

MIMO-OFDM Scheme Based on Permutation Spreading

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Abstract— In this paper, a novel transmission scheme is developed to effectively combine permutation spreading technique with MIMO-OFDM to obtain improved bit error rate performance in the presence of frequency selective fading channels with low system complexity. Unlike conventional MIMO-OFDMA, where users are separated in different frequency bands (subchannels), and each user is coded separately using STBC or SFBC, the proposed new scheme enables multi access by joint code design across multiple antennas, subcarriers, and users. Such system will benefit from the combined space and frequency domain freedom as well as multiuser diversity. Hence, better spectrum efficiency is achieved while improving bit error rate performance with respect to signal-to-interference ratio

Keywords— OFDM; MIMO; Error control coding; Permutation spreading; Block processing; Detection.

I. INTRODUCTION

Frequency selectivity challenge due to the large bandwidth in the next generation wireless communications is a major problem; as a result subcarriers in OFDM may experience high frequency dependent attenuations on transmission over such frequency selective fading channels. In a non-line-of-sight multipath transmission environment, the symbols carried by the subcarriers are consequently erased by the channel attenuations and cannot be accurately recovered at the receiver, which results a poor system performance. It thus becomes fundamental to exploit the spatial diversity made possible by MIMO system[1] [2]; especially when the channel and array structures are such that the transfer functions between different transmit and receive antenna pairs are sufficiently uncorrelated. ST coded[3] MIMO-OFDM cannot neither achieve multipath diversity nor high rate, on the other hand, SF-codedMIMO- OFDM [4][5] is considered the best candidate for future wireless communication. By mapping the symbols on other sub-channels, it can exploit the multipath diversity. However, the system complexity is a major obstacle

and the decoding complexity problem has to be tackled. In addition to that, most of the existing ST/SF codes are designed for single user systems only, for multiple access channels (MAC), the single-user ST/SF codes are always applied to each user independently, which results a reduced transmission rate.

In this paper, a new transmission scheme belongs to SF-coded MIMO-OFDM family based on permutation spreading methods is proposed. In this scheme, the data symbol to be transmitted across each antenna is spreaded by a spreading code; the choice of this code is determined by the transmitted message vector across the multiple antennas. At the receiver side, the data detection relies on correlators matched to the different spreading codes used by the transmitter, once the spreading code is identified in the first stage, the probability of error in determining the correct block of information bits is very low. In other words the probability of error is dominated by the errors caused by incorrect spreading sequence determination. This technique was originally proposed for CDMA in [6] and recently adapted for MIMO-CDMA in the presence of frequency selective fading channel [7]. A novel approach is developed here to effectively combine and permutation block spreading techniques with MIMO-OFDM to obtain improved bit error performance in the existence of frequency selective fading channel and greatly lower system complexity. In MIMO-OFDMA, users are separated in different frequency bands (sub-channels), and each user is coded separately using STBC or SFBC, leading to data rate reduction for each user when the number of users is increasing. The proposed new scheme enables multi access through the use of orthogonal spreading codes, where multiple data symbols share common subcarriers while their signals remain separable at the receiver. With suitable selections of spreading codes, the frequency diversity created by multipath propagation in the communications channel is exploited to improve the bit error rate (BER) over standard OFDM. The rest of the paper is organized as follows: in section 2, the conventional MIMO-OFDM is introduced, and then the

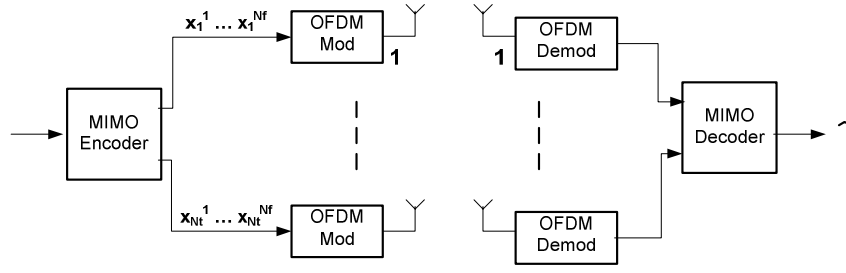


Figure 1. A simplified block diagram of MIMO-OFDM system

MIMO-OFDM with permutation spreading system is presented in section 3. In section 4 the simulation results for the proposed system are presented and section 5 concludes the results presented in this paper.

II. MIMO-OFDM

A general MIMO-OFDM system is shown in Figure 1, where N_t transmit antennas, N_r receive antennas, and N_f tone OFDM are used. The incoming bit stream is modulated using some modulation technique such as BPSK. Then a block of N_s data symbols $S = [s_1, s_2, \dots, s_{N_s}]$ are encoded into a codeword matrix X of size $N_t \times N_f$, which will then be sent through N_t antennas in one OFDM frame. The codeword matrix X could be expressed as.

$$X = \begin{pmatrix} X_1^1 & \dots & X_1^{N_f} \\ \vdots & \ddots & \vdots \\ X_{N_t}^1 & \dots & X_{N_t}^{N_f} \end{pmatrix} \quad (1)$$

Each row of the above matrix is passed through IFFT block, followed by appending the cyclic prefix. After passing through the MIMO channels, the received signals will be first sent to the reverse OFDM frame (cyclic prefix removal and FFT) and then sent to the decoder. The received vector at the decoder input is expressed as

$$Y^{(K=1:N_f)} = \sum_{I=1}^{N_t} H_I X_I (K=1:N_f) \quad (2)$$

Where H is $N_t \times N_r$ channel matrix,

$$H = \begin{pmatrix} h_{11} & \dots & h_{1N_r} \\ \vdots & \ddots & \vdots \\ h_{N_t1} & \dots & h_{N_tN_r} \end{pmatrix}$$

If the Channel State Information (CSI) is available at the receiver, then X could be recovered as

$$X^{(k=1:N_f)} = H^{-1} Y^{(k:N_f)} \quad (3)$$

and the original information stream is detected using a suitable technique such as Maximum Likelihood (ML). Recently enormous research efforts have been taken place to address the MIMO detection problem while maintaining a lower complexity order [8][9]. In this paper, a new transmission scheme based on permutation spreading is used, it significantly reduces the detection process as shown in the next section.

III. MIMO-OFDM WITH PERMUTATION SPREADING

Figure 2 shows a block diagram of the proposed MIMO-OFDM system with $N_t=4$ antennas. The information stream is spatially multiplexed into N_t transmitting antennas. The substream to be transmitted on antenna i on time interval n is spread by a spreading code vector $c_i^{(n)}$. The spreading code vector is of dimension $N_c \times 1$:

$$C_i^{(n)} = (c_i^{(n)}(1) c_i^{(n)}(2) \dots c_i^{(n)}(N_c))^T \quad (4)$$

Where N_c is the spreading factor and the subscript T represents the transpose operator, $N_c = T_s/T_c$ is an integer number where T_s is the symbol period and T_c is the chip period. The coded symbols are then converted to N_f parallel chips to form an OFDM frame which will be modulated using the OFDM and then transmitted by antenna i . For each data block of, N_t symbol length, the set M of all possible message vectors has 2^{N_t} different elements. Each data block (prior to IFFT processing block) is input to a systematic linear encoder which produces a set of parity bits, $\mathbf{p} = [p_1, p_2, \dots, p_k]^T$, where $K = \log_2(N_t)$. The set of message vectors that produce the all 0 parity vector is denoted by M_1 . This set is closed under modulo-2 addition. The set of message vectors that produces parity vector $\mathbf{p}_i$ is denoted by M_i . For example, for 4 transmitting antennas, the set M has 16 elements. Choosing $N = 8$ we can partition M into 8 different cosets. We choose the coset leader to have the greatest possible minimum Hamming distance, therefore: $M_1 = \{0000, 1111\}$, $M_2 = \{0001, 1110\}$, ..., $M_8 = \{0111, 1000\}$. In permutation spreading each transmitting antenna is allocated different spreading code, by determining

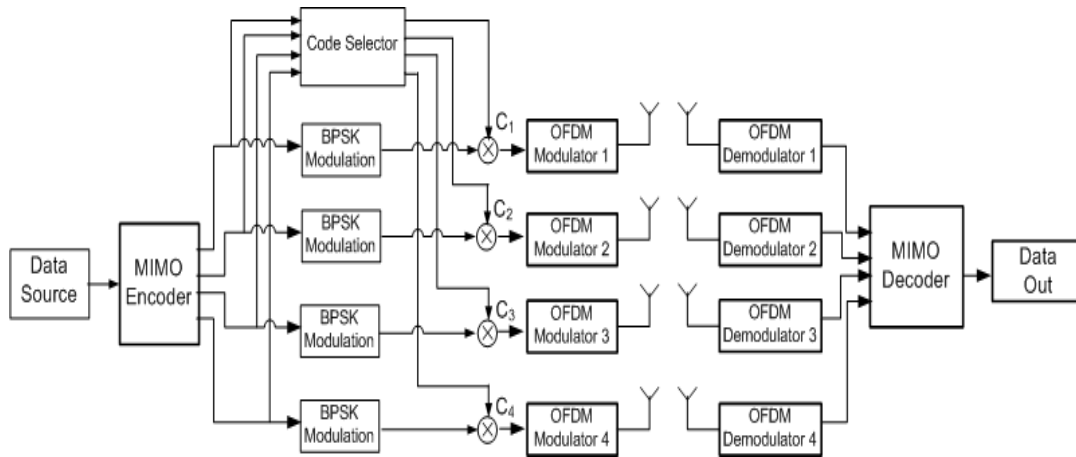


Figure 2. 4X4 MIMO-OFDM system with permutation spreading

which coset the message comes from, a unique permutation of the spreading codes are used to spread the message symbols. Each permutation employs N_c of the N spreading waveforms, to minimize the number of spreading codes that each permutation has in common, the design of different spreading permutations is based on t-designs which are used in permutation modulation schemes.

Table 1 lists the spreading permutations when 4 transmitting antennas are used.

After passing through the MIMO channels, the received signals is expressed as

$$Y = \sum_{i=1}^L H_i X + n \quad (5)$$

TABLE1: SPREADING PERMUTATIONS FOR MIMO-OFDM WITH 4 ANTENNAS

Coset	Message vectors	C ₁	C ₂	C ₃	C ₄
M ₁	0000 1111	c ₁	c ₃	c ₅	c ₇
M ₂	0001 1110	c ₈	c ₁	c ₄	c ₅
M ₃	0010 1101	c ₂	c ₄	c ₃	c ₈
M ₄	0011 1100	c ₅	c ₂	c ₆	c ₃
M ₅	0100 1011	c ₆	c ₇	c ₁	c ₄
M ₆	0101 1010	c ₃	c ₆	c ₈	c ₁
M ₇	0110 1001	c ₇	c ₈	c ₂	c ₆
M ₈	0111 1000	c ₄	c ₅	c ₇	c ₂

Where X is given by equation 1, n is additive white gaussian noise, L is number of channel paths, and H is N_t by N_r channel matrix, the received signal will be first sent to the reverse OFDM frame (cyclic prefix removal and FFT), then in the presence of full channel knowledge, the codeword X could be extracted as

$$X^{(k=1:N_f)} = H^{-1} y^{(k=1:N_f)} \quad (6)$$

a bank of matched filters is used to determine the coding sequence used by the transmitter where the received signal is matched to a different coding waveform.

$$\mu^{(k=1:N_f)} = \sum_{i=1}^{N_r} C^T X_i^{(k=1:N_f)} \quad (7)$$

Where

$\mu^{(k=1:N_f)}$ is the output of the matched filter
 C^T is the transpose of codes matrix

The index of the highest power in μ will determine the original used code at the receiver, after determining the coding sequence; the receiver can make use of the fact that each block of information symbols across the multiple antennas is carried by a specific coding sequence. Once the code is identified in the first stage, the maximum likelihood is used to detect the original data; hence the probability of error in determining the correct block of informationsymbols is very low. In other words the probability of error is dominated by the errors caused by incorrect coding sequence determination.

IV. SIMULATION RESULTS

Initial MATLAB simulations are carried out in order to validate the new scheme and compare it with well-known Alamouti STBC scheme.

TABLE 2 SIMULATION PARAMETERS

Parameter	Value
IFFT frame length	256
Cyclic Prefix length	64
Block length N_t	2X2 and 4X4
Modulation	BPSK
Number of simulation runs	10000
Spreading Code Length	8

The simulation parameters are summarized in Table 2. We consider MIMO-OFDM system in frequency selective channel. Figure 3 depicts the BER performance results when permutation selected spreading is used, it is observed that STBC is giving comparable result in case of 2X2 MIMO configuration while the proposed scheme outperforms STBC in case of 4X4 configuration. In addition to the improved BER performance, the proposed scheme enables multi-access for the MIMO system by allocating each user a unique set of codes. This allows users to share subcarriers with a manageable level of multi-user interference. Hence, better spectrum efficiency is achieved.

V. CONCLUSIONS

In this paper, MIMO-OFDM with parity bit selected and permutation block spreading scheme has been introduced, the new scheme improves the symbol detection due to the inherited coding in the spreading technique. In addition to that, it enables multi access by joint code design across

multiple antennas, subcarriers, and users, this allows users to share subcarriers with a manageable level of multi-user interference. Hence, better spectrum efficiency is achieved while improving bit error rate performance with respect to signal-to-interference rate.

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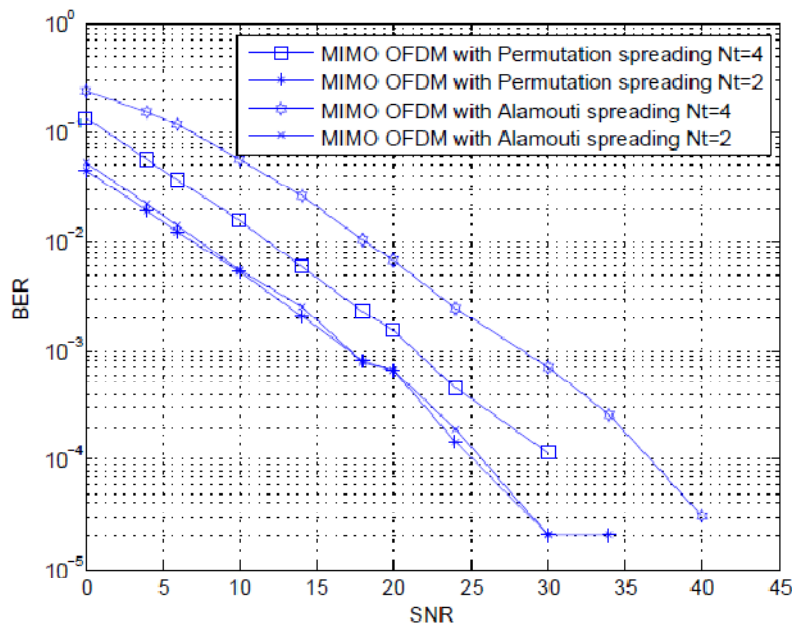


Figure 3. BER performance comparison between MIMO-OFDM with permutation spreading and conventional STBC for $N_t = 4$ and $N_t = 2$