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Performance of MIMO-OFDM systems combining STC with pre-FFT beamforming

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Abstract: In this letter, we propose a new technique that combines space time coding (STC) with pre-FFT multibeamforming for a multi-input multi-output (MIMO)-orthogonal frequency division multiplexing (OFDM) system. The proposed approach can effectively cancel a cochannel interference (CCI) while preserving the STC diversity and can mitigate the impairment of delay spread. The performance improvement of the proposed approach is investigated through computer simulation in a multipath channel with CCI.

Keywords: OFDM, MIMO, STC, beamforming
Classification: Wireless circuits and devices

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1 Introduction

In the multipath fading channel with CCI, the performance of MIMO-OFDM systems is greatly decreased because the received signals are much distorted by CCI during the space-time decoding. Beamforming in a wireless system is known as an effective technique to increase the performance due to the removal of CCI. Recently, the techniques combining MIMO-OFDM with beam-

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forming have been proposed to remove CCI in the wireless systems [1, 2, 3]. The previous schemes [3, 4] have the limitations that use only one wide beam toward the desired user and is effective only if the distance between direction of arrivals (DOAs) of desired signals are less than the beamwidth. In this paper, to overcome such as the limitation and to improve the performance of MIMO-OFDM system, we propose an effective CCI cancellation technique that combines STC with pre-FFT multibeamforming for MIMO-OFDM system while preserving the STC diversity. The proposed approach can track each DOAs of the signals from multi-antenna of desired user without being greatly dependent on the impinging angle. It is demonstrated that the proposed approach can effectively eliminate CCI while preserving STC diversity, thereby, greatly improving the system performance.

2 MIMO-OFDM systems with multibeamforming

Figure 1 shows a block diagram of MIMO-OFDM system with multibeamforming.

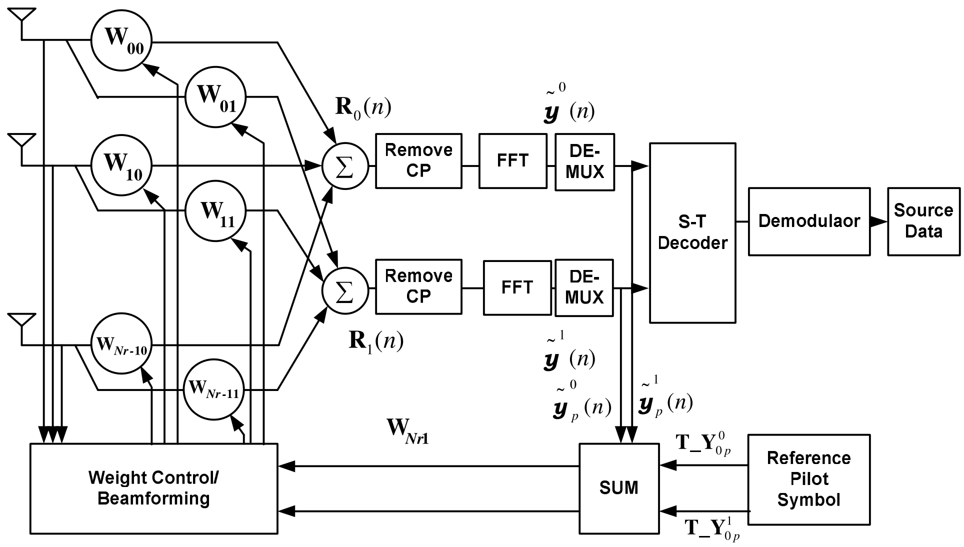

Fig. 1. A block diagram of MIMO-OFDM system with multibeamforming

In the figure, the transmitted signals from the multi-antennas of M users arrive at each Nr receiver antennas with multibeamformers. When the symbol vector for the m-th user in the frequency-domain is $\mathbf{Y}^m(n) = \left[y_0^m(n)\ y_1^m(n)\ \ldots\ y_{N-1}^m(n)\right]^T$, the encoded symbol matrix by Almouti encoder is given by

$$\mathbf{T\_Y}^m(n) = [\mathbf{T\_Y}_0^m(n) \quad \mathbf{T\_Y}_1^m(n)] \tag{1}$$

where $\mathbf{T\_Y}_0^m(n) = \left[y_0^m \ -y_1^{m*}\ y_2^m\ \ldots\ -y_{N-1}^{m*}\right]^T$,
$\mathbf{T\_Y}_1^m(n) = \left[y_1^m\ y_0^{m*}\ y_3^m\ \ldots\ y_{N-1}^{m*}\right]^T$.

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$\mathbf{T\_Y}_0^m(n)$ and $\mathbf{T\_Y}_1^m(n)$ are the encoded signal vector for the 0-th and the 1^{st} transmitter antenna of the m-th user, respectively and $*$ is represented conjugate. Here, N represents the number of sample in an OFDM block. The transformed signal matrix into time domain by IFFT is expressed as

$$\mathbf{T\_X}^m(n) = [\mathbf{T\_X}_0^m(n) \quad \mathbf{T\_X}_1^m(n)] \tag{2}$$

Here, the transmitted signal vector for the m-th user in the time domain is defined, respectively as

$$\mathbf{T\_X}_0^m(n) = \mathbf{F}^H(\mathbf{T\_Y}_0^m(n)) \tag{3}$$

$$\mathbf{T\_X}_1^m(n) = \mathbf{F}^H(\mathbf{T\_Y}_1^m(n)) \tag{4}$$

where $\mathbf{F}(n)$ and H are represented the FFT operation matrix and Hermitian transpose, respectively. The L multipath signals arrive at each antenna with the corresponding DOA. The signal matrix, $\mathbf{V}(n)$, received at the antennas is written by

$$\begin{aligned}\mathbf{V}(n) = &\sum_{l=0}^{L-1} {}^{l}\mathbf{A}^0(\theta)\mathbf{T\_X}^{0T}(n-\tau_l) \\ &+ \sum_{l=0}^{L-1}\sum_{m=1}^{M-1} {}^{l}\mathbf{A}^m(\theta)\mathbf{T\_X}^{mT}(n-\tau_l) + \mathbf{B}(n)\end{aligned} \tag{5}$$

where ${}^{l}\mathbf{A}^m(\theta) = \begin{bmatrix} {}^{l}a^m(\theta_{00}) & {}^{l}a^m(\theta_{10}) & \dots & {}^{l}a^m(\theta_{Nr-1,0}) \\ {}^{l}a^m(\theta_{01}) & {}^{l}a^m(\theta_{11}) & \dots & {}^{l}a^m(\theta_{Nr-1,1}) \end{bmatrix}^T$.

Here, ${}^{l}\mathbf{A}^m(\theta)$ is the array response matrix for the l-th path of the m-th user with argument of DOA $(=\theta)$ and $\mathbf{T\_X}^m(n-\tau_l)$ is the l-th delay path signal matrix of the m-th user, τ_l is the normalized time delay of the l-th path $(\tau_0 = 0)$. $\mathbf{B}(n)$ is the matrix for the background noise. The signal matrix multiplied by the weight of adaptive multibeamformer is given by

$$\mathbf{R}(n) = \mathbf{W}^H(n)\mathbf{V}(n) \tag{6}$$

where $\mathbf{W}(n) = \begin{bmatrix} \mathbf{W}_0 & \mathbf{W}_1 \end{bmatrix} = \begin{bmatrix} w_{00} & w_{10} & \dots & w_{Nr-1,0} \\ w_{01} & w_{11} & \dots & w_{Nr-1,1} \end{bmatrix}^T$.

$\mathbf{W}(n)$ represents the weight matrix of multibeamformers. The received signal vector after FFT operation is given by

$$\begin{aligned}\tilde{\mathbf{Y}}(n) &= \mathbf{F}\mathbf{R}^H(n) \\ &= \sum_{l=0}^{L-1} \mathbf{T}^l\_\tilde{\mathbf{Y}}^0(n) + \sum_{l=0}^{L-1}\sum_{m=1}^{M-1} \mathbf{T}^l\_\tilde{\mathbf{Y}}^m(n) + \eta(n).\end{aligned} \tag{7}$$

Here, $\mathbf{T}^l\_\tilde{\mathbf{Y}}^m(n)$ is the l-th path received signal matrix for the m-th user and $\eta(n)$ is the matrix for the background noise in the frequency domain. The proposed adaptive algorithm for the MIMO-OFDM systems transforms the error signals between the coded pilot symbols of desired user and the corresponding received signals from each multi-antennas, given in the frequency-domain, into the time-domain error signals so that the weights of the adaptive

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multibeamformer are updated in the time-domain in the direction of minimizing the MSE [5]. Therefore, the equation for updating the weight vector of multibeamformers are expressed as follows

$$\mathbf{W}_0(n+1) = \mathbf{W}_0(n) + 2\mu\mathbf{V}(n)\mathbf{F}_p^H(\mathbf{T\_Y}_{0p}^0(n) - \tilde{\mathbf{y}}_p^0(n)) \tag{8}$$

$$\mathbf{W}_1(n+1) = \mathbf{W}_1(n) + 2\mu\mathbf{V}(n)\mathbf{F}_p^H(\mathbf{T\_Y}_{1p}^0(n) - \tilde{\mathbf{y}}_p^1(n)) \tag{9}$$

where

$$\mathbf{F}_p = \begin{bmatrix} \gamma_{0,0} & \gamma_{0,1} & \cdots & \gamma_{0,N-1} \\ \gamma_{1,0} & \gamma_{1,1}\zeta_{1,1} & \cdots & \gamma_{1,N-1}\zeta_{1,N-1} \\ \vdots & \vdots & \vdots & \vdots \\ \gamma_{N-1,0} & \gamma_{N-1,0}\zeta_{N-1,1} & \cdots & \gamma_{N-1,N-1}\zeta_{N-1,N-1} \end{bmatrix}, \zeta_{i,l} = e^{-j2\pi(i)(l)/N},$$

$$\gamma_{i,l} = \begin{cases} 1 & \text{if} \quad l = k\Delta p \text{ or } l = k\Delta p + 1 \\ 0 & \text{otherwise} \end{cases}$$

$$k = 0, 1, 2, \ldots, N_p - 1 \; for \; i = 0, 1, 2, \ldots, N-1.$$

$\mathbf{T\_Y}_{jp}^0(n)$ and $\tilde{\mathbf{y}}_p^j(n)$ denote the coded pilot symbol vector of desired user and the received pilot signal vector in the frequency domain for the j-th beamformer, respectively.

After decoding, the detected signal at the i-th subcarrier is calculated by

$$z_0 = \left(\left|{}^0\alpha_{00}^0\right|^2 + \left|{}^0\alpha_{10}^0\right|^2 + \left|{}^0\alpha_{01}^0\right|^2 + \left|{}^0\alpha_{11}^0\right|^2 \right) {}^0y_0^0 + I_0 + I_{\inf 0} + \eta_0 \tag{10}$$

$$z_1 = \left(\left|{}^0\alpha_{00}^0\right|^2 + \left|{}^0\alpha_{10}^0\right|^2 + \left|{}^0\alpha_{01}^0\right|^2 + \left|{}^0\alpha_{11}^0\right|^2 \right) {}^0y_1^0 + I_1 + I_{\inf 1} + \eta_1. \tag{11}$$

Here, ${}^ly_k^m(= e^{-j2\pi\tau_l k/N}y_k^m)$ is the l-th delayed path signal of the m-th user which is transmitted the k-th subcarrier and I_i, $I_{\inf i}$ are the interference signals of multipath and other user to the i-th detected signal and η_i is the noise. And ${}^l\alpha_{ij}^m$ is defined as follows

$$\begin{aligned} {}^l\alpha_{00}^m &= {}^la^{m*}(\theta_{00})w_{00} + {}^la^{m*}(\theta_{10})w_{10} + \ldots + {}^la^{m*}(\theta_{Nr-10})w_{Nr-10} \\ {}^l\alpha_{01}^m &= {}^la^{m*}(\theta_{00})w_{01} + {}^la^{m*}(\theta_{10})w_{11} + \ldots + {}^la^{m*}(\theta_{Nr-10})w_{Nr-11} \\ {}^l\alpha_{10}^m &= {}^la^{m*}(\theta_{01})w_{00} + {}^la^{m*}(\theta_{11})w_{10} + \ldots + {}^la^{m*}(\theta_{Nr-11})w_{Nr-10} \\ {}^l\alpha_{11}^m &= {}^la^{m*}(\theta_{01})w_{01} + {}^la^{m*}(\theta_{11})w_{11} + \ldots + {}^la^{m*}(\theta_{Nr-11})w_{Nr-11} \end{aligned} \quad . \tag{12}$$

In Eq. (10), (11), we can get STC diversity gain and reduce CCI even though DOAs of the signals from multi-transmitter antennas of desired user are different.

3 Simulation and numerical results

In this section, the performances of the proposed technique for the MIMO-OFDM system are investigated by computer simulations. The radio channel for simulation is multipath Jacke's model with maximum time delay which is smaller than the cyclic prefix. The number of user (M) and multipath (L)

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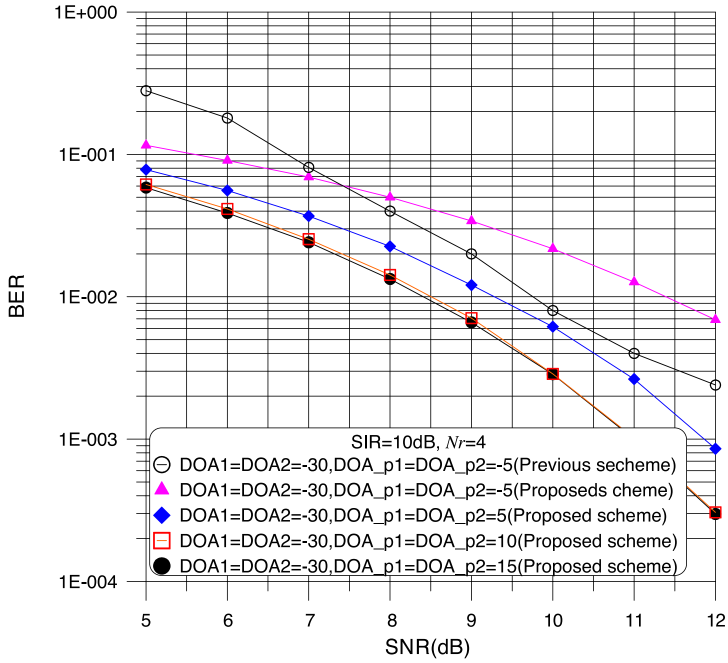

Fig. 2. BER performance of MIMO-OFDM with the proposed multibeamforming (DOACCI1 $= 45°$, DOACCI2 $= 60°$, DOACCI_p1 $= 70°$, DOACCI_p2 $= 85°$)

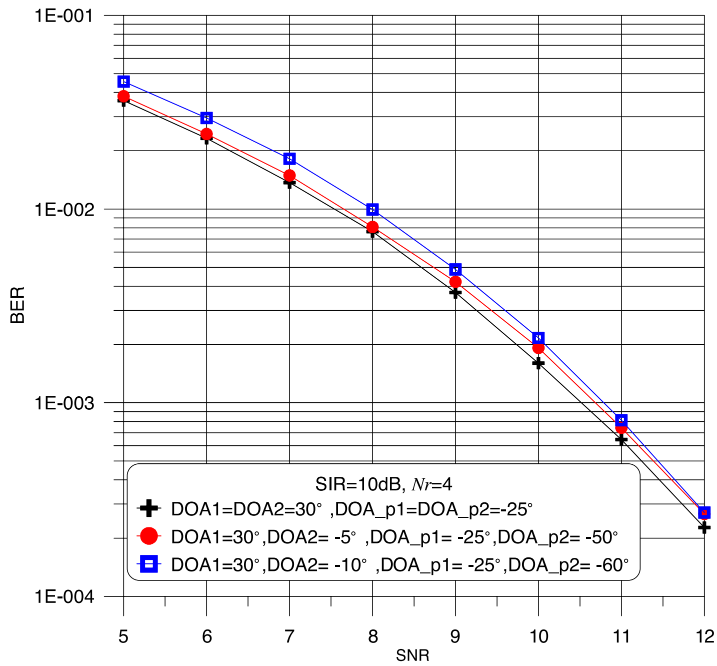

Fig. 3. BER performance of MIMO-OFDM system when DOAs of the desired signals from two transmitter antennas are different (DOACCI1 $= -65°$, DOACCI2 $= -70°$, DOACCI_p1 $= -80°$, DOACCI_p2 $= -85°$)

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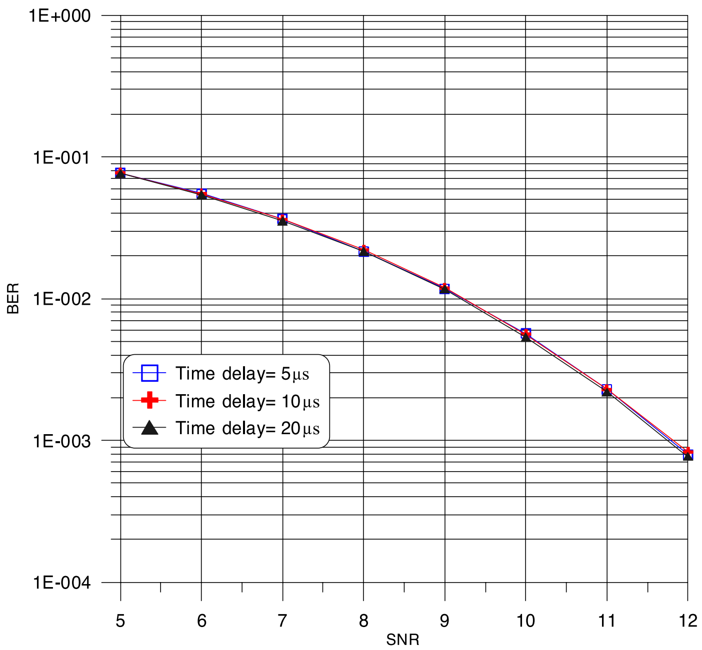

Fig. 4. BER performance of MIMO-OFDM system in the multipath channel with different time delays

are 2. The modulation scheme is QPSK and the size (N) of one OFDM block including pilot symbol is 256. Figure 2 shows the BER assuming that each DOA of desired signals (DOA1, DOA2) from two transmitter antennas and and multipath signals (DOA_p1, DOA_p2) is the same direction. We compare the performance of the proposed approach with the previous scheme [4]. This figure shows that the BER performance of the proposed approach is better than that of the previous scheme when the distance between the DOA of desired signal and that of the delayed path signal is large. When each DOA of the desired signals from two transmitter antennas is different, the BER is shown in the figure 3. It is shown that BER is not affected by the impinging angles of the desired signals. Figure 4 shows that the performance of the proposed scheme is not affected by the time delay due to removal of delayed path when the guard interval is larger than the time delay.

4 Conclusion

In this letter, we proposed an effective CCI cancellation technique that combines STC with pre-FFT multi-beamforming for MIMO-OFDM system while preserving the STC diversity. From the simulation results, we concluded that the proposed approach could significantly increase the performance of MIMO-OFDM system in the multipath fading channel with CCI. BER performance was insensitive to the impinging angle of desired signals and the time delay.

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