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On the Spectral Efficiency of MIMO MC-CDMA System

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ABSTRACT

The next generation wireless communication systems demand for high data rate, high capacity and high spectral efficiency for multimedia traffic. To full-fill these requirements Multiple Input Multiple Output Multi-Carrier Code Division Multiple Access (MIMO MC-CDMA) system is a suitable option for future wireless communication systems. As MIMO technique offers high data rate without bandwidth extension and small error rate. However, MC-CDMA provides high capacity and high spectral efficiency. Spectral efficiency planning is one of the major issues in designing of wireless communication systems, owing to the inadequate radio spectrum. This study investigates spectral efficiency of MC-CDMA system and MIMO MC-CDMA system for QAM modulation techniques. The results show that spectral efficiency of MIMO MC-CDMA system is better than the MC-CDMA system. Also the relative study of spectral efficiency of MIMO MC-CDMA for different order of QAM modulation techniques shows that each order of QAM modulation is optimal with in a specific range of SNR.

Keywords: MIMO, MC-CDMA, QAM, BER

I. INTRODUCTION

Upcoming wireless communication systems essentially require high capacity, high spectral efficiency and high data rate transmission to transport multimedia traffic. To achieve these goals Multiple Input Multiple Output Multi-Carrier Code Division Multiple Access (MIMO MC-CDMA) system is a promising choice for future wireless communication systems. As MIMO technique offers high data rate without bandwidth extension and small error rate [1, 2]. However, MC-CDMA provides high spectral efficiency [3]. MIMO and MC-CDMA techniques bring together to get the advantages of both the techniques [4]. Thus MIMO MC-CDMA is a combining technique, which can full-fill the requirement of next generation wireless communication system. The spectral efficiency planning of wireless communication systems in limited bandwidth, is big challenging issue owing to the, fast growth of wireless communication services and enormous growth of mobile users. Spectral efficiency of MC-CDMA system over Rayleigh fading channel is presented in [5]. In [4] MIMO channel capacities of OFDM and MC-CDMA in cellular environment with consideration of inter-code interference and co-channel interference have been proposed. Adaptive modulation and MIMO coding is introduced in [6]. In which it is shown that spectrum efficiency of wireless system is improved by using link adaptation techniques.

This paper investigates the spectral efficiency of MC-CDMA and MIMO MC-CDMA system. MIMO MC-CDMA scheme is more the spectral efficient than the MC-CDMA system. This work also analyzes spectral efficiency of MIMO MC-CDMA system for different number of receiving antennas and different number of users.

The rest of the paper is organized as follows: Section 2 describes MIMO MC-CDMA systems. Simulation results are shown in section 3. Finally, section 4 concludes the paper.

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II. MIMO MC-CDMA SYSTEM

In section *2.1* and *2.2,* MIMO MC-CDMA transmitter and receiver are described for downlink wireless communication system. Spectral efficiency of MIMO MC-CDMA system is represented in Section *2.3*.

2.1. MIMO MC-CDMA Transmitter

MIMO MC-CDMA transmitter for synchronous downlink is shown in Fig-1. Randomly generated *K* users data are independently encoded, modulated and then spreaded by *Walsh Hadamard (W-H)* code. Superposition is performed on spreaded data. The resultant spreaded data are modulated by multicarrier modulation. The continuous-time baseband signal after multicarrier modulation is given as;

$$x(t) = \sum_{i=1}^{I} \sum_{k=1}^{K} a_k \quad b_k(i) \quad s_k(t - iT_s) \tag{1}$$

where, k is the number of the active user, i is the number of the information symbol, a_k is the amplitude of *kth* user, $b_k(i)$ is the *ith* binary data sequence of *kth* user, s_k is the spreading sequence of *kth* user. Data of user k is $\mathbf{b}_k = [b_k(1), b_k(2), \ldots\ldots b_k(I)]$, spreading sequence is $\mathbf{S} = [\mathbf{s_1}, \mathbf{s_2}, \ldots\ldots \mathbf{s_k}]$ and $\mathbf{s_k} = [s_{k,1}, s_{k,2} \ldots\ldots s_{k,L}]$ where L is the spreading sequence length [7]. The spreaded, user's complex valued signal is given by $\mathbf{z}_k = \mathbf{b}_k\mathbf{s}_k$ [8]. After superposition, the resultant complex valued signal is given by $\mathbf{z} = z_1 + z_2 + \ldots z_k$.

$$\mathbf{z} = \sum_{k=1}^{K} z_k = \sum_{k=1}^{K} b_k s_k \tag{2}$$

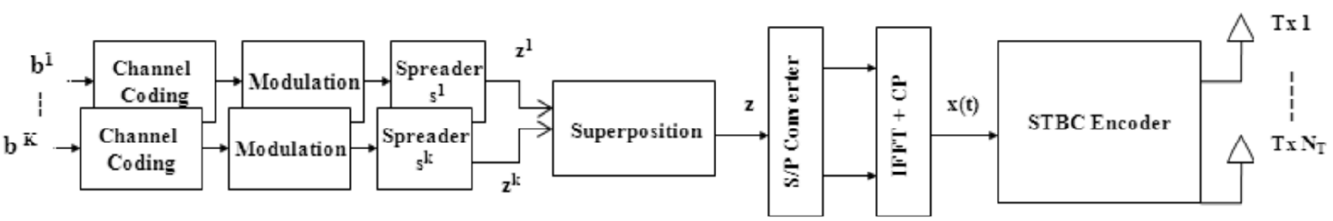

Figure 1: MIMO MC-CDMA Transmitter

The multicarrier modulated signal is encoded by Space Time Block Code (STBC) based on Alamouti scheme. STBC encoder, encoded multicarrier modulated symbols into groups of two symbols each. At a given time slot, from each group two symbols are transmitted concurrently from the two antennas. The encoded pattern of antenna one is g_1 and of antenna two is g_2, which is given as;

$$\begin{aligned} g_1 &= x_1(t = \tau_1); -x_2^* \quad (t = \tau_2) \\ g_2 &= x_2(t = \tau_1); -x_1^* \quad (t = \tau_2) \end{aligned} \tag{3}$$

where, * denotes complex conjugate operation and t is the time slot. Two time slot $Ä_1$ and $Ä_2$ are required to transmit two symbols. From antenna one at time slot τ_1 symbol x_1 and at time slot τ_2 symbol $-x_2^*$ are transmitted and from antenna two at time slot τ_1 symbol x_2 and at time slot τ_2 symbol x_1^* are transmitted [2].

2.2. MIMO MC-CDMA Rceiver

The MIMO MC-CDMA receiver is shown in Fig-2. The received signal at *pth* receiving antenna is given by

$$y_p(t) = \sum_{i=1}^{I} \sum_{q=1}^{N_T} \sum_{k=1}^{K} \beta_{q,p} a_k b_k(i) s_k(t - iT_s) + \eta_p(t) \tag{4}$$

where, $\eta_p(t)$ is the Additive White Gaussian Noise (AWGN) at *pth* receiving antenna with psd of $N_0/2$, $\eta_{q,p}$ is the channel coefficient between *qth* transmitting antenna and *pth* receiving antenna. Zero Forcing detection is used for STBC decoder. The decoded output is multicarrier demodulated and then de-spreaded. The de-spreaded output is demodulated and decoded to get the transmitted data.

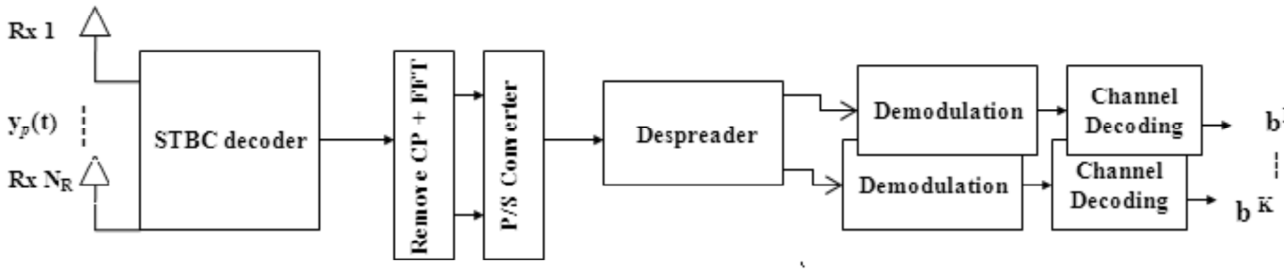

Figure 2: MIMO MC-CDMA Receiver

III. SPECTRAL EFFICIENCY IN MIMO MC-CDMA SYSTEM

The spectral efficiency is presented in numerous ways in the literature. The spectral efficiency of a channel is a measure of the number of bits per second per Hz. In this work, spectral efficiency is obtained for different order of QAM modulation technique, which is a function of short term SNR. To obtain spectral efficiency, maximum data rate and bit error rate are determined corresponding to each order of modulation technique. The spectral efficiency with channel coding is given as [6, 9]

$$\eta_s = (1 - P_e)^l k_b r \tag{5}$$

where, P_e is the bit error rate, l is the number of bits in the block, k_b *is* the number of bits per symbol and r is the overall coding rate. The spectral efficiency without channel coding is given as

$$\eta_s = (1 - P_e)^l k_b \tag{6}$$

IV. RESULTS AND DISCUSSIONS

Proposed design of MIMO MC-CDMA transmitter and receiver as described in section 2 has been simulated. For modulation, *QAM* is used, *Walsh-Hadamard* code is used for spreading the user data, spreading code length is L, number of subcarrier Nc is equal to the spreading code length, N_T and N_R are transmitting and receiving antenna, K is total number of active users and cyclic prefix is taken as ¼.

In Fig-3 comparison is shown among the MIMO MC-CDMA system and MC-CDMA system. From the results it is observed that MIMO MC-CDMA system has better spectral efficiency than the MC-CDMA system. At 10 dB SNR, spectral efficiency for MIMO MC-CDMA system is 2.496 bps/Hz and for MC-CDMA system, 0.3546 bps/Hz. This is due to the fact that with MIMO technique, diversity gain increase which reduces bit error rate. Thus spectral efficiency of MIMO MC-CDMA system is improved.

In Fig-4 a comparison of spectral efficiency is made among the different modulation techniques for the MIMO MC-CDMA system with Reed Solomon and convolutional channel coding. The channel coding rate is taken as1/2, and 3/4.

Spreading code length L is 16, numbers of active users K are 16 and coding rates for *16QAM* are taken as 1/2 and 3/4 and for 64QAM is 1/2. Each modulation technique has better spectral efficiency at different value of SNR. SNR is between 5dB to 11.3dB, 16QAM with coding rate 1/2 has better, between 11.3dB to 16.5dB, 16QAM with coding rate 3/4 has better and greater than 16.5dB, 64QAM with coding rate 1/2 has better spectral efficiency. Hence each order of modulation is optimal within a certain range of SNR.

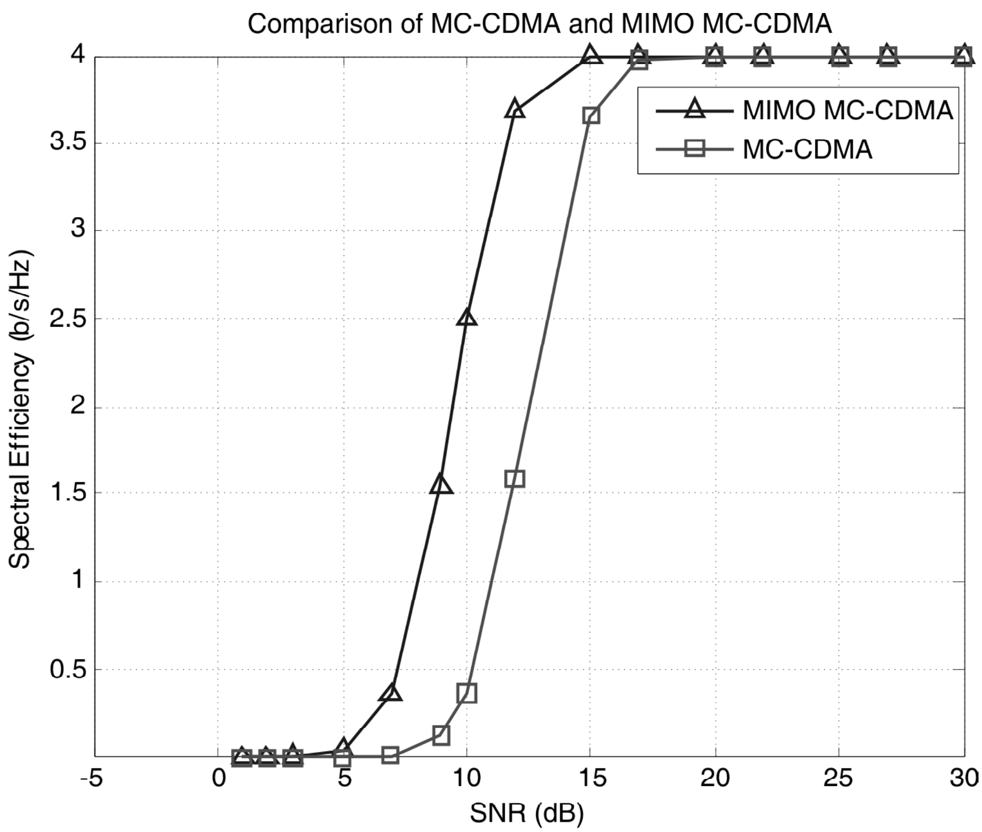

Figure 3: Spectral efficiency versus SNR for 16QAM modulation technique, L = 8, K = 8, N_T = 2 and N_R = 2

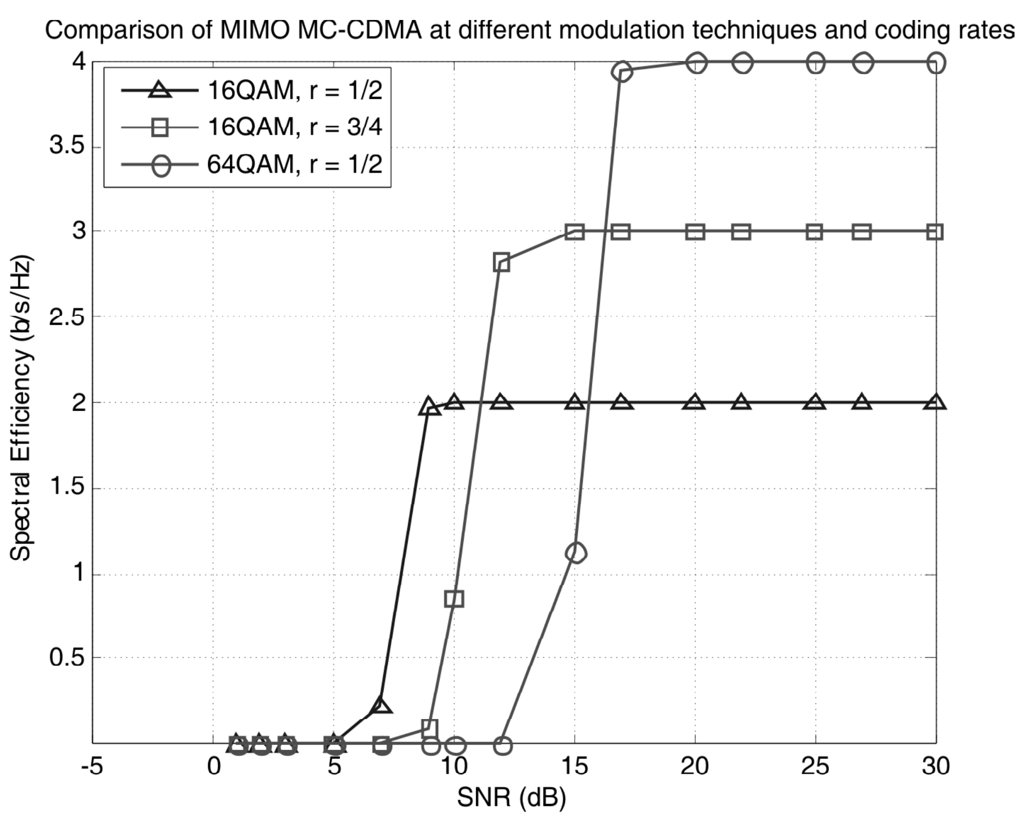

Figure 4: Spectral efficiency versus SNR for L = 16, K = 16, N_T = 2 and N_R = 2

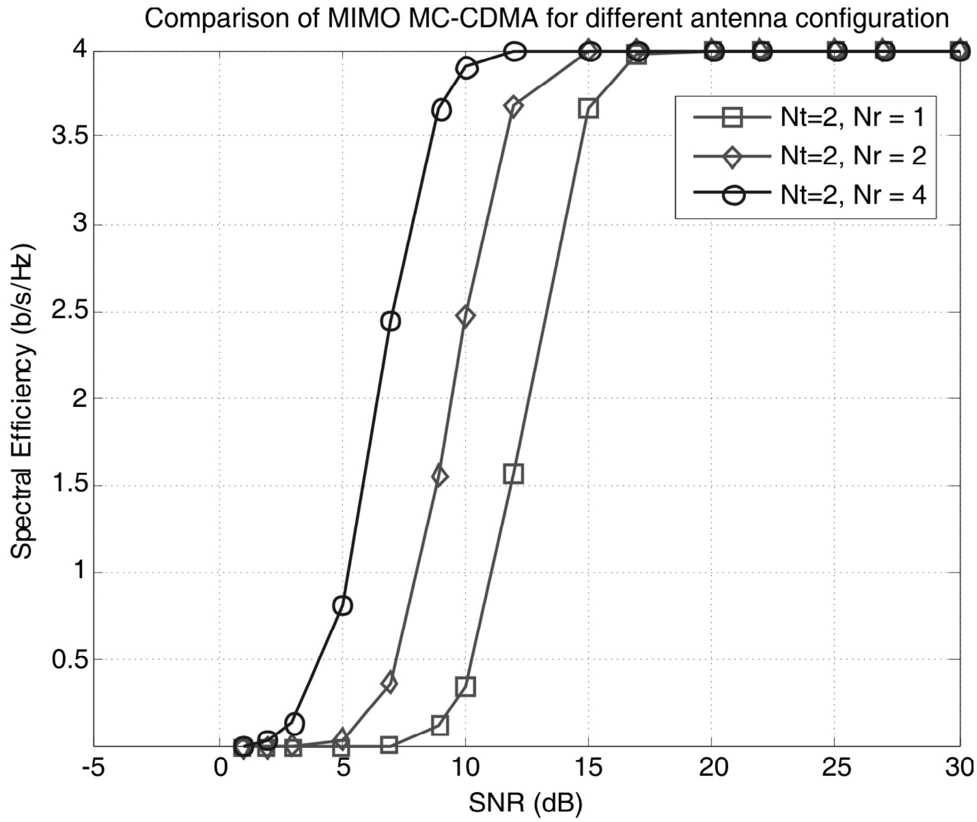

Figure 5: Spectral efficiency versus SNR for 16QAM modulation technique, L = 8, K = 8

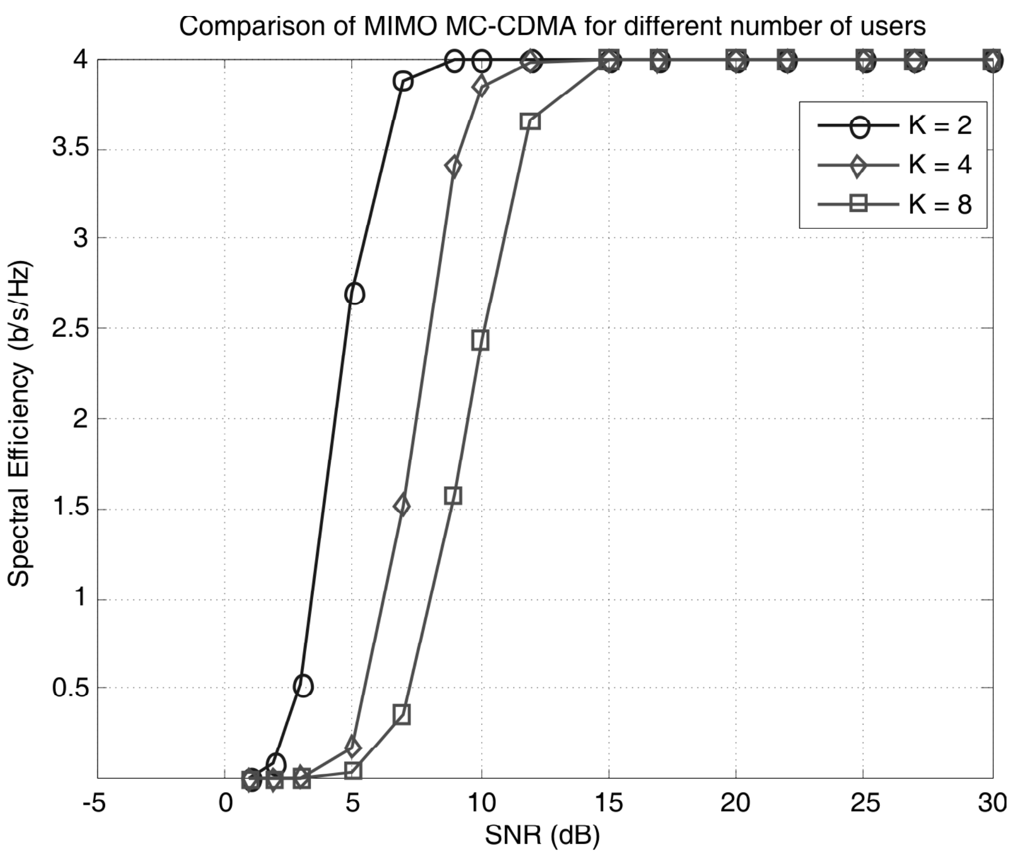

Figure 6: Spectral efficiency versus SNR for 16QAM modulation technique, L = 8, N_T = 2 and N_R = 2

In Fig. 5 comparison is shown among the transmitting antennas (N_T = 2) and receiving antennas (N_R = 1, 2 and 4) for MIMO MC-CDMA system without channel coding. At 7dB SNR, spectral efficiency is 2.445 bps/Hz for N_R = 4 whereas 0.3663bps/Hz for N_R = 2 and 0.01095 bps/Hz for N_R = 1.

Comparison of MIMO MC-CDMA system without channel coding for different number of users is shown in Fig-6. From the result it is clearly visible that spectral efficiency decreases as increasing the number of active users. For SNR = 5dB and for different number of active users K = 2, 4 and 8 corresponding spectral efficiency is 2.703 bps/Hz, 0.1761 bps/Hz and 0.03858 bps/Hz. This is due to the fact that with decreasing the number of active users multiple access interference decreases which improves the bit error rate hence increases spectral efficiency.

IV. CONCLUSION

This paper investigates the spectral efficiency of MC-CDMA and MIMO MC-CDMA systems. MIMO MC-CDMA system has better spectral efficiency than the MC-CDMA system. Spectral efficiency affects the capacity of the system. Improvement in spectral efficiency increases the capacity of the system. On comparing the performance among different order of QAM modulation techniques, it is shown that each order of modulation technique offer substantial performance improvement within a certain range of SNR. It is observed that spectral efficiency of MIMO MC-CDMA system increases with the increasing the number of receiving antennas because with increasing the receiving antennas, diversity gain increases which reduces bit error rate. Thus spectral efficiency is improved. Coding rate also affects the performance of the system. Less coding rate gives better spectral efficiency than the higher coding rate at lower SNR. Spectral Efficiency also affected by the spreading factor and number of users.

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