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Interference Mitigation in Uplink STBC MC-CDMA System Based on PIC Receiver

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Abstract—Multi Carrier Code Division Multiple Access (MC-CDMA) is attractive technique for high speed data transmission in multipath fading channel. MC-CDMA system cannot handle the sudden time variations of the channel which cause the subcarriers to lose their orthogonality. The loss of orthogonality between the subcarriers of a user or unwanted correlation between the spreading codes of different user can lead to increase in Multiple Access Interference (MAI). Space Time Block Code (STBC) based MC-CDMA system is chosen to achieve full diversity and transmission rate without the knowledge of Channel State Information (CSI) at the transmitter. Thus, in the paper STBC is introduced at the transmitter to improve the quality of the receiver. Space Time Block Code-Parallel Interference Cancellation (STBC-PIC) receiver has been proposed for MC-CDMA system. In the proposed STBC-PIC receiver, at each interference cancellation stage, weighted signal of the other user is subtracted from signal of the desired user, thereby reducing the MAI and improving the BER performance. From the simulation results, it is observed that the proposed receiver outperforms STBC-Orthogonal Complete Complementary Code (STBC-OCCC), STBC-Minimum Mean Square Error (STBC-MMSE) and STBC-Zero Forcing (STBC-ZF) receivers for MAI reduction.

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1. INTRODUCTION

Multi Carrier Code Division Multiple Access (MC-CDMA) is one of the most promising multi carrier modulation techniques in 4G technology [1]. MC-CDMA is the combination of Orthogonal Frequency Division Multiplexing (OFDM) and CDMA. The merits of MC-CDMA include maximum utilization of spectrum, easy adjustment to strict channel conditions without complex detection, and high resistance to Inter Symbol Interference (ISI) and fading caused by multipath propagation [2]. This is attractive technique for high speed data transmission over multipath fading channel. It minimizes multipath effects such as Inter Symbol Interference (ISI) and Inter Carrier Interference (ICI) and improves the security [3].

This system cannot handle the sudden time variations of the channel since OFDM is involved in MC-CDMA system. The frequency and timing offset cause the subcarriers to lose their orthogonality [4]. The loss of orthogonality between the subcarriers of a user or unwanted correlation between the spreading codes of different user can lead to increase in Multiple Access Interference (MAI). The factors required for MAI reduction include the number of users and spreading sequence [2]. Current techniques have not achieved the reduction in MAI with less computational complexity and lower BER.

Space Time Block Code (STBC) based MC-CDMA system is adapted in wireless communication standards to achieve full diversity and transmission rate without the knowledge of Channel State Information (CSI) at the transmitter [5, 6]. STBC is introduced at the transmitter to improve the quality of the receiver.

This paper is organized as follows. Section 2 gives the detailed review of related work. Proposed STBC-PIC receiver for MC-CDMA system is described in section 3. The simulation results are analyzed in Section 4 followed by conclusion.

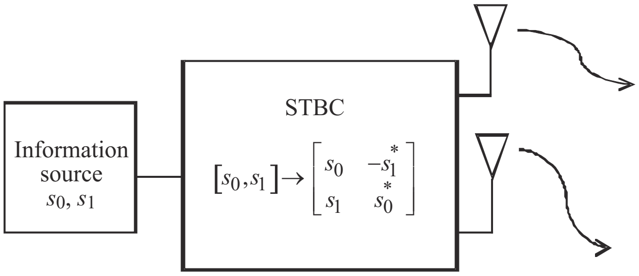

Fig. 1. Alamouti STBC with multiple transmitting antennas.

2. REVIEW OF RELATED WORK

Iraji and Lilleberg [7] have analyzed different receivers based on Maximum Ratio Combining (MRC), MMSE and Expectation Maximization (EM) algorithms for STBC based MC-CDMA system. Results show that MIMO configuration based STBC-MMSE receiver provides better performance than Single Input and Single Output (SISO) based STBC-MMSE receiver in International Telecommunication Union Recommendation (ITU-R) channel model. Portier et al. [8] analyzed STBC-ZF and STBC-MMSE receivers in MC-CDMA system under indoor and outdoor channels. It is found that STBC-MMSE receiver with spatial diversity provides better performance than STBC-ZF for indoor and outdoor channels. But, the computational complexity is higher in STBC-MMSE receiver.

Li et al. [9] proposed STBC-MRC receiver in MC-CDMA system. STBC-MRC receiver with two receive antennas has better performance than one receive antenna. In STBC-MRC receiver, the orthogonality is destroyed between the spreading sequences and hence, MAI is enhanced. Dorazio et al. [6] proposed STBC-Minimum BER (STBC-MBER) in MC-CDMA system. Here, STBC-MBER receiver uses an adaptive Least Mean Square (LMS) algorithm and shows an improved performance over conventional algorithms. But the STBC-MBER receiver has increased computational complexity due to the difficulty in selecting the weight coefficients.

Khan et al. [10] proposed STBC-MBER with different LMS algorithms in MC-CDMA system for STBC MC-CDMA receivers. The different LMS algorithms are Signed LMS, Signed-Regressor LMS and Signed-Signed LMS algorithms. These algorithms have higher convergence rate than conventional LMS algorithm. STBC-MBER receiver with Signed-Signed LMS algorithm provides low computation complexity and faster convergence rate when compared to STBC-MBER receiver with Signed LMS and Signed-Regressor LMS algorithms. STBC-MBER receiver with Signed-Signed LMS algorithm improves the performance of sub optimal receiver. But, the selection of weight coefficients is a challenging task.

Fayong Zhao [11] proposed STBC-Linearly Constraint Recursive Least Squares Constant Modulus Algorithm (LCRLSCMA) for STBC MC-CDMA receiver. Here, LCRLSCMA algorithm has been used in this receiver. The results show that two or three receive antennas have better performance than one receive antenna. Due to the improper selection of initial value, the performance is degraded and because of higher number of users the computational complexity is increased.

Genetic Algorithm (GA) is used to optimize the weights of STBC receiver in MC-CDMA system [12]. STBC receiver using GA shows faster convergence rate than conventional STBC receiver using LMS. But BER performance is not good and the computational complexity increases in STBC receiver when using GA in MC-CDMA system. Ajra et al. [13] analyzed Quasi Orthogonal STBC (QO-STBC) receiver in MIMO MC-CDMA system. QO-STBC receiver provides better performance than other detection techniques. But, the computational complexity is higher in QO-STBC receiver.

STBC-Orthogonal Complete Complementary Codes (STBC-OCCC) [14] receiver using Correlation Reconstruction MRC (CRMRC) scheme in MC-CDMA system has been proposed in [14]. STBC-OCCC receiver using CRMRC has better BER performance due to counteracting of the detrimental effects of MAI through orthogonality reconstruction. This is done by selecting the optimal interleaving pattern in the switched interleaver. In multipath environment, this scheme fails to remove MAI completely at particular channel condition due to the fact that received signals from multipath add destructively causing Multiuser Interference (MUI) which results in high error rate.

An efficient receiver design with Parallel Interference Cancellation (PIC) in STBC based MC-CDMA system with multiple transmitting and receiving antennas has been proposed to mitigate MAI. The proposed receiver model estimates and cancels out the MAI from the desired user and thereby improving the system

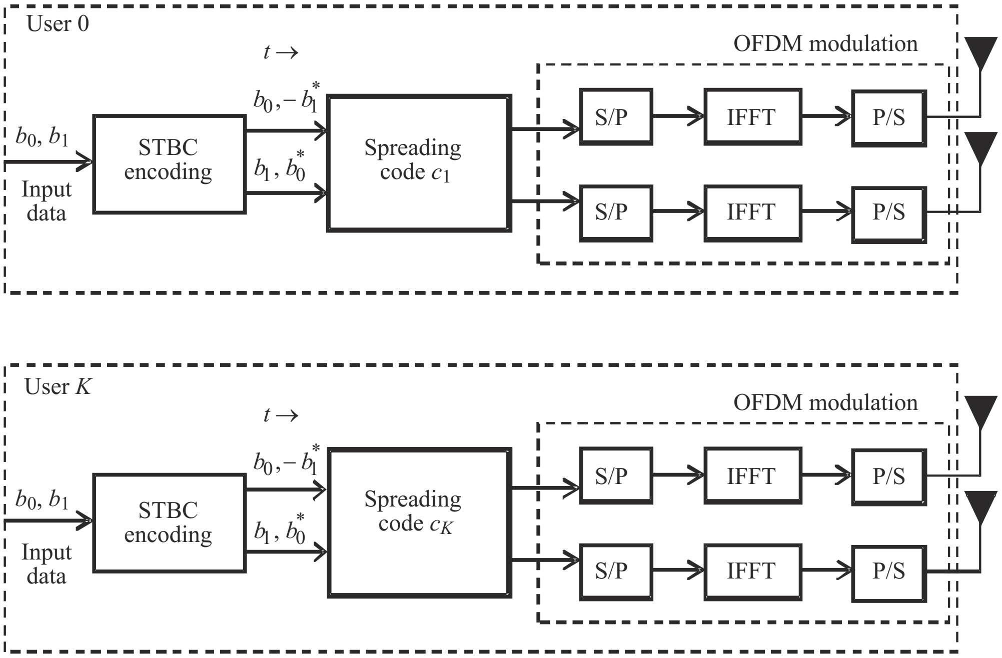

Fig. 2. STBC based MC-CDMA transmitter with multiple transmit antennas.

performance. The proposed STBC-PIC receiver has better performance than conventional receivers such as STBC-Zero Forcing (STBC-ZF), STBC-MMSE and STBC-OCCC. It has lower computational complexity than STBC-SIC (STBC-Successive Interference Cancellation) receiver.

3. PROPOSED STBC-PIC RECEIVER FOR MC-CDMA SYSTEM

3.1. STBC Based MC-CDMA Transmitter

In STBC based MC-CDMA system, multiple transmit antennas are used to achieve spatial diversity [15, 16]. It allows the system to achieve better performance in a fading environment. Alamouti STBC with multiple transmitting antennas is described in Fig. 1.

The symbols s_0 and s_1 are transmitted from first and second antennas, respectively at time t. At time $(t+T_s)$, where T_s is the symbol period, symbols $(-s_1^*)$ and s_0^* are transmitted from first and second antennas respectively. Uplink STBC based MC-CDMA transmitter with multiple transmit antennas is shown in Fig. 2.

Let K be the total number of users and N be the data symbol. Each user has $N \times 1$ vectors of data symbol. The spread signal x_k^j corresponding to jth bit of kth user after STBC encoding is given as

$$x_k^j = A_k c_k b_k^j, \tag{1}$$

where c_k is the spreading sequence of kth user, A_k is amplitude of kth user and the quantity b_k^j is jth bit of kth user data.

Defining a $2N \times 1$ matrix $y_k = [x_k^{0\mathrm{T}}, x_k^{1\mathrm{T}}]^{\mathrm{T}}$, which consists of a block of chips for kth user, through $2P$ point IFFT. The spread signal x_k^j is appended with the cyclic prefix (CP) and transmitted over the multipath fading channel.

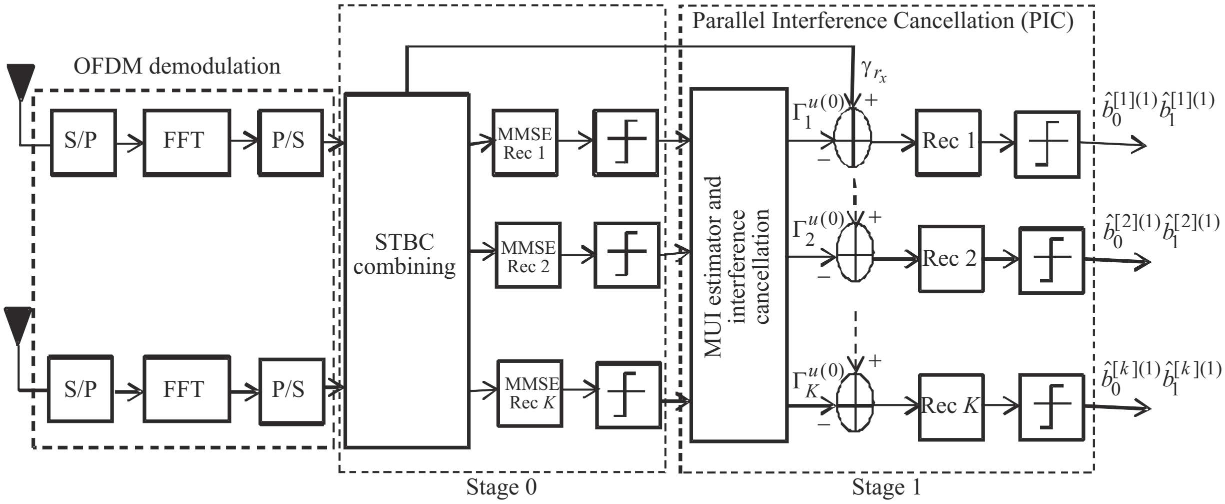

Fig. 3. Proposed model for STBC based MC-CDMA receiver with PIC and multiple receive antenna.

3.2. STBC-PIC Based MC-CDMA Receiver

Figure 3 shows the proposed model for uplink STBC based MC-CDMA receiver with one stage of PIC and multiple receive antenna. The received signal from r_xth receive antenna after OFDM demodulation at time t and $(t+T_s)$ is given as

$$\gamma_{r_x} = \sum_{k=1}^{K} \mathcal{H}_{r_x}^{[k]} y_k + N_{r_x}, \tag{2}$$

where $\gamma_{r_x} = [r_{r_x}^{\mathrm{T}}(t), r_{r_x}^{\mathrm{T}}(t+T_s)]$ with $r_{r_x}^{\mathrm{T}}(t)$ and $r_{r_x}^{\mathrm{T}}(t+T_s)$ are the received vectors at time t and $(t+T_s)$.

The quantity $\mathcal{H}_{r_x}^{[k]}$ is expressed as

$$\mathcal{H}_{r_x}^{[k]} = \begin{bmatrix} \mathcal{H}_{r_x,1}^{[k]} & \mathcal{H}_{r_x,2}^{[k]} \\ \mathcal{H}_{r_x,2}^{*[k]} & -\mathcal{H}_{r_x,1}^{*[k]} \end{bmatrix}, \tag{3}$$

where $\mathcal{H}_{r_x,t_x}^{[k]}$ is $N_c \times N_c$ diagonal channel matrix of kth user in frequency domain with respect to receive antenna r_x and transmit antenna t_x, N_{r_x} is additive white Gaussian noise (AWGN) for r_xth antenna.

3.2.1. Linear minimum mean square error detection in STBC-PIC based MC-CDMA receiver

Linear receivers are widely used compared to Maximum Likelihood (ML) receivers due to low complexity. In MIMO systems, linear receivers such as Minimum Mean Square Error (MMSE) receiver are adopted in IEEE 802.11n and 802.16e. Despite the intrinsic sub-optimality, Multi User Detection (MUD) algorithms based on MMSE criterion are often preferred in MC-CDMA due to reduced computational load and adaptive implementations.

MMSE is the minimization of average Mean Square Error (MSE) between the transmitted and estimated symbols [17]. The $(N \times 1)$-vector $v_{r_x,t_x}^{[k]}$ with respect to r_xth receive antenna and t_xth transmit antenna for the kth user is expressed as

$$v_{r_x,t_x}^{[k]} = \mathcal{H}_{r_x,t_x}^{[k]} c_k. \tag{4}$$

MMSE is obtained by minimizing the MSE in (5):

$$L_{\mathrm{MSE}} = E[\| A_{k_0} b_{k_0} - (Z_{r_x}^{[k_0]})^H \gamma_{r_x} \|^2], \tag{5}$$

where $\|\cdot\|$ represents the norm of a vector and $\mathbf{Z}_{r_x}^{[k_0]}$ for k_0th user corresponding r_xth receive antenna is given as

$$\mathbf{Z}_{r_x}^{[k_0]} = \begin{bmatrix} \mathbf{Z}_{r_x,1}^{[k_0]} & \mathbf{Z}_{r_x,2}^{*[k_0]} \\ \mathbf{Z}_{r_x,2}^{[k_0]} & -\mathbf{Z}_{r_x,1}^{*[k_0]} \end{bmatrix}. \tag{6}$$

The gradient is taken with respect to $\mathbf{Z}_{r_x}^{[k_0]}$ and is set to zero. After further mathematical manipulations, MMSE of k_0th desired user for r_xth receive antenna and t_xth transmit antenna is expressed as

$$\mathbf{Z}_{r_x,t_x}^{[k_0]} = \left(\sum_{k=1}^{K} \sum_{r_x=1}^{R_x} \sum_{t_x=1}^{T_x} A_k^2 v_{r_x,t_x}^{[k]} (v_{r_x,t_x}^{[k]})^{\mathrm{H}} + \sigma^2 I_N \right)^{-1} A_{k_0}^2 v_{r_x,t_x}^{[k_0]}, \tag{7}$$

where $(.)^{\mathrm{H}}$ denotes the Hermitian transpose of a matrix and $(.)^{-1}$ denotes the inverse of a matrix.

The resultant signal from r_xth receive antenna is processed to detect the data symbols. After despreading and threshold detection, the estimated bits of k_0th user is given as

$$[\hat{b}_0^{[k_0]} \hat{b}_1^{[k_0]}]^{\mathrm{T}} = \mathrm{sgn}\left\{ \mathrm{Re}\left(\sum_{r_x=1}^{R_x} \mathbf{Z}_{r_x}^{[k_0]} \gamma_{r_x} \right) \right\}, \tag{8}$$

where "Re" represents the real part, $(.)^{\mathrm{T}}$ denotes the transpose of a matrix and sgn{.} represents signum function.

3.2.2. Zero forcing detection in STBC-PIC based MC-CDMA receiver

Zero Forcing (ZF) detection recovers the information after the channel by applying the inverse frequency response of the channel on the received signal. The ZF detection of kth user for r_xth receive antenna and t_xth transmit antenna is given as

$$\mathbf{Z}_{r_x,t_x}^{[k_0]} = \left(\left(v_{r_x,t_x}^{[k_0]} \right)^{\mathrm{H}} v_{r_x,t_x}^{[k_0]} \right)^{-1} \left(v_{r_x,t_x}^{[k_0]} \right)^{\mathrm{H}}. \tag{9}$$

The estimated bits of k_0th user is given as

$$[\hat{b}_0^{[k_0]} \hat{b}_1^{[k_0]}]^{\mathrm{T}} = \mathrm{sgn}\left\{ \mathrm{Re}\left(\sum_{r_x=1}^{R_x} \mathbf{Z}_{r_x}^{[k_0]} \gamma_{r_x} \right) \right\}, \tag{10}$$

where $\mathbf{Z}_{r_x}^{[k_0]}$ is expressed in (6).

3.2.3. Multiple access interference analysis in STBC-PIC based MC-CDMA receiver

After despreading and threshold detection, the estimated bits of k_0th user is given as

$$[\hat{b}_0^{[k_0]}\hat{b}_1^{[k_0]}]^{\mathrm{T}} = \sum_{r_x=1}^{R_x} \mathbf{Z}_r^{[1]}\gamma_{r_x} = \mathbf{Z}_1^{[1]}\gamma_1 + \mathbf{Z}_2^{[1]}\gamma_2$$

$$= \begin{bmatrix} \mathbf{Z}_{1,1}^{[1]} & \mathbf{Z}_{1,2}^{*[1]} \\ \mathbf{Z}_{1,2}^{[1]} & -\mathbf{Z}_{1,1}^{*[1]} \end{bmatrix} \Big[r_1^{\mathrm{T}}(t) r_1^{\mathrm{T}}(t+T_x) \Big]^{\mathrm{T}} + \begin{bmatrix} \mathbf{Z}_{2,1}^{[1]} & \mathbf{Z}_{2,2}^{*[1]} \\ \mathbf{Z}_{2,2}^{[1]} & -\mathbf{Z}_{2,1}^{*[1]} \end{bmatrix} \Big[r_2^{\mathrm{T}}(t) r_2^{\mathrm{T}}(t+T_x) \Big]^{\mathrm{T}} + N_{r_x}$$

$$= \sum_{k=1}^{K} \left\{ \begin{bmatrix} \mathbf{Z}_{1,1}^{[1]} & \mathbf{Z}_{1,2}^{*[1]} \\ \mathbf{Z}_{1,2}^{[1]} & -\mathbf{Z}_{1,1}^{*[1]} \end{bmatrix} \begin{bmatrix} \mathcal{H}_{1,1}^{[k]} & \mathcal{H}_{1,2}^{[k]} \\ \mathcal{H}_{1,2}^{*[k]} & -\mathcal{H}_{1,1}^{*[k]} \end{bmatrix} \Big[x_k^{0T}, x_k^{1T} \Big]^{\mathrm{T}} \right\}$$

$$+ \sum_{k=1}^{K} \left\{ \begin{bmatrix} \mathbf{Z}_{2,1}^{[1]} & \mathbf{Z}_{2,2}^{*[1]} \\ \mathbf{Z}_{2,2}^{[1]} & -\mathbf{Z}_{2,1}^{*[1]} \end{bmatrix} \begin{bmatrix} \mathcal{H}_{2,1}^{[k]} & \mathcal{H}_{2,2}^{[k]} \\ \mathcal{H}_{2,2}^{*[k]} & -\mathcal{H}_{2,1}^{*[k]} \end{bmatrix} \Big[x_k^{0\mathrm{T}}, x_k^{1\mathrm{T}} \Big]^{\mathrm{T}} \right\} + N_{r_x}$$

$$= \mathbf{Z}_{1,1}^{[1]}\mathcal{H}_{1,1}^{[1]}x_0^{[1]} + \mathbf{Z}_{1,1}^{[1]}\mathcal{H}_{1,2}^{[1]}x_1^{[1]} + \mathbf{Z}_{1,2}^{*[1]}\mathcal{H}_{1,2}^{*[1]}x_1^{[1]} - \mathbf{Z}_{1,2}^{[1]}\mathcal{H}_{1,2}^{[1]}x_1^{[1]}$$

$$+ \underbrace{\mathbf{Z}_{2,1}^{[1]}\mathcal{H}_{2,1}^{[1]}x_0^{[1]} + \mathbf{Z}_{2,1}^{[1]}\mathcal{H}_{2,2}^{[1]}x_1^{[1]} + \mathbf{Z}_{2,2}^{*[1]}\mathcal{H}_{2,2}^{*[1]}x_0^{[1]} - \mathbf{Z}_{2,2}^{*[1]}\mathcal{H}_{2,1}^{*[1]}x_1^{[1]}}_{\text{desired signal}}$$

$$+ \sum_{k=2}^{K} \left\{ \begin{bmatrix} \mathbf{Z}_{1,1}^{[1]} & \mathbf{Z}_{1,2}^{*[1]} \\ \mathbf{Z}_{1,2}^{[1]} & -\mathbf{Z}_{1,1}^{*[1]} \end{bmatrix} \begin{bmatrix} \mathcal{H}_{1,1}^{[k]} & \mathcal{H}_{1,2}^{[k]} \\ \mathcal{H}_{1,2}^{*[k]} & -\mathcal{H}_{1,1}^{*[k]} \end{bmatrix} \Big[x_0^{[k]} x_1^{[k]} \Big]^{\mathrm{T}} \right\}$$

$$\underbrace{+ \sum_{k=2}^{K} \left\{ \begin{bmatrix} \mathbf{Z}_{2,1}^{[1]} & \mathbf{Z}_{2,2}^{*[1]} \\ \mathbf{Z}_{2,2}^{[1]} & -\mathbf{Z}_{2,1}^{*[1]} \end{bmatrix} \begin{bmatrix} \mathcal{H}_{2,1}^{[k]} & \mathcal{H}_{2,2}^{[k]} \\ \mathcal{H}_{2,2}^{*[k]} & -\mathcal{H}_{2,1}^{*[k]} \end{bmatrix} \Big[x_0^{[k]} x_1^{[k]} \Big]^{\mathrm{T}} \right\}}_{\text{multiple access interference}} + N_{r_x}. \tag{11}$$

3.2.4. Parallel interference cancellation in STBC-PIC based MC-CDMA receiver

PIC is a multiuser detection approach (Fig. 3) for single stage which detects and subtracts MAI in parallel for all the users. In the stage 0, data symbols of all users are estimated using Single User Detection (SUD) technique. The resulting MAI is subtracted from the received vector and data detection is performed again with reduced MAI in stage 1. This can be increased to multiple stages of PIC to have better MAI reduction.

Step 1: The estimated bits of kth user is computed as

$$[\hat{b}_0^{[k](0)}\hat{b}_1^{[k](0)}]^{\mathrm{T}} = \operatorname{sgn}\left\{ \operatorname{Re}\left(\sum_{r_x=1}^{R_x} \mathbf{Z}_{r_x}^{[k]}\gamma_{r_x} \right) \right\},$$

$$k = 1, 2, 3, \ldots, K; \tag{12}$$

Table 1. Simulation parameters for MAI analysis with different receivers

Parameters	Specifications
Number of users	32
Number of spreading codes	32
Number of subcarrier	256
Channel bandwidth	20 MHz
Carrier frequency	2.4 GHz
Modulation scheme	Binary Phase Shift Keying (BPSK)
Number of transmitting antenna	2
Number of receiving antenna	2
Spreading sequence	Walsh Hadamard

Step 2: Computation of MAI for uth desired user with respect to the r_xth receive antenna is given as

$$\Gamma_1^{u(0)} = \sum_{k=1,k\neq u}^{K} \left\{ \begin{bmatrix} \mathcal{H}_{1,1}^{[k]} & \mathcal{H}_{1,2}^{[k]} \\ \mathcal{H}_{1,2}^{*[k]} & -\mathcal{H}_{1,1}^{*[k]} \end{bmatrix} \left[x_k^{0\mathrm{T}}, x_k^{1\mathrm{T}} \right]^{\mathrm{T}} \right\}, \tag{13}$$

$$\Gamma_2^{u(0)} = \sum_{k=1,k\neq u}^{K} \left\{ \begin{bmatrix} \mathcal{H}_{2,1}^{[k]} & \mathcal{H}_{2,2}^{[k]} \\ \mathcal{H}_{2,2}^{*[k]} & -\mathcal{H}_{2,1}^{*[k]} \end{bmatrix} \left[x_k^{0\mathrm{T}}, x_k^{1\mathrm{T}} \right]^{\mathrm{T}} \right\}, \tag{14}$$

Step 3: Thus the final detection is given as

$$[\hat{b}_0^{[k](1)} \hat{b}_1^{[k](1)}]^{\mathrm{T}} = \mathrm{sgn}\left\{ \mathrm{Re}\left(\sum_{r_x=1}^{R_x} Z_{r_x}^{[k_0]} (\gamma_{r_x} - \Gamma_{r_x}^{u(0)}) \right) \right\}. \tag{15}$$

4. SIMULATION RESULTS

The performance of STBC based receivers have been analyzed through simulations using MATLAB. The parameters listed in Table 1 are used for the simulations that are performed under Rayleigh multipath channel.

Figure 4 shows the BER performance of the STBC-PIC, STBC-OCCC, STBC-MMSE and STBC-ZF receivers. It is observed that proposed STBC-PIC receiver requires SNR of 8 dB whereas STBC-OCCC, STBC-MMSE and STBC-ZF receivers require SNR of 16 dB, 20 dB and more than 20 dB respectively to achieve BER = 10^{-3}.

Figure 5 shows the BER performance of the STBC-PIC, STBC-OCCC, STBC-MMSE and STBC-ZF receivers with different number of receiving antennas. It is observed that proposed STBC-PIC receiver requires SNR = 8 dB whereas STBC-OCCC, STBC-MMSE and STBC-ZF receivers require SNR of 16, 20 and more than 20 dB respectively to achieve BER = 10^{-3} for one receive antenna. It is observed that STBC-PIC receiver requires SNR = 6 dB whereas STBC-OCCC, STBC-MMSE and STBC-ZF receivers require SNR of 12, 18 and more than 20 dB respectively to achieve BER = 10^{-3} for two receive antennas.

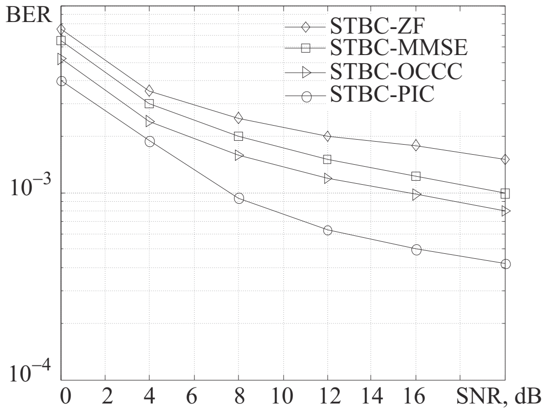

Fig. 4. BER performance of STBC-PIC, STBC-OCCC, STBC-MMSE and STBC-ZF receivers.

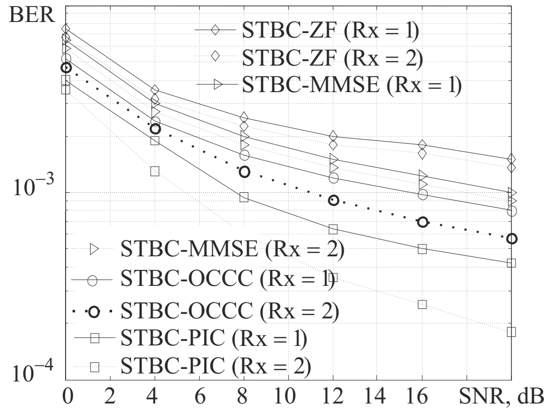

Fig. 5. BER performance of the STBC-PIC, STBC-OCCC, STBC-MMSE and STBC-ZF receivers with different number of receive antennas.

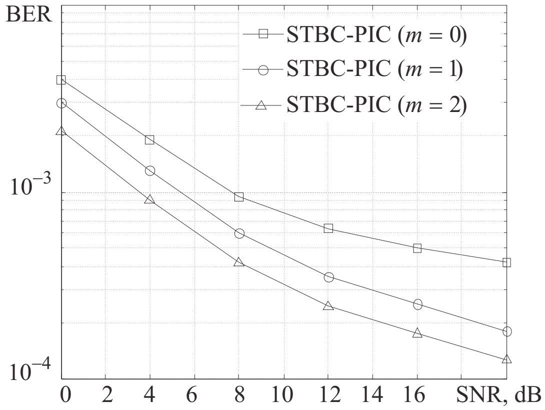

Fig. 6. BER performance of the proposed STBC-PIC receiver with different PIC stages.

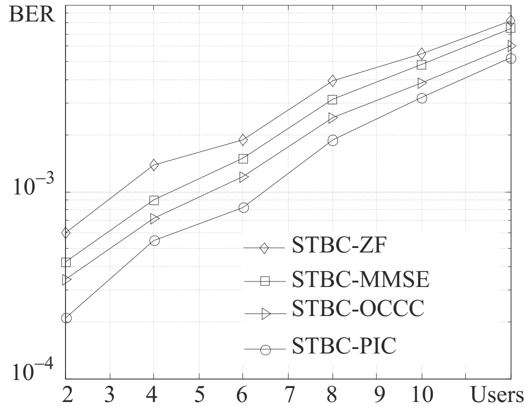

Fig. 7. BER performance of the STBC-PIC, STBC-OCCC, STBC-MMSE and STBC-ZF receivers for various number of users.

It is observed that STBC-PIC receiver with two receive antennas requires SNR of 6 dB whereas STBC-PIC receiver with one receive antennas requires SNR of 8 dB to achieve BER = 10^{-3}. STBC-PIC receiver with two receive antennas has improved performance due to spatial diversity technique which mitigates multipath fading. So, when the number of receive antennas increase, the system performance is eventually improved. Thus, STBC-PIC receiver with two receive antennas outperforms STBC-PIC with one receive antenna, STBC-OCCC, STBC-MMSE and STBC-ZF receivers with one and two receive antennas.

Thus, STBC-PIC receiver provides better BER performance than STBC-OCCC, STBC-MMSE and STBC-ZF receivers. In the proposed STBC-PIC receiver, at each interference cancellation stage, weighted signal of the other user is subtracted from signal of the desired user, thereby reducing the MAI and improves the BER performance.

Figure 6 shows the BER performance of the proposed STBC-PIC receiver with different PIC stages. It is observed that STBC-PIC receiver with second stage of PIC ($m = 2$) requires SNR = 4 dB whereas STBC-PIC receiver with first stage ($m = 1$) of PIC and without PIC ($m = 0$) shown in Fig. 3 require SNR of 6 and 8 dB respectively, to achieve BER = 10^{-3}. Thus, STBC-PIC receiver with $m = 2$ provides better BER performance than STBC-PIC receiver with $m = 1$ and $m = 0$. Thus, the system gives better performance, if the number of PIC stages increases.

Figure 7 shows the BER performance of the STBC-PIC, STBC-OCCC, STBC-MMSE and STBC-ZF receivers for various number of users. It is observed that proposed STBC-PIC receiver achieve a BER lower than STBC-OCCC, STBC-MMSE and STBC-ZF receivers for 6 users. As the number of user increases, STBC-PIC receiver provides better BER performance than STBC-OCCC, STBC-MMSE and STBC-ZF receivers.

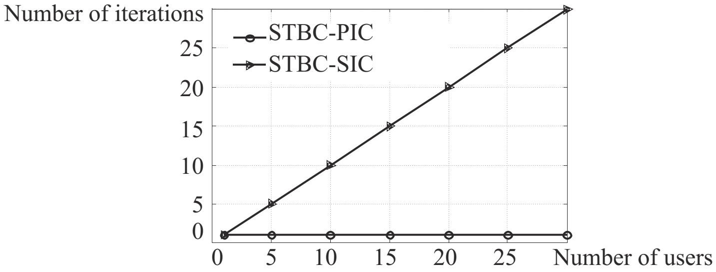

Fig. 8. Computational complexity analysis of STBC-PIC and STBC-SIC receivers.

Figure 8 shows the complexity analysis of the proposed MC-CDMA STBC-PIC and STBC-SIC receivers. It is observed that STBC-PIC receiver requires single iteration whereas STBC-SIC receiver requires 30 iterations for 30 users. Thus, MC-CDMA STBC-PIC receiver is less computationally complex than STBC-SIC receiver.

5. CONCLUSIONS

In this paper, an efficient receiver design with PIC in STBC based MC-CDMA system with multiple transmit and receive antennas has been proposed and analyzed. The simulation results show that the proposed STBC-PIC receiver outperforms STBC-OCCC, STBC-MMSE and STBC-ZF receivers for MAI reduction. In the proposed STBC-PIC receiver, at each interference cancellation stage, weighted signal of the other user is subtracted from signal of the desired user, thereby reducing the MAI and improves the BER performance.

It is observed that STBC-PIC receiver with two receive antennas has improved performance due to spatial diversity technique which mitigates multipath fading. Further, STBC-PIC receiver has improved performance, if the number of PIC stages increases.

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