Performance evaluation of MIMO based WiMAX system

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***Abstract*— In mobile communication system signals transmitted by a mobile station are reflected and scattered by the surrounding objects. Hence, the signals travel multiple paths, of different lengths and attenuations, before arriving at the base station. This phenomenon is well known as multipath propagation. Multipath propagation results in fading problem, which sets a bottleneck for achieving a very high data rate in Broadband Wireless Access (BWA) systems. Antenna diversity techniques have been proposed in the literatures to combat multipath fading problem. In this regard, Multiple-Input Multiple-Output (MIMO) techniques are considered to be essential for BWA systems like the IEEE 802.16e, which is popularly known as mobile WiMAX systems. Mobile WiMAX systems define the physical (PHY) layer and Medium Access Control (MAC) layer for mobile and portable BWA systems. In this paper, the performances of MIMO based WiMax system have been investigated. The simulation results presented in this paper show that the system performances, in terms of throughput and Bit Error Rate (BER), of WiMAX system can be improved significantly by using MIMO technique.**

***Index Terms*— diversity, MIMO, multipath,WiMAX**

I. Introduction

Worldwide Interoperability for Microwave Access (WiMAX) technology is considered as the most popular technology for achieving the “last mile” high speed data services. WiMAX is considered as one of the promising technologies that can ensure a very high bit rate services with wide area coverage. However, there are some issues of WiMax systems including power and spectral efficiency still need to be resolved. In 2004, the IEEE 802.16d standard [1] was published for Fixed Wireless Access (FWA) applications. In December 2005 the IEEE ratified the 802.16d standard and introduced IEEE 802.16e[2] to support Mobile Wireless Access (MWA) with seamless network coverage. This standard is now receiving a considerable industrial attention. The mobile WiMAX air interface adopts Scalable Orthogonal Frequency Division Multiple Access (SOFDMA) for improving system performance in Non-Line-of-Sight (NLoS) multipath environments. SOFDMA provides resource allocation flexibility. According to the 802.16e standard data is transmitted using a number of sub-channels, which can be varied and adaptively optimized to maximize system performance [3]. The mobile WiMAX system uses the wireless-MAN-OFDMA air interface. In essence, the principle of OFDMA consists of different users who share the Fast Fourier Transform (FFT) space. The architecture is based on a scalable sub-channelization structure with variable FFT sizes according to the channel bandwidth. With flexible channelization, each user may be assigned one or more sub-channels, and several users may transmit simultaneously in each time slot. Some of the advantages of OFDMA are (i) it has tolerant to multipath propagation, and (ii) it can perform well under frequency selective fading condition. The use of a Cyclic Prefix (CP) can completely eliminate Inter Symbol Interference (ISI) as long as its duration is longer than the maximum channel delay spread [4]. Initial profiles under the development in the WiMAX Forum Technical Working Group for release-1 specify bandwidths of 5 MHz and 10MHz, with an FFT size of 512 and 1024 respectively[5].

Multiple-Input Multiple-Output (MIMO) based wireless systems equipped with multiple antennas at both transmitting and receiving ends have promised enormous capacity gains [15]-[16] over Single-Input Single-Output (SISO) based wireless systems. Products on MIMO based wireless system are already in the market now [17]-[20]. However, it is hard to find MIMO techniques that can perform satisfactorily under all realistic propagation conditions. MIMO integration into real life wireless applications can be considered to be still in its infancy level. MIMO systems are considered suitable technology because they have the ability to exploit NLoS channels, and hence they can increase spectral efficiency compared to SISO systems. The advantages of MIMO system include diversity gains, multiplexing gains, interference suppression, and array gains. It is considered suitable for Mobile WiMAX because it supports a full range of smart antenna technologies, including Space Time Block Codes (STBC), Spatial Multiplexing (SM), and beamforming. MIMO is considered as a critical component in the future developments of mobile WiMAX. Suitable MIMO orientated link adaptation strategies are critical to exploit the wide range of MIMO systems and channel conditions [6]. For example, STBC offers diversity gain, but cannot improve capacity without the use of Adaptive Modulation and Coding (AMC). SM combined with higher order modulation schemes can

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increase the peak throughput, but such schemes require extremely high SNR levels [6]. The inclusion of MIMO technique alongside flexible sub-channelization and AMC enables mobile WiMAX technology to improve system coverage and capacity. Importantly, if correctly configured, these benefits will be achieved using power and spectrum efficient terminals. This paper focuses on the study of MIMO enabled mobile WiMAX. The rest of the paper is organized as follows: Section II introduces Alamouti space time block code for MIMO system. Spatial multiplexing has been explained in Section III. MIMO capacity analysis has been illustrated in Section IV. Simulation model and results have been described in Section V. This paper concludes with Section VI.

II. ALAMOUTI SPACE TIME BLOCK CODE FOR MIMO SYSTEM

The channel coding techniques used in wireless communication systems can be broadly classified as “block code” and “convolutional code”. A block code operates on a “block” of data at a time. In block code output only depends on the current input bits. On the other hand, in convolution codes, the output not only depends on the current input bits but also on the previous input bits. The convolution code may not produce the same output for a given input, because previous input is involved. The block code requires less power, to decode a block code, as compared to convolution code. In this investigation, a “block code” named Alamouti code has been used. The Alamouti code is also known as Space Time Block Code (STBC). The Alamouti coding is described by the following matrix-

$$\mathbf{Y} = \begin{bmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{bmatrix} \qquad \textbf{(1)}$$

where Y is the encoder output, X_1 and X_2 are the input symbols. The “*”denotes the complex conjugate.

Fig.1 shows the block diagram of the transmitter module in MIMO system based on the Alamouti code. The binary bits enter a modulator and are converted into “symbols”. These “symbols” are represented by complex numbers and they are fed into the Alamouti encoder. The Alamouti encoder maps the symbols onto the transmitter by using the above mentioned matrix defined by (1). In this matrix, the rows represent the transmit antennas, and columns represent the time. The elements of the matrix define the symbols that to be transmitted from a particular antenna. The Alamouti code works with a pairs of symbols at a time. It takes two time periods to transmit the two symbols [7].

The operation MIMO transmitter based on the Alamouti code can be described as follows: let us assume that (S_1, S_2) represents a group of two consecutive symbols to be transmitted. During the first symbol period t_1, transmit antenna one (Tx_1) transmits symbol S_1 and transmit antenna two (Tx_2) transmits symbol S_2

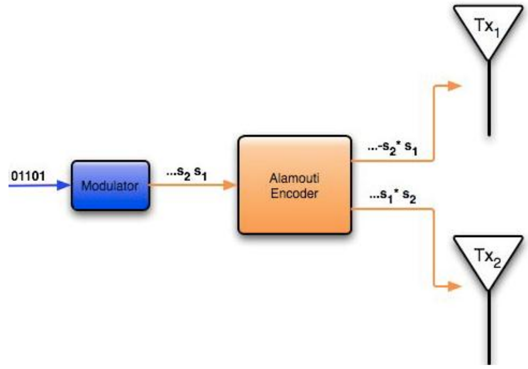

Fig.1. MIMO Transmitter (using Alamouti code).

During the second interval t_2, transmitting antenna one (Tx_1) transmits S_2^* and transmitting antenna two (Tx_2) transmits $-S_1^*$, where “*” denotes the complex conjugate. Denoting the channel response from the transmitting antenna one (Tx_1) to the receiver by h_1 and the same from the transmitting antenna two (Tx_2) to the receiver by h_2, the received signal samples at the two transmission instants are respectively given by [8]:

$$r_1 = h_1 S_1 + h_2 S_2 + n_1 \qquad \textbf{(2)}$$

$$r_2 = h_1 S_2^{\,*} h_2 S^*{}_1 + n_2 \qquad \textbf{(3)}$$

Here n_1 and n_2 represent complex noise/ interference in the received baseband signal affecting the two channels.

The receiver computes the quantities defined by

$$X_1 = h_1^* r_1 - h_2 r_2^* = (|h_1|^2 + |h_2|^2) S_1 + h_1 * n_1 - h_2 n_2^* \qquad \textbf{(4)}$$

$$X_2 = h_2^* r_1 - h_1 r_2^* = (|h_1|^2 + |h_2|^2) S_2 + h_2 * n_1 - h_1 n_2^* \qquad \textbf{(5)}$$

These two expressions clearly show that the symbols $S_1$and S_2 can be recovered from X_1 and X_2 without any interference. These expressions also represent a perfect second order diversity that equivalently represents the receiver diversity based on maximum ratio combining.

III. SPATIAL MULTIPLEXING AND MAXIMUM LIKELIHOOD DECISION RULE

The MIMO based system based on Alamouti code can be considered as a pure spatial multiplexing [9]-[10]. This type of spatial multiplexing doesn’t benefit any diversity gain on the transmitter side. But, it does offer a second order diversity gain on the receiver side by using maximum-likelihood (ML) detection. To simply the notations we omit the time and frequency dimensions leaving only the space dimension. The symbols transmitted in parallel by transmitting antenna one (Tx_1) and transmitting antenna two (Tx_2) are denoted by S_1 and S_2 respectively. Denoting the channel response from transmitter *i* to receiver *j* by h_{ij}, the signals received by the two receiver antennas are given by:

$$r_1 = h_{11}S_1 + h_{12}S_2 + n_1 \quad \textbf{(6)}$$
$$r_2 = h_{21}S_1 + h_{12}S_2 + n_2 \quad \textbf{7)}$$

These two equations can be combined and written in matrix form as

$$\begin{pmatrix} r_1 \\ r_2 \end{pmatrix} = \begin{pmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{pmatrix} \begin{pmatrix} S_1 \\ S_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \quad \textbf{(8)}$$

The ML detector makes an exhaustive search over all possible values of the transmitted symbols and decides in favor of (S_1, S_2) which minimizes the Euclidean distance defined as:

$$D(S_1, S_2) = \left\{ | r_1 - h_{11}S_1 - h_{12}S_2 |^2 + | r_2 - h_{21}S_1 - h_{22}S_2 |^2 \right\} \quad \textbf{(9)}$$

To investigate the advantages of using Alamoiti STBC we simulated a Binary Phase Shift Keying (BPSK) system under a Raleigh fading condition. We consider two cases namely (i) simple BPSK system with single transmitting and receiving antenna, and (ii) BPSK system with two transmitting antennas and one receiving antenna. To investigate the performance of the above mentioned two cases a number of simulations were conducted. In each simulation 25 and 10^6 bits/ symbols were transmitted. Fig.2 shows the variation of bit-error-rate (BER) of a BPSK system with the Signal-to-Noise Ratio (SNR). The SNR is expressed in dB. It is depicted in the figure that the performance of a BPSK system based on Alamouti STBC with two transmitting and one receiving antennas performs better in terms of BER compared with simple BPSK system with one transmitting and one receiving antenna.

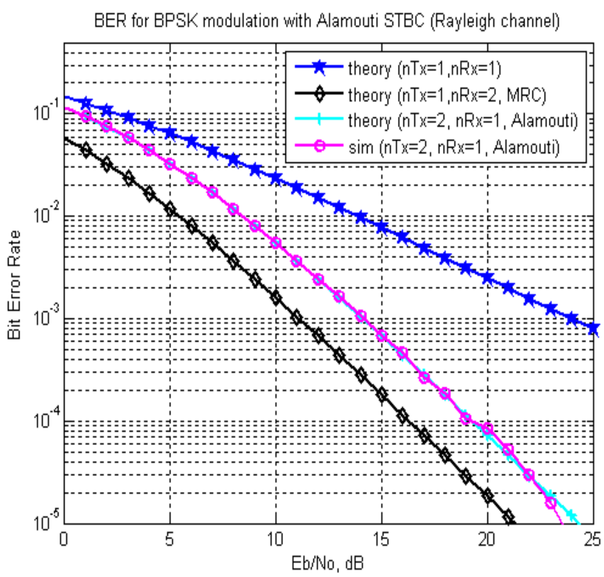

Fig.2. BER for BPSK Modulation using Alamouti and MRC Schemes.

The BER performance of the second case was much better than the first case because of the diversity gain. Here the effective channel concatenating the information from two receiving antennas over two symbols results in a diversity order of 4. Since the estimate of the transmitted symbol with the Alamouti STBC scheme is identical to that obtained from Maximal Ratio Combiner (MRC), the BER with Alamouti STBC scheme should be same as that for MRC. With Alamouti STBC, the symbols are transmitted by two antennas, hence the total transmit power in the Alamouti scheme is twice as that used in MRC. To make the comparison fair, we need to make the total transmit power from two antennas in STBC case to be equal to that of power transmitted from a single antenna in the MRC case. With this scaling, it is depicted that BER performance of two transmitting antennas and one receiving antenna Alamouti STBC case has roughly 3dB power performance compared to that of one transmitting antenna and two receiving antenna case. The above simulations and results suggest a practical approach of using multiple antennas at the base station and single receiving antenna at mobile stations.

The BER results in the previous figure suggest that the MIMO option to be used is a function of a channel SNR and throughput required. In SISO systems, the throughput is optimized through link adaptation, which selects a signal constellation and code rate as the function of the channel. This concept called Adaptive Modulation and Coding (AMC), and must be extended to the space dimension in multi-antenna systems to make the best use of available MIMO option .

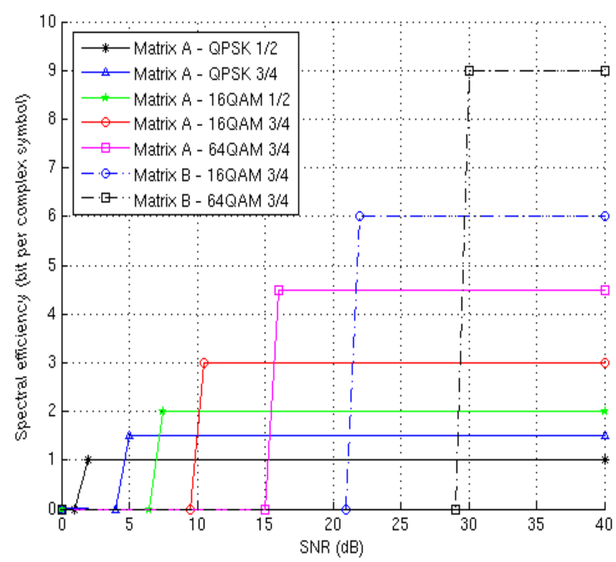

Fig. 3. Extension of AMC to MIMO system.

The basic idea of AMC is to dynamically adapt the modulation and coding scheme to the channel conditions so as to achieve the highest spectral efficiency at all times. It changes the coding scheme and/or modulation method depending on channel-state information. The system data throughput can be increased by using high level (AMC) and MIMO.

IV. MIMO CAPACITY ANALYSIS

The basic objective of MIMO communication system is to achieve a high capacity. The MIMO systems provide tremendous capacity gains, which has spurred significant activity to develop transmitting and receiving techniques that realize these capacity benefits and exploit diversity. This paper also presents the Shannon capacity limits of single and multi user MIMO system [11]-[12] as shown in Figure 4.

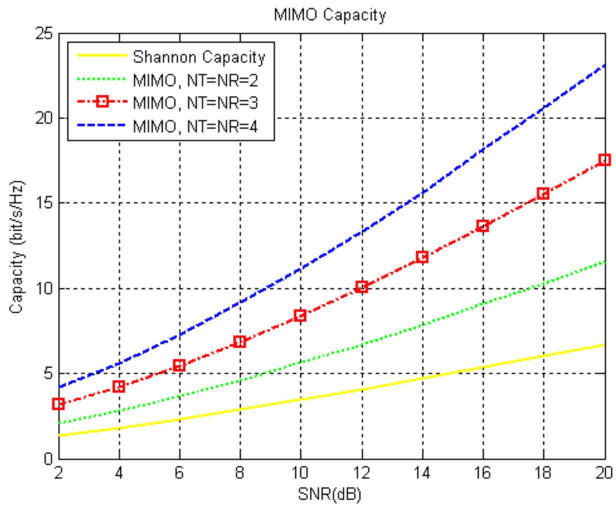

Fig. 4. Capacity of MIMO system compared with Shannon capacity.

The limit of single and multi user MIMO systems show the maximum data rates that can be transmitted over the MIMO channel. The channels have small error probability and assuming no constraint on the delay. MIMO system transmits two or more data streams in the same channel. The data streams are sent at the same time. MIMO system is also used to design a high capacity system by using *N* transmitting antennas and M receiving antennas [13]. MIMO system consists of multiple transmitting and receiving antennas interconnected with multiple transmission paths. It increases the capacity of system by utilizing multiple antennas both at transmitter and receiver without increasing the bandwidth.

V. SYSTEM MODEL AND SIMULATIONS RESULTS

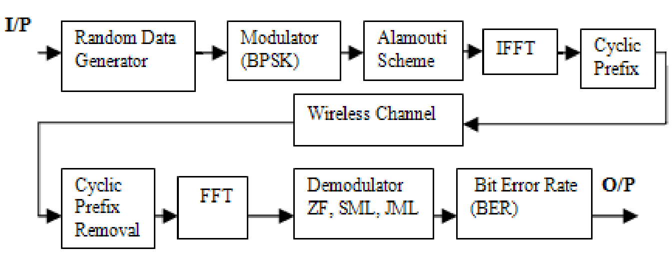

Fig.5. Block Diagram (System Model)

The system model that has been used to investigate the performance of BER of BPSK in OFDM–SFBC WiMAX system over the Rayleigh fading channel is shown in Figure 6. In this model, 128 sub carriers of OFDM have been taken along with 12 multipath links. The sampling frequency is considered to be 800,000 samples/sec. The simulations were conducted by changing the decoding algorithms. Four famous decoding algorithms namely conventional simple maximum likelihood, joint maximum likelihood, decision feedback diction and zero forcing equalizer have been investigated in this paper.

Since the complexity of the ML detector grows quadratically with the size of the signal constellation, we were motivated to use simpler practically realizable suboptimum receivers. Zero forcing (ZF) receivers invert the channel matrix. These receivers ignore the additive noise. Joint Maximum Likelihood (JML) improves the estimation performance of channel gains and multipath delays compared with traditional maximum likelihood estimator. Decision feedback receivers make a decision on one of the symbols and subtract its interference on the other symbol based on that decision. Sphere detectors reduce the number of symbol values used in the ML detector.

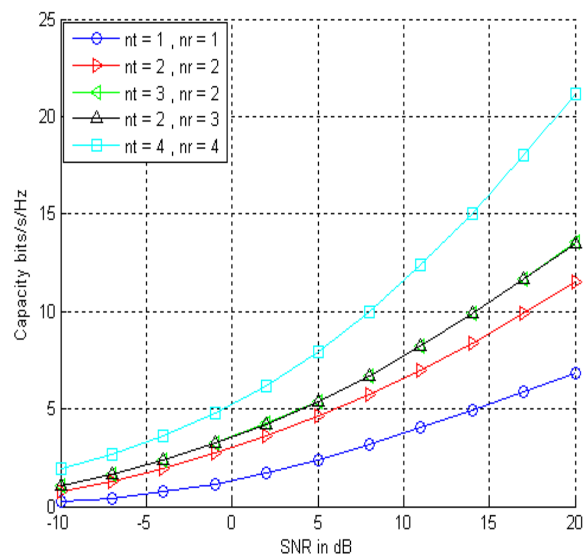

Fig.6. Capacity of a MIMO channel with nt transmitting antenna and nr receiving antenna.

The capacity analysis of the system having multiple transmitting and receiving antennas has been shown in Fig. 6. The capacity of the MIMO system has been plotted against SNR (expressed in dB). This provides a fundamental limit in the data throughput in MIMO systems. It is also depicted that with the increase in the number of antennas at the both sides, the capacity increases linearly i.e. with *nt*=4 and *nr*=4, we have achieved highest capacity in MIMO systems. It is also worth to mention that when *nt*=2 and *nr*=3, the result is same with *nt*=3 and *nr*=2, which shows that the increasing the number of

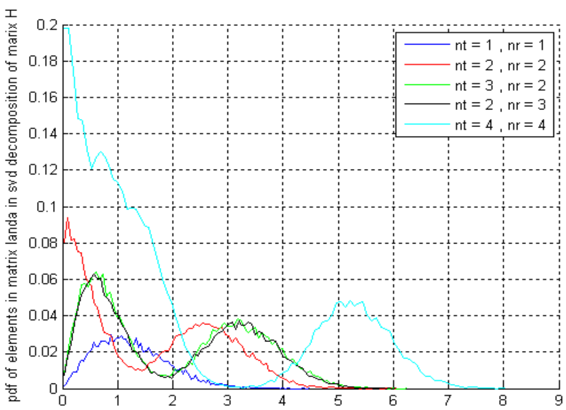

Fig. 7. PDF of a Matrix lanada elements .

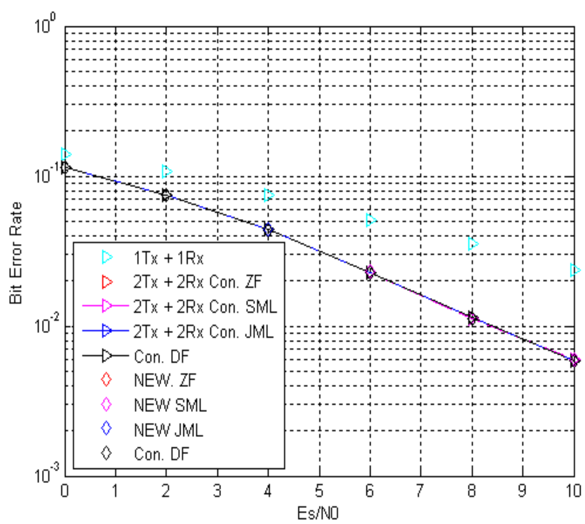

Fig. 8.BER performance in BPSK-OFDM-SFBC system.

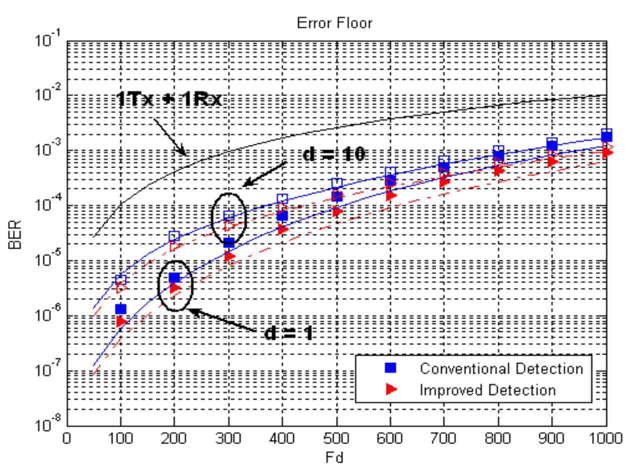

Fig. 9. Error Floor in conventional and improved detection.

antennas at either side of the MIMO system will have same effect in rising the capacity. The optimal power allocation scheme is also known as water filling algorithm [14]. The power in parallel channel (after decomposition) is distributed as water-filling algorithm. The PDF of the matrix lanada elements is depicted in Figure 7.

The BER performance of BPSK SFBC-OFDM [20] system has been depicted in Figure 8. The performance comparison has been done in two cases with one transmitting antenna and one receiving antenna, and two transmitting antenna and one receiving antenna. It is clear that with an increase from one to two antennas at the transmitting side the BER performance is improved. It can also be concluded that with the increase in SNR the performance gain of two antennas is increased. Also It is also depicted that by using conventional ZF, SML, DF and JML decoding algorithms BER performance is increased significantly in the high SNR regime.

The error floor [21] between the conventional and improved detection is also shown in the Fig. 9. In SFBC (OFDM) the receiver experiences both the inter-symbol interference (ISI) as well as Inter-Carrier Interference (ICI) [22]. In SFBC (OFDM) with .highly selective frequency channel the 'quasi-static' (QS) assumption violation becomes a source of significant Inter-Symbol Interference (ISI) in the frequency dimension. If left uncared for, this results in error floors. Further, in any OFDM system, the orthogonality among subcarriers is lost if the channel changes within an OFDM symbol duration, which results in inter-carrier interference (ICI). Thus, in addition to the issue of ISI caused due to frequency-selectivity of the channel, SFBC(OFDM) experiences ICI caused due to time-selectivity of the channel (i.e., channel varying within one OFDM symbol duration) [23]. Like ISI, ICI, if uncared for, also will result in error floors.

VI. Conclusions

This paper shows that the overall performance WiMAX sytem can be improved if MIMO is used. It has been shown that STBC offers diversity gain and it can be used to increase system coverage. When combined with AMC, the spectrum efficiency was seen to improve relative to the SISO case. Furthermore, the results showed 2-by-2 STBC should be considered. The results clearly showed that even the combined exploitation of MIMO, OFDMA and AMC could not achieve satisfactory performance. The preliminary results showed that in combination with MIMO-STBC (2-by-1 and 2-by-2), could achieve near ideal coverage in a mobile WiMAX system. From the simulation results, it is shown that theoretical and simulation result matches closely with each other. Moreover the results of MIMO capacity shows that an increase in the number of antennas at the both transmitting side and receiving side capacity increases linearly. With two transmitting and one receiving antenna and applying conventional ZF, SML, and JML decoding algorithm, the diversity of two antennas improved at lower SNR.

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