Performance Analysis of MIMO OFDM Systems for Wireless Communication using Adaptive Modulation Technique

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Abstract: ***In the present scenario, with the growing demand for wireless communication in today's life, along with the rapid growth of digital communication technology, new innovative ideas are coming into existence which needs to be implemented. The main need of any communication system is basically high speeds of data transmission with higher accuracy and reliability. Multiple input multiple output (MIMO) provides high-rate transmission through expended channels by multiple array antennas on both sender and receiver side. Also orthogonal frequency division multiplexing (OFDM) is well-known as the most appropriate technique for high data rate transmission. Adaptive modulation and coding (AMC) changes a modulation order and coding rate according to channel conditions, so it is possible that the spectral efficiency is improved at the fixed error performance. Cyclic prefix (CP) is one of the most important technique in OFDM system and is reducing inter-symbol interference (ISI) effects in high speed wireless mobile communication system. In this paper, a model of MIMO-OFDM system with AMC stated to improve system capacity by reducing error rate has been proposed.***

Keywords: MIMO, OFDM, AMC, QAM, ISI

1. Introduction

Today, communication has become an integral part of our lives and the past 10 years witnessed various innovations in the mobile telephony. The demand for data services also increased. Also, the frequency spectrum available is limited.On the other hand, single carrier transmission is used for communication. In single carrier communication information carrier is a single radio frequency (RF) carrier which carries information in the form of bits. This cannot provide the required high data rate transmission channel.

Normally, for communication one pair of transmitting and receiving antenna called as single input single output (SISO) is used. It cannot serve for high data rate services because of single antenna at both ends of the link. To mitigate this, MIMO system is used. In MIMO, array of multiple antenna‟s are used at both ends, which operates at same frequency and at the same time. OFDM is a technique which sends multiple subcarriers of the same signal at the same time over the same channel by maintaining orthogonality between each subcarrier. The capacity of the channel can be increased using MIMO-OFDM [15] by availing extra spatial channels which increase spectral efficiency.

Along with the advantages offered by OFDM, there are some disadvantages of likesensitivity to carrier frequency offset, large Peak to Average Power Ratio (PAPR) and fixed modulation scheme. These disadvantages lead to poor BER which can be improved by using adaptive modulation.

On the basis of the value of SNR desired, different QAM techniques are applied to the OFDM system which enhances the BER performance of the OFDM. This improves the system efficiency and reliability. Maximum throughput can be achieved by combining MIMO and OFDM, combination of these two techniques compliments each other for improving system performance.

2. OFDM system

OFDM is a multicarrier communication technique in which the signal is divided into several parallel bit streams before transmission. All the subcarriers are transmitted over the channel at the lower bit rate than the original data rate of the signal.This is achieved by modulating the subcarriers at lower bit rate. Because of the simple and flexible architecture of OFDM, it is used in several wired and wireless applications. Some examples of OFDM applications are Digital Audio broadcasting (DAB),High Rate Digital Subscribers Line (HDSL), and very high rate digital subscriber line (VHDSL) systems, which operate over twisted pair channels. In multi-tone modulation single wideband signal is replaced with several narrowband signals transmitted simultaneously with the same overall bandwidth as the original signal. In principle, the two schemes are equivalent to an AWGN channel. For implementation of OFDM in discrete time, at transmitter inverse fast Fourier transform (IFFT) is used and at receiver fast Fourier transform (FFT) is used. Symbol duration of OFDM symbol is less than or equal to maximum delay spread. Guard intervals are inserted between OFDM symbols to reduce the ISI. Figure 1 below shows the basic block diagram of an OFDM system.

2.1 Inverse Fast Fourier Transform (IFFT)

It converts the input data which is in frequency domain to time domain, because the channel is in time domain. Samples generated by IFFT blocks are orthogonal to each other, meaning no interference occurs between the subcarriers. The mathematical model of OFDM symbol defined by IFFT which would be transmitted duringthe simulation is given bellow:

$$x(i,n) = IFFT_N[X(i,k)] = \frac{1}{N}\sum_{k=0}^{N-1} X(i,k)e^{\frac{j2\pi nk}{N}} \qquad (1)$$

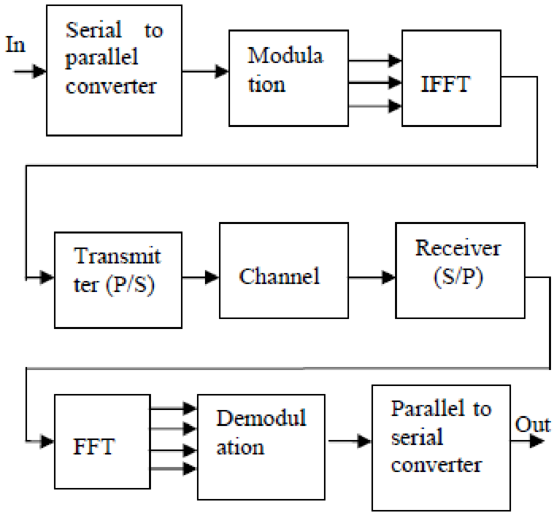

Figure 1: Basic OFDM system

where $X(i,k)$ is the transmitted data symbol at the k^{th} subcarrier of the i^{th} OFDM symbol, N is the FFT size. Similarly FFT converts signal from time domain to frequency domain because OFDM system works in frequency domain [2]. By calculating the outputs and simultaneously taking advantage of the cyclic properties of the multipliers FFT technique reduce the number of computations to the order of N log(N). The FFT is most efficient when N is a power of two[3].

2.2 Guard Time / Cyclic Prefix (CP)

When signal travels through multipath fading channel the subcarriers may lose orthogonality and interfere with each other. Cyclic prefix (CP) or guard time are techniques to reduce the effect of ISI and inter carrier interference (ICI) introduced by the multipath channel. By increasing the symbol period with help of Guard interval OFDM signal becomes more robust to the multipath delay spread effect. As shown in figure 2 this guard time is actually a copy of the last portion of the OFDM data symbol which is known as the cyclic prefix (CP). Cyclic prefix is attached at the front of transmitted symbol. The length of the CP (Tg) must be chosen longer than the maximum delay spread of the multipath environment.

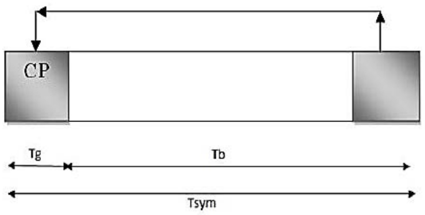

Figure 2: Cyclic prefix in OFDM.

Thus, the total length of the OFDM symbol is:

$$T_{sym} = T_b + T_g \quad (2)$$

where, Tb is the useful symbol period, and Tg represents the guard time. A parameterG is defined as the ratio of the CP length to the useful symbol time and is given by:

$$G = T_g \,/\, T_b \quad (3)$$

G should be as small as possible since it costs energy to the transmitter [10].

3. Multiple input multiple output (MIMO)

Traditionally, SISO systems are used in wireless communication systems. The disadvantage of SISO systems is that the capacity cannot be increased unless more spectrum or transmit power is used.

The capacity of MIMO system increases linearly with the number of transmit-receive antennas.

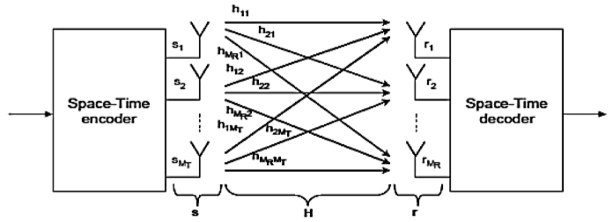

Figure 3: MIMO system

The basic purpose of using MIMO antenna system is to increase the received signal to noise ratio by making use of random fading channel coefficients as channel gain [12].

$$\gamma = \sum_{i=1}^{N} \sum_{j=1}^{M} \left| h_{ij} \right|^2 \frac{\varepsilon_x}{\sigma^2 N} \quad (4)$$

Where: γ – received signal to noise ratio,
N – Number of transmitting antennas,
M – Number of receiving antennas,
ε_x – Transmitted power,
σ^2 – Noise variance.

MIMO system can be employed with full potential for increasing the multipath channel capacity between transmitter and receiver for transmission of parallel multi-channel data independently. This in turn increases spectral efficiency of the channel. MIMO can reduce the multipath fading effect but for frequency selective deep fading channel it doesn‟t work. Hence solution to this problem is to use combination of MIMO-OFDM as shown in figure 4.

Combination of MIMO-OFDM meets the requirement of high data rate and high performance channel over time-selective and frequency selective channel conditions [6].The MIMO-OFDM wireless communication system can be based on various transmit (Tx) and receive (Rx) antenna combinations such as 2×1, 2×2, 3×2, 4×2. These systems can support 64, 128, 256 and 512 point FFT transform along with Rayleigh fading channel and QPSK, M-QAM etc modulation techniques.

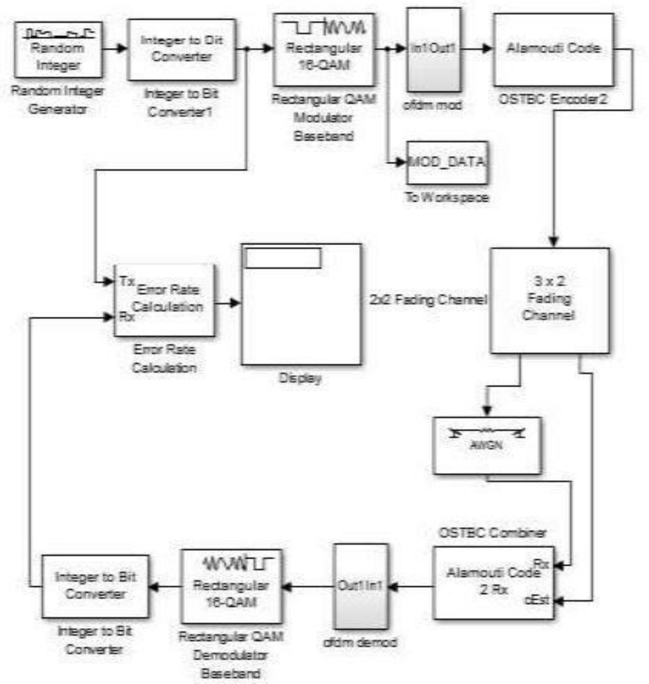

Figure 4: MIMO-OFDM system model

3.1 Space-Time Block Codes

Space-Time Block Codes (STBC)[14] are the simplest types of spatial temporal codes that exploit the diversity offered in systems with several transmit antennas. The transmit diversity technique proposed by Alamouti was the first STBC [7]. The encoding and decoding operation is carried out in sets of two modulated symbols. Therefore, here they are denoted by S_1 and S_2 the two modulated symbols that enter the space-time encoder. In the Alamouti[8-11]scheme, during the first time instance t_1, the symbols S_1 and S_2 are transmitted by the first and the second antenna elements respectively. During the second time instancet_1, the negative of the conjugate of the second symbol, i. e. -$S_1{}^*$ is sent to the first antenna while the conjugate of the first constellation point. i.e.$S_2{}^*$ is transmitted from the second antenna. The transmission rate is equal to the transmission rate of a SISO system.

The space-time encoding mapping of Alamouti 2x2 can be represented by the coding matrix:

$$S = \begin{bmatrix} S_1 & -S_2{}^* \\ S_2 & S_1{}^* \end{bmatrix} \quad (5)$$

The received signals at the time t and t + T can then be expressed as:

$$\begin{aligned} r_1 &= r_1(t) = h_{11}s_1 + h_{21}s_2 + n_1 \\ r_2 &= r_1(t+T) = -h_{11}s_2{}^* + h_{21}s_2{}^* + n_2 \\ r_3 &= r_2(t) = h_{12}s_1 + h_{22}s_2 + n_3 \\ r_4 &= r_2(t+T) = -h_{12}s_2{}^* + h_{22}s_2{}^* + n_4 \end{aligned} \quad (6)$$

Where $r_1, r_3$are the received signals at time t and r_1, r_4 are the received signals at time t + T, $n_1, n_{2,} n_3$ andn_4 are complex random variables representing receiver noise and interference.

This can be written in matrix form as:

$$r = HS + n \quad (7)$$

Where H is the complex channel vector and n is the noise vector at the receiver:

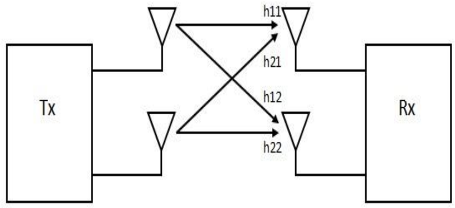

Figure 5: MIMO channel model (2x2)

3.2 Spatial Multiplexing

In spatial multiplexing, a signal is divided into different streams and each stream is transmitted from a different transmit antenna in the same frequency channel. If these signals arrive at the receiver antenna array with sufficiently different spatial signatures, and the receiver has accurate channel state information (CSI) then it can separate these streams into parallel channels. Spatial multiplexing is very powerful technique for increasing channel capacity at higher Signal to Noise Ratio (SNR). It can be used with or without transmit channel knowledge. Consider that the transmission sequence is S_1,S_2,…..,S_n.For 2 transmit antenna the symbols are paired and in the first time slot, S_1 and S_2 from the first and second antenna is sent. Similarly, in the second time slot S_3 and S_4 from the first and second antenna are sent. It can be noticed that grouping two symbols and sending them in one time slot, needs only n /2 time slots to complete the transmission, so data is doubled.The Vertical-Bell Laboratories Layered Space-Time (V-BLAST) transmission for 2 x 2 MIMO systems can be represented in matrix notation as follows:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \quad (8)$$

Where, r_1, r_2 are the received symbol on the first and second antenna respectively, h_{ij} is the channel from i^{th} transmit antenna to j^{th} receive antenna,S_1,S_2 are the transmitted symbols that use first and second constellation mapped respectively and $n_{1,}n_2$is the noise on $1^{th}, 2^{nd}$ receive antennas.

4. Adaptive Modulation Algorithm

The following figure shows instantaneous SNR of received symbol for fixed MQAM techniques. It shows that when fixed 64QAM is applied to system the instantaneous SNR is less than 0.2 dB. Similarly when fixed 32QAM is applied to system the instantaneous SNR is in the range 0.2dB to 0.5dB[13]. Also for 16QAMinstantaneous SNR is in the range 0.5dB to 0.75dB and for 4QAM instantaneous SNR is in the range 1.1dB to 1.75dB. For fixed 2QAM, system response shows that, instantaneous SNR is more than 1.75dB. Hence, it is clear that for higher modulation instantaneous SNR is less as compare to lower modulation and therefore 64QAM is utilized when instantaneous SNR is greater than 1.75dB.Hence, from these instantaneous SNR values switching threshold are made for adaptive modulation as shown in Table 1. When instantaneous SNR is good then higher modulation scheme is applied and vice versa.

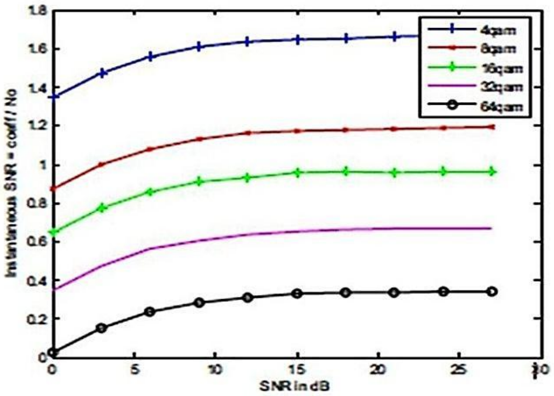

Figure 6: Instantaneous SNR of fixed modulation

The switching threshold for activating different modulations can be determined by extensive simulation of the fixed modulation system. The switching thresholdsused for the adaptive modulation is presented in Table 1.

Table 1: Switching threshold for fixed modulation

Threshold	*Modulation*
1.75dB≤SNR	64QAM
1.1dB≤SNR<1.75dB	32QAM
0.75dB≤SNR<1.1dB	16QAM
0.5dB≤SNR<0.75dB	8QAM
SNR<0.2dB	2QAM

5. Simulation Results

The switching threshold for activating different modulations can be determined by extensive simulation of the fixed modulation system. The switching thresholds used for the adaptive modulation is presented in Table 2.

Table 2: Switching threshold for adaptive modulation

Threshold	*Modulation*
4dB<SNR≤4.5dB	4QAM
4.5dB<SNR≤5.75dB	8QAM
5.75dB<SNR≤6.5dB	16QAM
6.5dB<SNR≤7.5dB	32QAM
7.5dB<SNR≤8dB	64QAM

Simulation results for BER of SISO-OFDM and Adaptive MIMO-OFDM (AMIMO-OFDM)for4-QAM, 16-QAM and 64-QAM are given as:

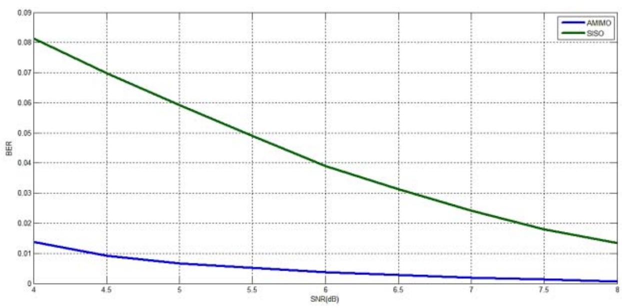

Figure 7: BER Comparison for SISO-OFDM andAMIMO-OFDM with (Nt=Nr=2) 4 ary QAM

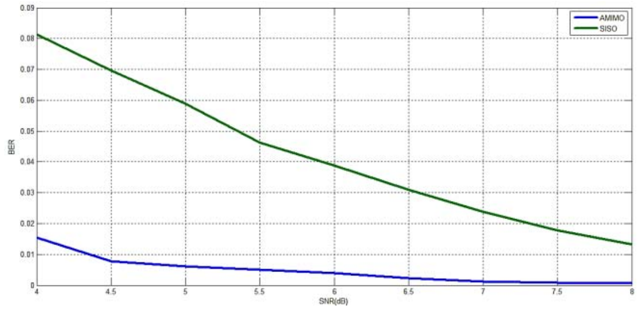

Figure 8: BER Comparision for SISO-OFDM and AMIMO-OFDM with (Nt=Nr=2) 16 ary QAM

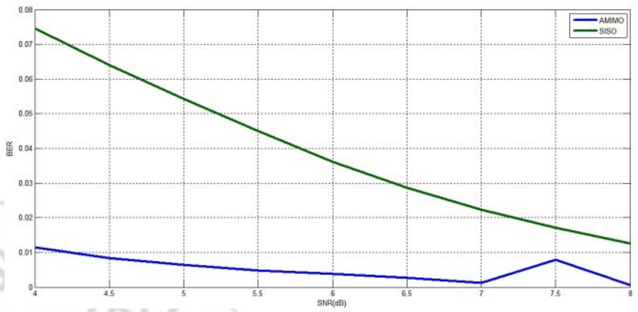

Figure 9: BER Comparision for SISO-OFDM, AMIMO-OFDM with (Nt=Nr=2) 64 ary QAM

6. Conclusion

Performance of both SISO-OFDM and AMIMO-OFDM is described in this paper. It can be observed from figure 7, 8 and 9, as the SNR value of signal increase BER decreases. BER of MIMO-OFDM systems is very much less than that of SISO-OFDM system. As in SISO system only one signal is transmitted, if that signal fades too much then data from that signal will be lost. While in MIMO system multiple copies of signal are transmitted, so if one signal fades too much then another signal data will be used. So the average SNR value is calculated and that value is used for further transmission. To avoid average value of SNR, adaptive modulation is used.Adaptive modulation when used with MIMO-OFDM system it gives better performance than both MIMO and SISO systems.

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