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Iterative OSTBC-based Multi-User MIMO Interference Cancellation for Uplink Systems

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ABSTRACT

In next-generation wireless communication systems, high-rate data transmission is required with the multimedia contents. Therefore, the wireless communication technology of high channel capacity is required. The Multiple antenna wireless communication systems have recently significant attention due to their higher capacity and better immunity to fading. Multi-user multiple-input multiple-output (MIMO) uplink transmission system has a trade-off between multiplexing and diversity scheme. There are several methods for obtaining the diversity gain in a special space multiplexing technique. Orthogonal space-time block codes (OSTBC) can be obtained diversity gain by reducing the muti-user interference (MUI). In space-time code, OSTBC scheme is the best method to simplify encoding and decoding and improves the diversity gain. This scheme is used by reducing the MUI in a wireless communication system. However, it is only applicable for downlink transmission. In uplink transmission system, one method that tried to reduce MUI using the unitary property of OSTBC configured the same number of receive antennas with the number of users at the base station, and each receive antenna could detect only single user signal. Therefore, even when equipped with multiple number of receive antennas larger than the number of users, receiver diversity gain can not be obtained. In this paper, we propose an interference cancellation detector with a simple decoding structure for a multi-user MIMO uplink transmission system that utilizes the equivalent channel of each user using the special property of the OSTBC. The proposed OSTBC-based interference cancellation algorithm reduces interferences received from the other users, and simultaneously diversity gain can be achieved. The simulation results validate the proposed algorithm in terms of the bit error rate (BER) performance.

KEYWORDS: Interferences, Multiple-input-multiple-output (MIMO), Multi-users, Orthogonal Space Time Block Code (OSTBC), Uplink

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1. Introduction

The MIMO scheme offers improved capacity and reliability compared with single-antenna wireless systems [1]. Several MIMO techniques have been studied for spatial multiplexing [2] or for spatial diversity [3], [4]. However, these approaches share two major drawbacks of multi-user MIMO uplink systems. The first problem is multiple user interference (MUI), which depends on the number of users. In order to solve this problem, the combined minimum mean square error and successive interference cancellation (MMSE-SIC) scheme has been studied [5]-[7]. The MMSE-SIC scheme shows excellently improved performance in the presence of weak interference. On the contrary, in the presence of strong interference from the other user in this scheme, the performance is degraded. The second problem is that spatial multiplexing [2] and spatial diversity [3], [4] cannot be obtained simultaneously.

For diversity, some research has focused on obtaining high diversity gain in the receiver [8]-[10]. In [9], the suggested technology provided a decoding method that focused on achieving full diversity gain through the virtues of a quasi-orthogonal space-time block code (QOSTBC); however, it is only applicable for downlink transmission. For uplink transmission, a conventional decoding method [11], [12] uses QOSTBC at user equipment (UE) with multiple transmit antennas and at base station with multiple receive antennas that is more than the number of UE. In uplink transmission system, one method that tried to reduce MUI using the unitary property of orthogonal space-time block codes (OSTBC) [13] configured the same number of receive antennas with the number of users at the base station, and each receive antenna could detect only single user signal. Therefore, even when equipped with multiple number of receive antennas larger than the number of users, we cannot expect to obtain the receiver diversity gain.

In this paper, an OSTBC-based interference cancellation algorithm is used for improving the MUI cancellation performance of the OSTBC scheme and compensating the disadvantage of the system in [13]. From utilizing the special structure of OSTBC [13], an iterative MUI cancellation decoding algorithm is derived. The proposed algorithm can significantly reduce the undesired user signals and provide diversity gain at the same time.

The rest of the paper is organized as follows. Section II presents the features and properties of the OSTBC scheme. In section III, we describe the conventional iteration interference cancellation decoding method and the proposed method with MUI cancellation of OSTBC. In section IV, we evaluate the simulation results based on the description. Finally, our conclusions are given in section V.

2. OSTBC Scheme

The OSTBC is one of the space-time coding schemes. This scheme allows full diversity gain with simple encoding and decoding structures [9], and is presented in [8] with *N* transmit antennas and an OSTBC codeword with *N* symbols. The channel gain $h=\left[h_0 \cdots h_{N-1}\right]$ is a row vector of *N* symbols to be transmitted, thus the OSTBC channel matrix $\mathbf{H}$ is expressed as

$$\mathbf{H}=\begin{bmatrix} \mathbf{h}\mathbf{A}_0+\mathbf{h}^*\mathbf{B}_0^* \\ \vdots \\ \mathbf{h}\mathbf{A}_{N-1}+\mathbf{h}^*\mathbf{B}_{N-1}^* \end{bmatrix}, \tag{1}$$

where A_n and B_n are the $N\times N$ real constant coefficient matrices of OSTBC.

For example, in the case of *N* = 2, A_n and B_n with zero-th and first time slot using the Alamouti scheme can be expressed as

$$\mathbf{A}_0=\mathbf{I}_{2\times 2},\quad \mathbf{B}_0=\mathbf{0}_{2\times 2},\quad \mathbf{A}_1=\mathbf{0}_{2\times 2},\quad \mathbf{B}_1=\begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix}. \tag{2}$$

With (2), we can obtain the OSTBC matrix $H=\begin{bmatrix} hA_0 \\ h^*B_0 \end{bmatrix}=\begin{bmatrix} h_0 & h_1 \\ -h_1^* & h_0^* \end{bmatrix}$ is simplified and satisfied as

$$\begin{aligned}\mathbf{H}^{\mathbf{H}}\mathbf{H}&=\begin{bmatrix} h_0^* & -h_1 \\ h_1^* & h_0 \end{bmatrix}\cdot\begin{bmatrix} h_0 & h_1 \\ -h_1^* & h_0^* \end{bmatrix} \\ &=\begin{bmatrix} h_0^*h_0+h_1h_1^* & 0 \\ 0 & h_0^*h_0+h_1h_1^* \end{bmatrix}=\|\mathbf{H}\|^2\cdot\mathbf{I}_{2\times 2},\end{aligned} \tag{3}$$

where $[\,\bullet\,]^H$ is the Hermitian operation.

The MIMO system is assumed that a base station has M receive antennas. Through *N* transmit antennas, each user transmits the OSTBC codeword. The OSTBC codeword matrix **S**(*k*) of the *k*-th user can be expressed as [13]

$$\mathbf{S}(k)=\left[\mathbf{A}_0\mathbf{s}_k+\mathbf{B}_0^*\mathbf{s}_k,\cdots,\mathbf{A}_{N-1}\mathbf{s}_k+\mathbf{B}_{N-1}^*\mathbf{s}_k\right], \tag{4}$$

where s_k is the transmitted source data vector $s_k=\left[s_{k0},\cdots,s_{k(N-1)}\right]^T$ of the k-th user with the OSTBC code length of *N*.

The received signal matrix **Y** of uplink can be expressed as

$$Y=\sum_{k=0}^{K-1}H(k)S(k)+n, \tag{5}$$

where $H(k)$ is the $N\times N$ channel matrix at the base station, and **n** is the independent identically distributed (i.i.d.) complex-valued additive white Gaussian noise (AWGN) matrix with zero mean and variance σ^2.

It is assumed that the base station has perfect knowledge of each uplink channel from all of the users.

3. Iterative MUI Cancellation

3.1 Conventional interference cancellation

OSTBC-based conventional interference cancellation of the uplink was presented to solve the MUI problem [13]. It is assumed that the number of users of *K* equals the number of receive antennas of *M*, *K* = *M*.

The received signal of each receive antenna, r_m, with the OSTBC code length of N can be expressed as

$$\begin{aligned}\mathbf{r}_m &= \left[r_{m0},\cdots,r_{m(N-1)}\right]^T \\ &= \sum_{k=0}^{K-1}\mathbf{C}_{mk}\mathbf{s}_k + \mathbf{n}_m, \quad m=0,\ldots,M-1\end{aligned}, \qquad (6)$$

where $C_{mk} = \begin{bmatrix} h_{mk}A_{0} + (h_{mk})^{*}B_0^{*} \\ \vdots \\ h_{mk}A_{N-1} + (h_{mk})^{*}B_{N-1}^{*} \end{bmatrix}$ and $n_m = \begin{bmatrix} n_{m0} \\ \vdots \\ n_{m(N-1)} \end{bmatrix}$ which h_{mk} is the row vector of the channel coefficient for the *k-th* user on the *m-th* antenna. It is assumed that fading is not dependent on the time. Structure of the equivalent channel C_{mk} is identical to structure of **X** in (1).

Fig. 1 shows the conventional OSTBC-based interference cancellation [13]. For OSTBC operation, it is assumed that the M receiver antennas and K users.

In the first iteration, new r_m is obtained by r_0 multiplied by the standardized C_{00}^H subtracted from r_m multiplied by the standardized C_{m0}^H for reduce interference s_0. New equivalent channel response C_{mk} can be obtained each iteration as

$$\mathbf{C}_{mk} = \frac{\mathbf{C}_{mi}^H\mathbf{C}_{mk}}{\frac{1}{2}\times\left\|\mathbf{C}_{mi}\right\|^2} - \frac{\mathbf{C}_{ii}^H\mathbf{C}_{ik}}{\frac{1}{2}\times\left\|\mathbf{C}_{ii}\right\|^2}, \qquad (7)$$

where a variable i, indicating the number of performed iterations is initialized to zero.

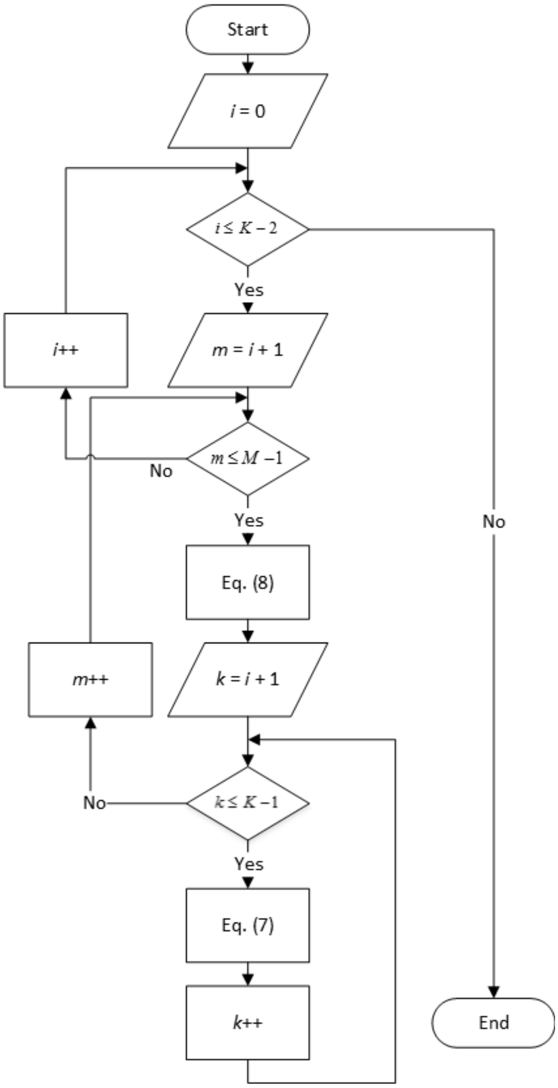

그림 1. 종래의 OSTBC를 이용한 간섭 제거 기법
Figure 1. Conventional interference cancellation with OSTBC

The OSTBC structure of this channel response C_{mk} is maintained, while the iterative method reduces the interferences. Interference is reduced by the same operation from 2 to $M-1$ iteration as

$$\mathbf{r}_m = \frac{\mathbf{C}_{mi}^H}{\frac{1}{2}\times\left\|\mathbf{C}_{mi}\right\|^2}\mathbf{r}_m - \frac{\mathbf{C}_{ii}^H}{\frac{1}{2}\times\left\|\mathbf{C}_{ii}\right\|^2}\mathbf{r}_i \quad . \tag{8}$$

In the last M iteration, received signal r_{M-1} is obtained by r_{K-2} multiplied by the standardized $C^H_{(K-2)(K-2)}$ subtracted from r_{M-1} multiplied by the standardized $C^H_{(M-1)(K-2)}$ for reduce interference s_{K-2}.

The received signal r_{M-1} through M iterations can be expressed as

$$\begin{aligned}\mathbf{r}_{M-1} = &\left(\frac{\mathbf{C}^H_{(M-1)(K-2)}\mathbf{C}_{(M-1)(K-1)}}{\frac{1}{2}\left\|\mathbf{C}_{(M-1)(K-2)}\right\|^2} - \frac{\mathbf{C}^H_{(K-2)(K-2)}\mathbf{C}_{(K-2)(K-1)}}{\frac{1}{2}\left\|\mathbf{C}_{(K-2)(K-2)}\right\|^2}\right)\mathbf{s}_{K-1} \\ &+ \frac{\mathbf{C}^H_{(M-1)(K-2)}}{\frac{1}{2}\left\|\mathbf{C}_{(M-1)(K-2)}\right\|^2}\mathbf{n}_{M-1} - \frac{\mathbf{C}^H_{(K-2)(K-2)}}{\frac{1}{2}\left\|\mathbf{C}_{(K-2)(K-2)}\right\|^2}\mathbf{n}_{K-2} \quad .\end{aligned} \tag{9}$$

The number of iteration are determined for this algorithm, considering the number of user, K, and the number of receiver antennas, M. This method has to identically configure the number of receive antennas and users, and each receive antenna could only detect a single user signal. Therefore, even when equipped with multiple receive antennas, this method could not provide receiver diversity gain.

3.2 Proposed interference cancellation

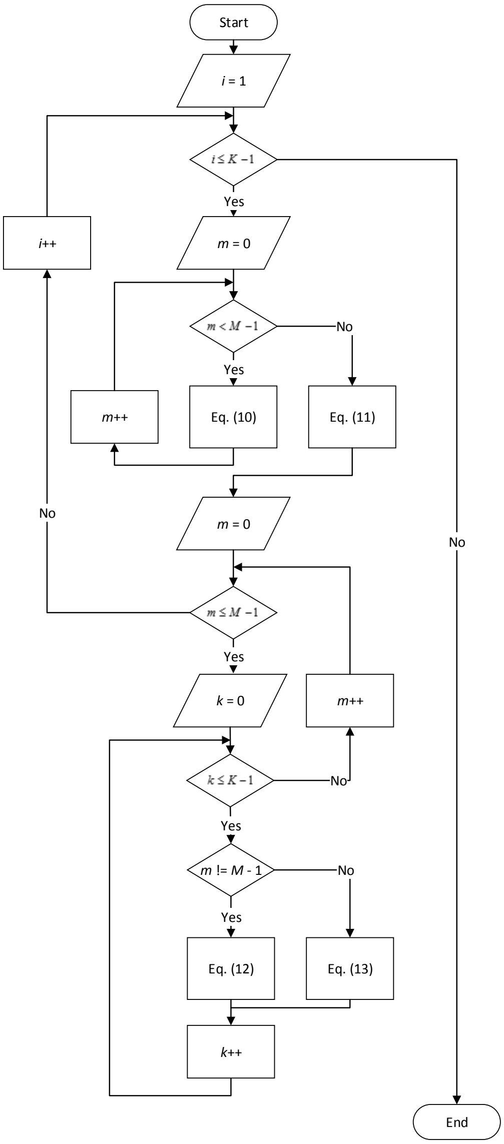

그림 2. OSTBC를 이용한 새로운 간섭 제거 기법
Figure 2. New interference cancellation with OSTBC

The conventional MUI cancellation method configures the same number of antennas as of users. By using one receive antenna among M antennas, one user’s symbol can be detected to reduce the undesired user signals one-by-one, in sequence. Each receive antenna detects a different user signal. Therefore, this scheme cannot provide diversity gain even when the system is equipped with multiple receive antennas.

In this section, we propose a new MUI cancellation scheme to overcome the disadvantage of the conventional MUI cancellation algorithm with the same number of antennas and users. This method reduces the interference by subtracting the received signal of a next antenna from that of a specific antenna that is not last antenna and the received signal of a first antenna from that of a last antenna.

<Fig. 2> shows the proposed new OSTBC-based interference cancellation. For OSTBC operation, it is assumed that the M receiver antennas and K users.

In the first iteration, i = 1, if m is not equal to M - 1, new signal of m-th antenna $r_m^{(1)}$ is obtained by initial signal of (m + 1)-th antenna $r_{m+1}^{(0)}$ multiplied by the standardized $\left(C_{(m+1)1}^{(0)}\right)^H$ subtracted from initial signal of m-th antenna $r_m^{(0)}$ multiplied by the standardized $\left(C_{m1}^{(0)}\right)^H$ for reduce interference s_1. Otherwise, new signal of last antenna $r_{M-1}^{(1)}$ is obtained by initial signal of first antenna $r_0^{(0)}$ multiplied by the standardized $\left(C_{01}^{(0)}\right)^H$ subtracted from initial signal of last antenna $r_{M-1}^{(0)}$ multiplied by the standardized $\left(C_{(M-1)1}^{(0)}\right)^H$ for reduce interference s_1. New equivalent channel response C_{mk} can be obtained each iteration as

$$\mathbf{C}_{mk}^{(i)} = \frac{\left(\mathbf{C}_{mi}^{(i-1)}\right)^H \mathbf{C}_{mk}^{(i-1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{mi}^{(i-1)}\right\|^2} - \frac{\left(\mathbf{C}_{(m+1)i}^{(i-1)}\right)^H \mathbf{C}_{(m+1)k}^{(i-1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{(m+1)i}^{(i-1)}\right\|^2} \text{ if } m < M-1 \quad , \qquad (10)$$

$$\mathbf{C}_{mk}^{(i)} = \frac{\left(\mathbf{C}_{mi}^{(i-1)}\right)^H \mathbf{C}_{mk}^{(i-1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{mi}^{(i-1)}\right\|^2} - \frac{\left(\mathbf{C}_{0i}^{(i-1)}\right)^H \mathbf{C}_{0k}^{(i-1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{0i}^{(i-1)}\right\|^2} \text{ if } m = M-1 \quad . \qquad (11)$$

Interference is reduced by the same equation from 2 to K iteration as

$$\mathbf{r}_m^{(i)} = \frac{\left(\mathbf{C}_{mi}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{mi}^{(i-1)}\right\|^2}\mathbf{r}_m^{(i-1)} - \frac{\left(\mathbf{C}_{(m+1)i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(m+1)i}^{(i-1)}\right\|^2}\mathbf{r}_{m+1}^{(i-1)} \text{ if } m \neq M-1 \quad , \qquad (12)$$

$$\mathbf{r}_m^{(i)} = \frac{\left(\mathbf{C}_{mi}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{mi}^{(i-1)}\right\|^2}\mathbf{r}_m^{(i-1)} - \frac{\left(\mathbf{C}_{0i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{0i}^{(i-1)}\right\|^2}\mathbf{r}_0^{(i-1)} \text{ if } m = M-1 \quad . \qquad (13)$$

In the last K iteration, received signal of m-th antenna $r_m^{(K-1)}$ is obtained. The OSTBC structure of this channel response C_{mk} is maintained, while the iterative method reduces the interferences. Therefore, the received signal for the above iterations can be obtained as

$$\begin{aligned}
\mathbf{r}_0^{(i)} &= \frac{\left(\mathbf{C}_{0i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{0i}^{(i-1)}\right\|^2}\mathbf{r}_0^{(i-1)} - \frac{\left(\mathbf{C}_{1i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{1i}^{(i-1)}\right\|^2}\mathbf{r}_1^{(i-1)} \\
\mathbf{r}_1^{(i)} &= \frac{\left(\mathbf{C}_{1i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{1i}^{(i-1)}\right\|^2}\mathbf{r}_1^{(i-1)} - \frac{\left(\mathbf{C}_{2i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{2i}^{(i-1)}\right\|^2}\mathbf{r}_2^{(i-1)} \\
&\vdots \\
\mathbf{r}_{M-1}^{(i)} &= \frac{\left(\mathbf{C}_{(M-1)i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)i}^{(i-1)}\right\|^2}\mathbf{r}_{M-1}^{(i-1)} - \frac{\left(\mathbf{C}_{0i}^{(i-1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{0i}^{(i-1)}\right\|^2}\mathbf{r}_0^{(i-1)} \, .
\end{aligned} \qquad (14)$$

The details of derivation of the proposed interference cancellation algorithm are given in Appendix.

For the desired signal s_0, through K - 1 iterations, results using (14) are as follows:

$$\begin{aligned}\mathbf{r}_0^{(K-1)} &= \mathbf{C}_{00}^{(K-1)}\mathbf{s}_0 + \mathbf{n}_0^{(K-1)}\\ \mathbf{r}_1^{(K-1)} &= \mathbf{C}_{10}^{(K-1)}\mathbf{s}_0 + \mathbf{n}_1^{(K-1)}\\ &\vdots\\ \mathbf{r}_{M-1}^{(K-1)} &= \mathbf{C}_{(M-1)0}^{(K-1)}\mathbf{s}_0 + \mathbf{n}_{M-1}^{(K-1)}\,.\end{aligned} \tag{15}$$

The receiver combining for M branches is as follows:

$$\begin{aligned}\tilde{\mathbf{s}}_0 &= \left(\mathbf{C}_{00}^{(K-1)}\right)^H \mathbf{r}_0^{(K-1)} + \left(\mathbf{C}_{10}^{(K-1)}\right)^H \mathbf{r}_1^{(K-1)} + \cdots\\ &\quad + \left(\mathbf{C}_{(M-1)0}^{(K-1)}\right)^H \mathbf{r}_{M-1}^{(K-1)}\\ &= \left(\alpha_0^2 + \alpha_1^2 + \alpha_2^2 + \cdots + \alpha_{M-1}^2\right)\mathbf{s}_0\\ &\quad + \left(\mathbf{C}_{00}^{(K-1)}\right)^H \mathbf{n}_0^{(K-1)} + \left(\mathbf{C}_{10}^{(K-1)}\right)^H \mathbf{n}_1^{(K-1)} + \cdots\\ &\quad + \left(\mathbf{C}_{(M-1)0}^{(K-1)}\right)^H \mathbf{n}_{M-1}^{(K-1)}\end{aligned}\ , \tag{16}$$

where α_m is the amplitude of $C_{m0}^{(K-1)}$. The interference has been reduced and the desired user signal $\tilde{s}_0$ can be obtained.

The number of iteration are determined for this algorithm, considering the number of user, K. This method can be applied for a system with different numbers of receive antennas and users. Therefore, diversity gain can be obtained due to antenna combining.

4. Simulation Results

In this section, the bit error rate (BER) performance of the proposed approach is compared to that of the conventional approach described in [13].

We consider a large number of users, with two transmit antennas for each user, for use with the Alamouti OSTBC scheme, and we assume that the channel is Rayleigh flat fading. Also, we assume that the channel state information (CSI) is perfectly known to the receiver.

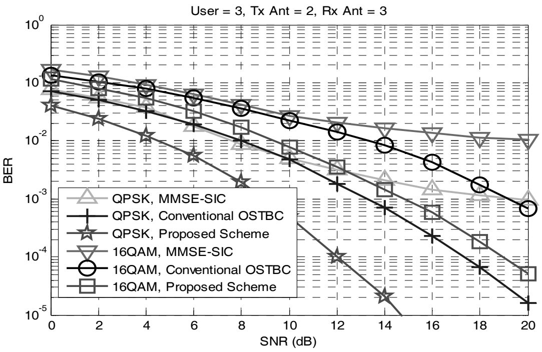

그림 3. 사용자가 3명이고, 2개의 송신 안테나와 3개의 수신 안테나를 사용했을 때의 BER 성능 비교

Figure 3. Comparison of BER performance with three users, two transmit antennas, and three receive antennas

<Fig. 3> shows the BER performance comparisons for MMSE-SIC, the conventional OSTBC, and the proposed methods when the number of users is three. The transmitter has two antennas for the Alamouti OSTBC. In the conventional OSTBC method, the number of receive antennas should be the same as the number of users, because each receive antenna can recover

only one user signal. From these plots, we observe that the proposed method shows superior performance compared to the conventional method because of diversity effects. For $BER = 10^{-3}$, the proposed interference cancellation can achieve about 4dB and 11dB of performance gain compared with the conventional OSTBC and MMSE-SIC, respectively, with QPSK modulation. In addition, the proposed method can significantly reduce the undesired user signals and provide diversity gain at the same time. Therefore, the performance gain of the proposed method is improved because the residual component is minimized.

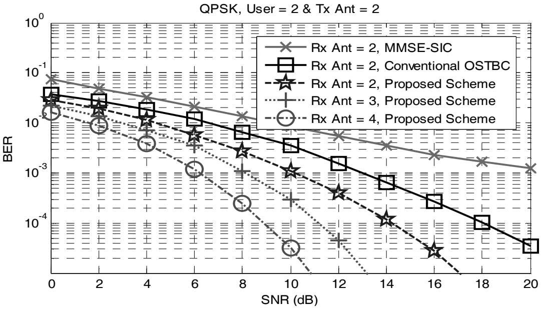

그림 4. 사용자가 2명이고, 2개의 송신 안테나를 사용하고 수신 안테나 수를 다르게 사용했을 때 QPSK의 BER 성능 비교
Figure 4. Comparison of BER performances of QPSK with two users, two transmit antennas, and different numbers of receive antennas

<Fig. 4> compares the BER performances of QPSK with two users, two transmit antennas, and for different numbers of receive antennas. In the conventional scheme, the number of users and receive antennas must be the same. However, in proposed scheme, the number of users and receive antennas can be different number and diversity gain can be obtained. For $BER = 10^{-4}$, the proposed new OSTBC interference cancellation scheme with two receive antennas, three receive antennas, and four receive antennas can achieve about 4dB, 7dB, and 9dB performance gain compared with the conventional, respectively. It is improved that the performance of proposed scheme with high diversity gain as the increasing number of receive antennas.

5. Conclusions

In a multiple antenna system with multiple users, it is essential to reduce MUI in order to improve the system performance. However, the conventional method using the unitary property of OSTBC provides limited performance without diversity gain even though it used iterative MUI cancellation. Furthermore, this method required the same number of receive antennas and users.

In this paper, we proposed a new interference cancellation scheme to resolve these disadvantages of the conventional interference cancellation algorithm. The proposed algorithm using the orthogonal characteristic of OSTBC iteratively reduces the interference signals of other users even when the numbers of users and antennas are different. Therefore, the proposed OSTBC-based interference cancellation algorithm can be used to improve the performance of MIMO systems, because the residual component is minimized and diversity gain is obtained.

The proposed new OSTBC-based interference cancellation can be used to improve the performance of multi-user MIMO systems.

Appendix Computation of Proposed Interference Cancellation

For desired signal s_0 detection, the new interference cancellation can be described as follow:

In the first iteration, *i* = 1, if m is not equal to *M* - 1, new signal of *m*-th antenna $r_m^{(1)}$ is obtained by initial signal of (*m* + 1)-th antenna $r_{m+1}^{(0)}$ multiplied by the standardized $\left(C_{(m+1)1}^{(0)}\right)^H$ subtracted from initial signal of m-th antenna $r_m^{(0)}$ multiplied by the standardized $\left(C_{m1}^{(0)}\right)^H$ for reduce interference s_1 as

$$\begin{aligned}
\mathbf{r}_0^{(1)} &= \frac{\left(\mathbf{C}_{01}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{01}^{(0)}\right\|^2}\mathbf{r}_0^{(0)} - \frac{\left(\mathbf{C}_{11}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{11}^{(0)}\right\|^2}\mathbf{r}_1^{(0)} \\
&= \frac{\left(\mathbf{C}_{01}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{01}^{(i-1)}\right\|^2}\left(\mathbf{C}_{00}^{(0)}\mathbf{s}_0 + \mathbf{C}_{02}^{(0)}\mathbf{s}_2 + \cdots + \mathbf{C}_{0(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_0^{(0)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{11}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{11}^{(0)}\right\|^2}\left(\mathbf{C}_{10}^{(0)}\mathbf{s}_0 + \mathbf{C}_{12}^{(0)}\mathbf{s}_2 + \cdots + \mathbf{C}_{1(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_1^{(0)}\right) \\
\mathbf{r}_1^{(1)} &= \frac{\left(\mathbf{C}_{11}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{11}^{(0)}\right\|^2}\mathbf{r}_1^{(0)} - \frac{\left(\mathbf{C}_{21}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{21}^{(0)}\right\|^2}\mathbf{r}_2^{(0)} \\
&= \frac{\left(\mathbf{C}_{11}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{11}^{(0)}\right\|^2}\left(\mathbf{C}_{10}^{(0)}\mathbf{s}_0 + \mathbf{C}_{12}^{(0)}\mathbf{s}_2 + \cdots + \mathbf{C}_{1(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_1^{(0)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{21}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{21}^{(0)}\right\|^2}\left(\mathbf{C}_{20}^{(0)}\mathbf{s}_0 + \mathbf{C}_{22}^{(0)}\mathbf{s}_2 + \cdots + \mathbf{C}_{2(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_2^{(0)}\right) \\
&\vdots \\
\mathbf{r}_{M-2}^{(1)} &= \frac{\left(\mathbf{C}_{(M-2)1}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-2)1}^{(0)}\right\|^2}\mathbf{r}_1^{(0)} - \frac{\left(\mathbf{C}_{(M-1)1}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)1}^{(0)}\right\|^2}\mathbf{r}_2^{(0)} \\
&= \frac{\left(\mathbf{C}_{(M-2)1}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-2)1}^{(0)}\right\|^2}\left(\mathbf{C}_{(M-2)0}^{(0)}\mathbf{s}_0 + \cdots + \mathbf{C}_{(M-2)(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_{(M-2)}^{(0)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{(M-1)1}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)1}^{(0)}\right\|^2}\left(\mathbf{C}_{(M-1)0}^{(0)}\mathbf{s}_0 + \cdots + \mathbf{C}_{(M-1)(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_{(M-1)}^{(0)}\right).
\end{aligned} \tag{17}$$

Otherwise, new signal of last antenna $r_{M-1}^{(1)}$ is obtained by initial signal of first antenna $r_0^{(0)}$ multiplied by the standardized $\left(C_{01}^{(0)}\right)^H$ subtracted from initial signal of last antenna $r_{M-1}^{(0)}$ multiplied by the standardized $\left(C_{(M-1)1}^{(0)}\right)^H$ for reduce interference s_1 as

$$\begin{aligned}
\mathbf{r}_{M-1}^{(1)} &= \frac{\left(\mathbf{C}_{(M-1)1}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)1}^{(0)}\right\|^2}\mathbf{r}_{M-1}^{(0)} - \frac{\left(\mathbf{C}_{01}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{01}^{(0)}\right\|^2}\mathbf{r}_0^{(0)} \\
&= \frac{\left(\mathbf{C}_{(M-1)1}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)1}^{(0)}\right\|^2}\left(\mathbf{C}_{(M-1)0}^{(0)}\mathbf{s}_0 + \cdots + \mathbf{C}_{(M-1)(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_{M-1}^{(0)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{01}^{(0)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{01}^{(0)}\right\|^2}\left(\mathbf{C}_{00}^{(0)}\mathbf{s}_0 + \cdots + \mathbf{C}_{0(K-1)}^{(0)}\mathbf{s}_{K-1} + \mathbf{n}_0^{(0)}\right).
\end{aligned} \tag{18}$$

If m is not equal to *M* - 1, new equivalent channel response $C_{mk}^{(1)}$ can be obtained as

$$\mathbf{C}_{mk}^{(1)} = \frac{\left(\mathbf{C}_{m1}^{(0)}\right)^H\mathbf{C}_{mk}^{(0)}}{\frac{1}{2}\times\left\|\mathbf{C}_{m1}^{(0)}\right\|^2} - \frac{\left(\mathbf{C}_{(m+1)1}^{(0)}\right)^H\mathbf{C}_{(m+1)k}^{(0)}}{\frac{1}{2}\times\left\|\mathbf{C}_{(m+1)1}^{(0)}\right\|^2}. \tag{19}$$

Otherwise

$$\mathbf{C}_{mk}^{(1)} = \frac{\left(\mathbf{C}_{m1}^{(0)}\right)^H\mathbf{C}_{mk}^{(0)}}{\frac{1}{2}\times\left\|\mathbf{C}_{m1}^{(0)}\right\|^2} - \frac{\left(\mathbf{C}_{01}^{(0)}\right)^H\mathbf{C}_{0k}^{(0)}}{\frac{1}{2}\times\left\|\mathbf{C}_{01}^{(0)}\right\|^2}. \tag{20}$$

The OSTBC structure of this *i*-th iteration channel response $C_{mk}^{(i)}$ is maintained.

In the second iteration, *i* = 2, if m is not equal to M - 1, new signal of m-th antenna $r_m^{(2)}$ is obtained by previous signal of (m + 1)-th antenna $r_{m+1}^{(1)}$ multiplied by the standardized $\left(C_{(m+1)2}^{(1)}\right)^H$ subtracted from previous signal of m-th antenna $r_m^{(1)}$ multiplied by the standardized $\left(C_{m2}^{(1)}\right)^H$ for reduce interference s_2 as

$$\begin{aligned}
\mathbf{r}_0^{(2)} &= \frac{\left(\mathbf{C}_{02}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{02}^{(1)}\right\|^2}\mathbf{r}_0^{(1)} - \frac{\left(\mathbf{C}_{12}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{12}^{(1)}\right\|^2}\mathbf{r}_1^{(1)} \\
&= \frac{\left(\mathbf{C}_{02}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{02}^{(1)}\right\|^2}\left(\mathbf{C}_{00}^{(1)}\mathbf{s}_0 + \mathbf{C}_{03}^{(1)}\mathbf{s}_3 + \cdots + \mathbf{C}_{0(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_0^{(1)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{12}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{12}^{(1)}\right\|^2}\left(\mathbf{C}_{10}^{(1)}\mathbf{s}_0 + \mathbf{C}_{13}^{(1)}\mathbf{s}_3 + \cdots + \mathbf{C}_{1(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_1^{(1)}\right) \\
\mathbf{r}_1^{(2)} &= \frac{\left(\mathbf{C}_{12}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{12}^{(0)}\right\|^2}\mathbf{r}_1^{(1)} - \frac{\left(\mathbf{C}_{22}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{22}^{(0)}\right\|^2}\mathbf{r}_2^{(1)} \\
&= \frac{\left(\mathbf{C}_{12}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{12}^{(0)}\right\|^2}\left(\mathbf{C}_{10}^{(1)}\mathbf{s}_0 + \mathbf{C}_{13}^{(1)}\mathbf{s}_3 + \cdots + \mathbf{C}_{1(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_1^{(1)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{22}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{22}^{(0)}\right\|^2}\left(\mathbf{C}_{20}^{(1)}\mathbf{s}_0 + \mathbf{C}_{23}^{(1)}\mathbf{s}_3 + \cdots + \mathbf{C}_{2(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_2^{(1)}\right) \\
&\vdots \\
\mathbf{r}_{M-2}^{(2)} &= \frac{\left(\mathbf{C}_{(M-2)2}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-2)2}^{(0)}\right\|^2}\mathbf{r}_1^{(1)} - \frac{\left(\mathbf{C}_{(M-1)2}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)2}^{(0)}\right\|^2}\mathbf{r}_2^{(1)} \\
&= \frac{\left(\mathbf{C}_{(M-2)2}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-2)2}^{(0)}\right\|^2}\left(\mathbf{C}_{(M-2)0}^{(1)}\mathbf{s}_0 + \cdots + \mathbf{C}_{(M-2)(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_{(M-2)}^{(1)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{(M-1)2}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)2}^{(0)}\right\|^2}\left(\mathbf{C}_{(M-1)0}^{(1)}\mathbf{s}_0 + \cdots + \mathbf{C}_{(M-1)(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_{(M-1)}^{(1)}\right).
\end{aligned} \tag{21}$$

Otherwise, new signal of last antenna $r_{M-1}^{(2)}$ is obtained by previous signal of first antenna $r_0^{(1)}$ multiplied by the standardized $\left(C_{02}^{(1)}\right)^H$ subtracted from previous signal of last antenna $r_{M-1}^{(1)}$ multiplied by the standardized $\left(C_{(M-1)2}^{(1)}\right)^H$ for reduce interference s_2 as

$$\begin{aligned}
\mathbf{r}_{M-1}^{(2)} &= \frac{\left(\mathbf{C}_{(M-1)2}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)2}^{(1)}\right\|^2}\mathbf{r}_{M-1}^{(1)} - \frac{\left(\mathbf{C}_{02}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{02}^{(1)}\right\|^2}\mathbf{r}_0^{(1)} \\
&= \frac{\left(\mathbf{C}_{(M-1)2}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{(M-1)2}^{(1)}\right\|^2}\left(\mathbf{C}_{(M-1)0}^{(1)}\mathbf{s}_0 + \cdots + \mathbf{C}_{(M-1)(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_{M-1}^{(1)}\right) \\
&\quad - \frac{\left(\mathbf{C}_{02}^{(1)}\right)^H}{\frac{1}{2}\times\left\|\mathbf{C}_{02}^{(1)}\right\|^2}\left(\mathbf{C}_{00}^{(1)}\mathbf{s}_0 + \cdots + \mathbf{C}_{0(K-1)}^{(1)}\mathbf{s}_{K-1} + \mathbf{n}_0^{(1)}\right).
\end{aligned} \quad . \tag{22}$$

If m is not equal to M − 1, new equivalent channel response $C_{mk}^{(2)}$ can be obtained as

$$\mathbf{C}_{mk}^{(2)} = \frac{\left(\mathbf{C}_{m2}^{(1)}\right)^H\mathbf{C}_{mk}^{(1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{m2}^{(1)}\right\|^2} - \frac{\left(\mathbf{C}_{(m+1)2}^{(1)}\right)^H\mathbf{C}_{(m+1)k}^{(1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{(m+1)2}^{(1)}\right\|^2} \quad . \tag{23}$$

Otherwise

$$\mathbf{C}_{mk}^{(2)} = \frac{\left(\mathbf{C}_{m2}^{(1)}\right)^H\mathbf{C}_{mk}^{(1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{m2}^{(1)}\right\|^2} - \frac{\left(\mathbf{C}_{02}^{(1)}\right)^H\mathbf{C}_{0k}^{(1)}}{\frac{1}{2}\times\left\|\mathbf{C}_{02}^{(1)}\right\|^2} \quad . \tag{24}$$

Interference is reduced by the same equation from 3 to K − 1 iteration. In the last K iteration, received signal of m-th antenna $r_m^{(K-1)}$ is obtained by previous signal of (m + 1)-th antenna $r_{m+1}^{(K-2)}$ multiplied by the standardized $\left(C_{(m+1)(K-1)}^{(K-2)}\right)^H$ subtracted from previous signal of m-th antenna $r_m^{(K-2)}$ multiplied by the standardized

$\left(C_{m(K-1)}^{(K-2)}\right)^H$ for reduce interference s_{K-1} as

$$\begin{aligned}
r_0^{(K-1)} &= \frac{\left(C_{0(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{0(K-1)}^{(K-2)}\parallel^2} r_0^{(K-2)} - \frac{\left(C_{1(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{1(K-1)}^{(K-2)}\parallel^2} r_1^{(K-2)} \\
&= \frac{\left(C_{0(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{0(K-1)}^{(K-2)}\parallel^2}\left(C_{00}^{(K-2)} s_0 + n_0^{(K-2)}\right) - \frac{\left(C_{1(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{1(K-1)}^{(K-2)}\parallel^2}\left(C_{10}^{(K-2)} s_0 + n_1^{(K-2)}\right)
\end{aligned}$$

$$\begin{aligned}
r_1^{(K-1)} &= \frac{\left(C_{1(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{1(K-1)}^{(K-2)}\parallel^2} r_1^{(K-2)} - \frac{\left(C_{2(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{2(K-1)}^{(K-2)}\parallel^2} r_2^{(K-2)} \\
&= \frac{\left(C_{1(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{1(K-1)}^{(K-2)}\parallel^2}\left(C_{10}^{(K-2)} s_0 + n_1^{(K-2)}\right) - \frac{\left(C_{2(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{2(K-1)}^{(K-2)}\parallel^2}\left(C_{20}^{(K-2)} s_0 + n_2^{(K-2)}\right)
\end{aligned} \tag{25}$$

$$\vdots$$

$$\begin{aligned}
r_{M-2}^{(K-1)} &= \frac{\left(C_{(M-2)(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{(M-2)(K-1)}^{(K-2)}\parallel^2} r_1^{(K-2)} - \frac{\left(C_{(M-1)(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{(M-1)(K-1)}^{(K-2)}\parallel^2} r_2^{(K-2)} \\
&= \frac{\left(C_{(M-2)(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{(M-2)(K-1)}^{(K-2)}\parallel^2}\left(C_{(M-2)0}^{(K-2)} s_0 + n_{(M-2)}^{(K-2)}\right) - \frac{\left(C_{(M-1)(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{(M-1)(K-1)}^{(K-2)}\parallel^2}\left(C_{(M-1)0}^{(K-2)} s_0 + n_{(M-1)}^{(K-2)}\right).
\end{aligned}$$

Otherwise, received signal of last antenna $r_{M-1}^{(K-1)}$ is obtained by previous signal of first antenna $r_0^{(K-2)}$ multiplied by the standardized $\left(C_{0(K-1)}^{(K-2)}\right)^H$ subtracted from previous signal of last antenna multiplied by the standardized for reduce interference s_{K-1} as

$$\begin{aligned}
r_{M-1}^{(K-1)} &= \frac{\left(C_{(M-1)(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{(M-1)(K-1)}^{(K-2)}\parallel^2} r_{M-1}^{(K-2)} - \frac{\left(C_{0(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{0(K-1)}^{(K-2)}\parallel^2} r_0^{(K-2)} \\
&= \frac{\left(C_{(M-1)(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{(M-1)(K-1)}^{(K-2)}\parallel^2}\left(C_{(M-1)0}^{(K-2)} s_0 + n_{(M-1)}^{(K-2)}\right) - \frac{\left(C_{0(K-1)}^{(K-2)}\right)^H}{\frac{1}{2}\parallel C_{0(K-1)}^{(K-2)}\parallel^2}\left(C_{00}^{(K-2)} s_0 + n_0^{(K-2)}\right).
\end{aligned} \tag{26}$$

If m is not equal to total number of antennas M new equivalent channel response $C_{mk}^{(K-1)}$ can be obtained as

$$C_{mk}^{(K-1)} = \frac{\left(C_{m(K-1)}^{(K-2)}\right)^H C_{mk}^{(K-2)}}{\frac{1}{2}\parallel C_{m(K-1)}^{(K-2)}\parallel^2} - \frac{\left(C_{(m+1)(K-1)}^{(K-2)}\right)^H C_{(m+1)k}^{(K-2)}}{\frac{1}{2}\parallel C_{(m+1)(K-1)}^{(K-2)}\parallel^2}. \tag{27}$$

Otherwise

$$C_{mk}^{(K-1)} = \frac{\left(C_{m(K-1)}^{(K-2)}\right)^{H} C_{mk}^{(K-2)}}{\frac{1}{2}\parallel C_{m(K-1)}^{(K-2)}\parallel^{2}} - \frac{\left(C_{0(K-1)}^{(K-2)}\right)^{H} C_{0k}^{(K-2)}}{\frac{1}{2}\parallel C_{0(K-1)}^{(K-2)}\parallel^{2}} \qquad (28)$$

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상향링크 전송 시스템에서 반복적인 OSTBC 기반의 다중 사용자 MIMO 간섭제거 방법

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요 약

차세대 무선 통신 시스템은 멀티미디어 콘텐츠를 포함하는 고속의 데이터 통신이 축이 됨에 따라 고속의 데이터 전송이 요구되어서, 채널 용량이 많은 무선 통신 기술이 필요하게 된다. 차세대 무선 통신 시스템 설계에는 두 가지 큰 문제를 가지고 있다. 하나는 스펙트럼이 부족하다는 것이고, 다른 하나는 페이딩과 간섭에 의한 통화 품질이 저하된다는 것이다. 이러한 문제는 다중 송수신 안테나 시스템을 사용함으로써 해결할 수 있다. 그러나 다중 사용자 MIMO 상향링크 시스템은 다중화기법과 다이버시티 기법간의 트레이드오프가 있다. 특수한 공간 다중화 기법으로 다이버시티 이득을 얻기 위한 몇 가지 방법들이 있는데, 그 중 OSTBC 기법은 다중 사용자 간섭을 제거함으로써 다이버시티 이득을 얻는다. 이러한 시공간 부호 기법 중 OSTBC 기법은 부호화와 복호화가 간단하고 다이버시티 이득을 향상시켜주는 가장 좋은 기법이므로 무선 통신 시스템 설계에서 다중 사용자 간섭을 제거하는 방법으로 많이 이용된다. 그러나 상향링크 전송 시스템에서 OSTBC를 사용하여 MUI를 감소시키는 방법은 기지국에서 사용자의 수와 수신 안테나의 수가 동일해야하고, 각 수신 안테나는 오직 하나의 사용자 신호만 검출할 수 있다. 따라서 사용자의 수보다 더 많은 수신 안테나를 사용하는 경우에도, 수신 다이버시티 이득을 얻을 수 없다. 본 논문에서 우리는 OSTBC의 특성을 이용하여 각 사용자의 채널이 직교성을 유지하는 다중 사용자 MIMO 상향링크 전송 시스템에서 단순한 복호 구조를 갖는 간섭 제거 검출기를 제안한다. 제안된 OSTBC 기반 간섭 제거 알고리즘은 다른 사용자로부터 수신 받은 간섭을 제거하고, 동시에 다이버시티 이득을 얻을 수 있다. 시뮬레이션 결과는 BER 성능 면에서 제안된 알고리즘을 검증한다.

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