samples of a waveform with frequency component satisfying orthogonality condition. It also removes the need of oscillator. A general *N*-to-*N* point linear transformation requires N^2 multiplications and additions. This would be true of the DFT and IDFT if each output symbol were calculated separately.

However, by calculating the outputs simultaneously and taking advantage of the cyclic properties of the multipliers $e^{\pm j2\pi kn/N}$ 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. Several variations of the FFT exist, with different ordering of the inputs and outputs, and different use of temporary memory.

➢ One way to prevent IS1 is to create a cyclically extended guard interval, where each OFDM symbol is preceded by a periodic extension of the signal itself.

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Considering the discrete time implementation of the Multi Carrier system, sampling the transmitted Multi Carrier signal at a rate equal to the data rate one obtains a frame structure composed of the IDFT of the data symbols and of a cyclic prefix and where the OFDM frame will contain $N_{total} = L + N$ samples. Here L is the number of samples copied from the end of N sample IDFT frame and glued at the start of each IDFT frame.

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. Performing a DFT on the received samples after the cyclic prefix is discarded, the periodic convolution is transformed into multiplication, as it was the case for the analog Multi Carrier receiver.1/2 or 1/4 or1/8 or 1/16 or 1/32 times of data symbol is added at beginning of the OFDM.

3. MULTI INPUT MULTI OUTPUT (MIMO) SYSTEMS

Multi-antenna systems can be classified into three main categories. Multiple antennas at the transmitter side are usually applicable for *beam forming* purposes. Transmitter or receiver side multiple antennas for realizing different (frequency, space) *diversity* schemes. The third class includes systems with multiple transmitter and receiver antennas realizing *spatial multiplexing* (often referred as MIMO by itself).

In radio communications MIMO means multiple antennas both on transmitter and receiver side of a specific radio link. In case of spatial multiplexing different data symbols are transmitted on the radio link by different antennas on the *same* frequency within the same time interval.

Multipath propagation is assumed in order to ensure the correct operation of spatial multiplexing, since MIMO is performing better in terms of channel capacity in a rich scatter multipath environment than in case of environment with LOS (line of sight). This fact was spectacularly shown in [6]. MIMO transmission can be characterized by the time variant channel matrix:

$$H(\tau, T)=\begin{pmatrix} h_{1,1}(\tau,t) & h_{1,2}(\tau,t) & \dots & h_{1,N_R}(\tau,t) \\ h_{2,1}(\tau,t) & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ h_{N_T,1}(\tau,t) & \dots & \dots & h_{N_T,N_R}(\tau,t) \end{pmatrix} \quad (3)$$

where the general element, $h_{nt,nr}$ $(\tau,\ t)$ represents the complex time-variant channel transfer function at the path between the $n_{t\text{-}th}$ transmitter antenna and the $n_{r\text{-}th}$ receiver antenna. N_T and N_R represent the number of transmitter and receiver antennas respectively.

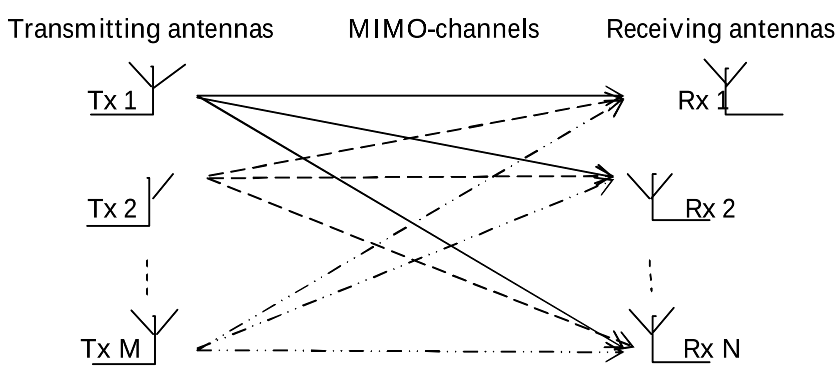

Figure 2:- Block Diagram of a generic MIMO system with M transmitters and N receivers

Derived from Shannon's law, for the capacity of MIMO channel the following expression was proven in [6] and [7]:

$$C = \max_{tr(R_{ss})\leq p} log_2\,(det(I + HR_{ss}H^H)) \quad (4)$$

where H denotes the channel matrix and H^H its transpose conjugate, I represents the identity matrix and R_{ss} the covariance matrix of the transmitted signal s.

3.1 MIMO-OFDM IN WiMAX WITH ALAMOUTI 2 X N_R SPACE TIME CODING

In this case, there are two antennas at the transmitter side and N_R receiving antennas at the receiver side [8]. First, consider the signal model received at a receiver side with a single receive antenna, i.e. $N_R = 1$. In this case, the received signal can be represented in the following form

$$\tilde{y} = \sqrt{\frac{P_o}{2}}\,\overline{H^{(0)}}\,x_0 + \sum_{k=1}^{K}\sqrt{\frac{P_k}{2}}\,\overline{H^{(k)}}\,x_k + n \quad (5)$$

where x, y and n are transmit, receive and noise vectors respectively (with zero mean and variance σ_n^2, circularly symmetric normal distributed entries), and H_k is the N_t X N_r channel matrix, K is the number of interferers and P_k is the received power from the K_{th} receiver and is given by:

$$P_k = P_T\,G_K\,\frac{10^{X_k/10}}{L(d_k)} \quad (6)$$

here P_T is the transmit power, X_k is the log normal shadowing, $L(d_k)$ is the path loss at the distance d_k, and G_k is the aggregate antenna gain. $\overline{H^{(k)}}$ is an equivalent channel matrix given by

$$\overline{H^{(k)}} = \begin{bmatrix} h_{0,0}^{(k)} & h_{0,1}^{(k)} \\ h_{0,1}^{(k)*} & -h_{0,0}^{(k)*} \end{bmatrix} \quad (7)$$

We then premultiply the received vector with the transpose conjugate of the equivalent channel matrix for an MRC receiver, i.e., $w = \overline{H^{(0)}}$. Thus, we have that

$$z = w^*\,\tilde{y}$$

$$= \sqrt{\frac{P_o}{2}}\,\overline{H^{(0)H}}\;\overline{H^{(0)}}\,x_0 + \sum_{k=1}^{K}\sqrt{\frac{P_k}{2}}\,\overline{H^{(0)H}}\;\overline{H^{(k)}}\,x_k + \overline{H^{(0)H}}\,n \quad (8)$$

The SINR on the stream is given as follows

$$\gamma_s = \frac{\frac{1}{2}P_o\,(\overline{H^{(0)H}}\;\overline{H^{(0)}})_{ss}}{\frac{1}{2}\sum_{k=1}^{K}P_k\frac{(\overline{\overline{H^{(k)}}\;\overline{H^{(0)}}H^{(0)H}}\;\overline{H^{(k)}})_{ss}}{(\overline{H^{(0)H}}\;\overline{H^{(0)}})_{ss}} + \sigma_n^2} \quad (9)$$

where $(.)_{ss}$ denotes the s^{th} row and s^{th} column element of the matrix within the braces. Note the transmit power is shared between two antennas and hence the power is scaled by 2. The signal power and interference power are given as

$$f(.) = \frac{1}{2}\,(\overline{H^{(0)H}}\;\overline{H^{(0)}})_{ss} \quad (10)$$

and

$$g(.) = \frac{1}{2}\,\frac{(\overline{\overline{H^{(k)}}\;\overline{H^{(0)}}H^{(0)H}}\;\overline{H^{(k)}})_{ss}}{(\overline{H^{(0)H}}\;\overline{H^{(0)}})_{ss}} \quad (11)$$

Next the STC Alamouti scheme can be extended to any number of receive antennas, $N_R \geq 2$, by row appending (stacking) channel matrix from each receiver. Hence, now the equivalent matrix would be

$$\overline{H^{(0)}} = [\overline{H_1^{(0)}}\;\;\overline{H_2^{(0)}}\;\;.......\;\;\overline{H_{N_r}^{(0)}}]^T \quad (12)$$

Where $\overline{H_{N_r}^{(0)}}$ is the equivalent Alamouti matrix to the n_r^{th} antenna.

3.2 SIGNAL DETECTION OF MIMO-OFDM SYSTEM

Signal detection of MIMO-OFDM system can be carried out by various sub-carrier channel signal detection. Although the whole channel is a frequency-selective fading, but various sub-carriers channel divided can be regarded as flat fading, so the flat fading MIMO signal detection algorithm for MIMO-OFDM system can be directly into the detection of all sub-channels, and signal detection algorithm of the corresponding MIMO-OFDM system can be obtained. Similarly, the other optimization algorithms used in flat fading MIMO signal detection can also be leaded into the MIMO-OFDM system.

3.2.1 ZERO FORCING ALGORITHM [9]

Zero Forcing algorithm is regard the signal of each transmitting antenna output as the desired signal, and regard the remaining part as a disturbance, so the mutual interference between the various transmitting

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antennas can be completely neglected. The specific algorithm is as follows:

For $k = 0,1,\ldots\ldots\ldots\ldots,K-1$, so that,

$$Y(k) = [Y_1(k), Y_2(k), \ldots\ldots\ldots\ldots, Y_N(k)]^T \quad (13)$$

$$X(k) = [X_1(k), X_2(k), \ldots\ldots\ldots\ldots, X_M(k)]^T \quad (14)$$

$$N(k) = [N_1(k), N_2(k), \ldots\ldots\ldots\ldots, N_N(k)]^T \quad (15)$$

$$H(k) = \begin{bmatrix} H(k)_{11} & H(k)_{12} & \cdots & H(k)_{1M} \\ H(k)_{21} & H(k)_{22} & \cdots & H(k)_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ H(k)_{N1} & H(k)_{N2} & \cdots & H(k)_{NM} \end{bmatrix} \quad (16)$$

Here *Y(k), X(k), N(k)* respectively express output signal, the input signal and noise vector of the k sub-channels in MIMO-OFDM system, for M transmitting antennas and N receiving antennas, H(k) expresses channel matrix of the k sub-channels, mathematical expression of sub-channel in the MIMO-OFDM system is as follows:

$$Y(k) = H(k)X(k) + N(k) \quad (17)$$

There is a linear relationship between input signal *X(k)* and output signal *Y(k),* that is similar to the flat fading channel for each subcarrier channel in MIMO-OFDM system. Its equivalent block diagram is shown in Figure 3.

Therefore, signal detection can be transformed into K sub-channels in their signal detection to complete in MIMO-OFDM system and each sub-channel detection of the above can be used flat fading MIMO channel to achieve the detection algorithm. Zero-forcing (ZF) detection algorithm for MIMO detection algorithm is the most simple and basic algorithms, and the basic idea of zero forcing algorithm is get rid of MIMO-channel interference by multiplying received signal and the inverse matrix of channel matrix . Zero-Forcing solution of MIMO-OFDM system is as follows:

$$X_{ZF} = H^{-1}\, Y = X + H^{-1}\, N \quad (18)$$

In which H^{-1} is the channel matrix for the generalized inverse matrix, the type is obtained for hard-decision demodulation after that to be the source signal estimates:

$$\hat{X}_{ZF} = E(X_{ZF}) \quad (19)$$

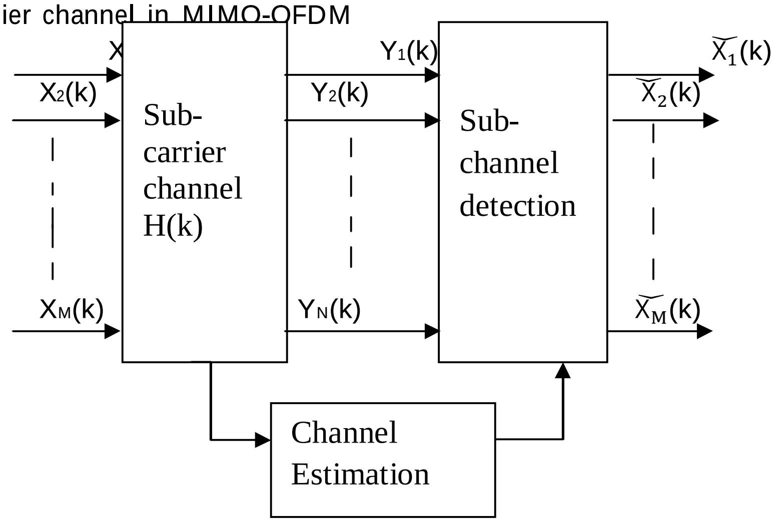

Figure 3:- Baseband block diagram of k subcarrier channel in MIMO-OFDM system

4. SIMULATION PARAMETER AND RESULTS

Table 1: - WiMAX Specifications

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PARAMETERS	VALUES
N_{FFT}	256
Nominal channel B.W.	2.5MHz.
No. of used sub-carriers	192
Sub carrier spacing (Δf)	11.2
Upper guard	28
Lower guard	27
N_{DC}	1(prefix 128)
$F_{S(\text{sampling frequency})}$	2.86MHz
T_b	89 micro sec.
$T_g = G.T_b$	Variable.
$T_{symbols} = T_b + T_g$	Variable.
Ratio guard time to symbol time(G)	Variable (1/4,1/8,1/16,132)

The WiMAX system is implemented according to the table 1 [10]. Then, the data output of the down link is transmitted using the alamouti space time coding using 2 transmitting antennas. At, the receiver side the input data is detected using the Zero Forcing Algorithm. The analysis is done on the basis of SNR vs BER graph for AWGN and Rayleigh channels.

In figure 4, SNR vs BER performance of QPSK modulation using ½ convolution code rate is shown in AWGN channel.

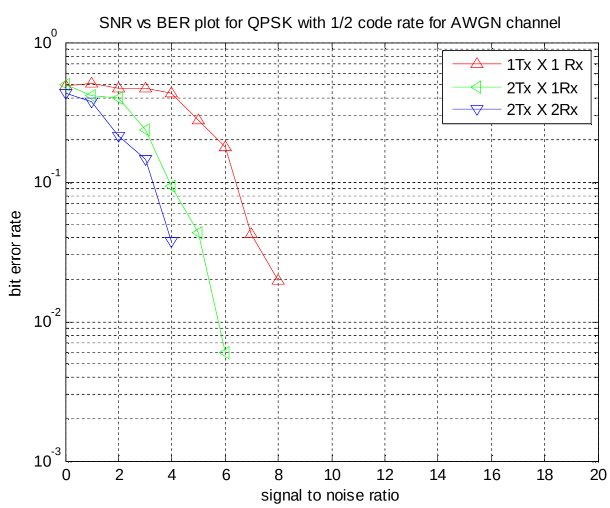

Figure 4:- SNR vs BER plot for QPSK with ½ code rate for AWGN channel employing MIMO-OFDM in WiMAX Physical Layer

In figure 5, the performance the analysis using same channel and same modulation is shown but, using different code rate for convolution coding i.e. 3/4.

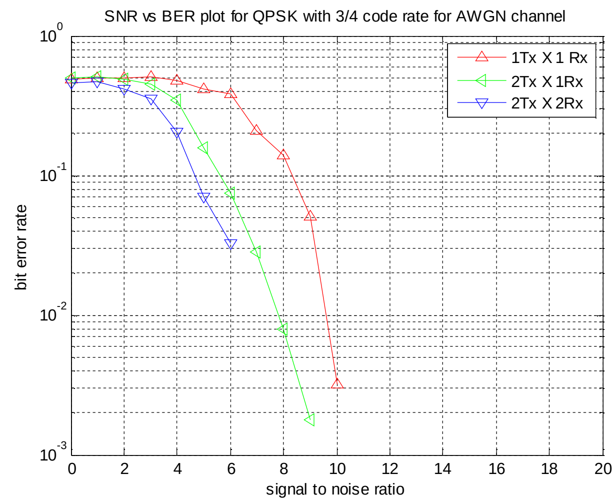

Figure 5:- SNR vs BER plot for QPSK with 3/4 code rate for AWGN channel employing MIMO-OFDM in WiMAX Physical Layer

In figure 6, SNR vs BER performance of QPSK modulation using ½ convolution code rate is shown in Rayleigh channel.

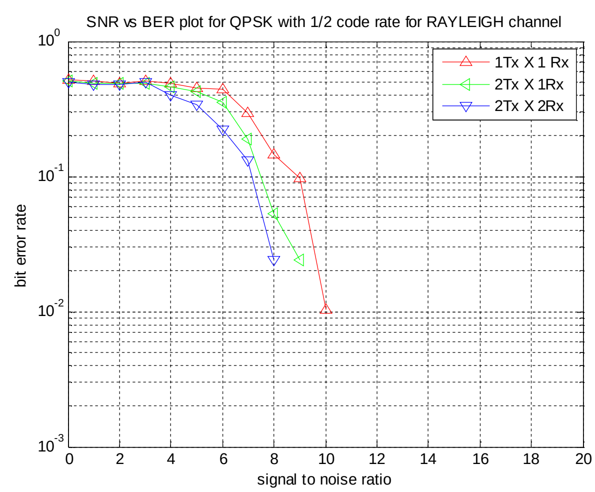

Figure 6:- SNR vs BER plot for QPSK with 1/2 code rate for Rayleigh channel employing MIMO-OFDM in WiMAX Physical Layer

In figure 7, the performance the analysis using same channel and same modulation is shown but, using different code rate for convolution coding i.e. 3/4.

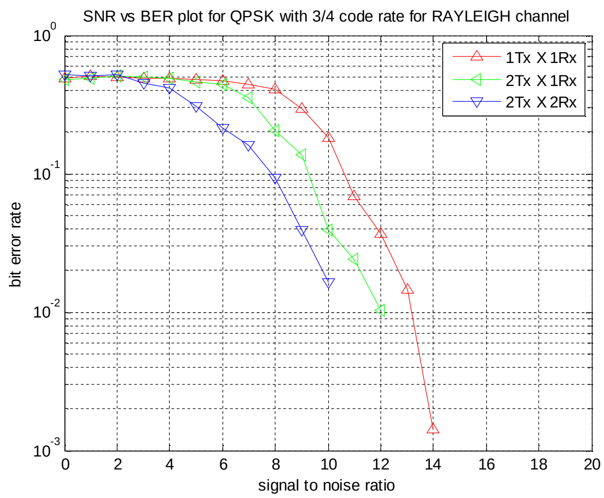

Figure 7:- SNR vs BER plot for QPSK with 3/4 code rate for Rayleigh channel employing MIMO-OFDM in WiMAX Physical Layer

5. CONCLUSION

In this paper effect of employing MIMO space time coding in 802.16e PHY layer has been simulated along with mathematical analysis. Both ideal (AWGN) and practical (Rayleigh) channels has been analyzed. Results have shown that in both cases as we goes on increasing the no. of transmitters or receiver the BER decreases. BER is higher for SISO system, but when we employ the MIMO in WiMAX the BER decreases proportionally with increase in number of antennas.

Also the BER is higher for the system employing 3/4 convolutional code as compared to the system employing 1/2 code rate.

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