LETTER

An Improved Cooperative Technique Sharing the Channel in OFDMA-Based System*

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SUMMARY Cooperative communication has been proposed to improve the disadvantages of the multiple-input multiple-output (MIMO) technique without using extra multiple antennas. In an orthogonal frequency division multiple access (OFDMA) system, a cooperative communication that each user shares their allocated sub-channels instead of the MIMO system has been proposed to improve the throughput. But the cooperative communication has a problem as the decreased throughput because it is necessary that users send and receive the information to each other to improve reliability. In this letter, the modified cooperative transmission scheme is proposed to improve reliability in the fading channel, and it can solve the problem for BER performance that is dependent on the errors in the first phase that exchanges the information between both users during the first time.
key words: *cooperative communication, DF, OFDMA, STBC*

1. Introduction

The MIMO technique has been studied to achieve high reliability and throughput of received data simultaneously, without extra bandwidth and energy consumption in wireless communication systems. The MIMO technique has been already utilized in several wireless communication systems such as LTE, WiMAX and IEEE 802.11ac. But two modes for MIMO and non-MIMO exist in the LTE, WiMAX and IEEE 802.11ac. Because of the constraints for device size, cost, power and hardware implementation, the use of MIMO mode is difficult in the wireless portable devices. Therefore, the OFDM cooperative channel sharing technique for non-MIMO mode is proposed to improve the reliability of transmitted data in the wireless communication systems. But the cooperative communication has a disadvantage of the decreased throughput due to relaying in the cooperation phase. Some schemes were proposed to overcome the disadvantage [4]–[7]. The new transmission scheme [9] was proposed to achieve the improved throughput at 3/4 symbols per channel use. However, the scheme has a serious problem that whole performance is too sensitive to errors occurring in the first phase. The first phase means the first step for exchanging information between both users during the first time. So, in this letter, the modified cooperative transmission structure is proposed to solve the sensitiveness problem for the first phase error that means the error between transmitted signal and decoded signal in the first step for exchanging information. And the BER performance of the proposed scheme is better than the conventional scheme in fading channel.

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2. System Model

2.1 Cooperation Model

The proposed scheme employs decoded and forward space time block code (DF-STBC). Figure 1 shows the system configuration of DF-STBC. The system consists of two users and one base station (BS) with one antenna. Each user relays the received symbols from the other user by using the decoded and forward (DF) cooperation. H_1 and H_2 mean channels between each user and BS. And H_{ic} means a channel between user i and user j. In this letter, it is assumed that the user with the best inter-user channel H_{ic} condition is already selected in the BS by using the received signal to noise ratio (SNR) value. The relative SNR of the inter-user channel means the relative difference of SNR values of the received signals through the direct channel (H_1, H_2) and the inter-user channel (H_{ic}). And it is assumed that each channel remains constant during the cooperation.

2.2 OFDMA System

The OFDMA system consists of K orthogonal sub-carriers and P active users. Each user accesses a sub-channel which

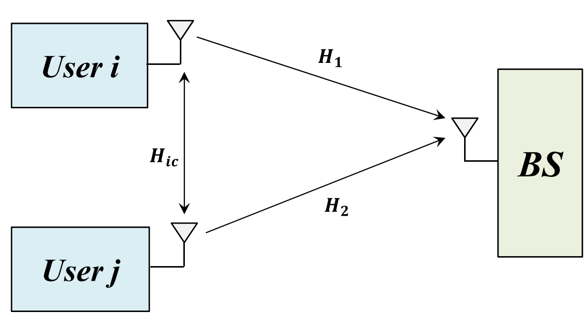

Fig. 1 System configuration of the proposed scheme.

is a cluster of sub-carriers. Each user is assigned to following sub-channel K_p [6], [9],

$$K_p = \{k | N_{K_P} \cdot (p-1) \le k < N_{K_P} \cdot p\}, \quad (1)$$

where k and p mean sub-carrier index and user index respectively. And $N_{K_p} = K/P$ means the number of sub-carriers assigned to each user. In this letter, it is assumed that the number of the subcarriers assigned to two users is same. In frequency domain, the data symbol $S^p(k)$ of the p-th user is mapped into following symbol,

$$X^p(k) = \begin{cases} S^p(k), & k \in K_p \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

Equation (2) is transformed to an OFDMA symbol by the inverse fast Fourier transform (IFFT) during the symbol duration T. In the time domain, the n-th sample for the p-th user can be written as $x_n^p = IFFT\{X^p(k)\}, k \in K_p$;

$$x_n^p = \frac{1}{\sqrt{K}} \sum_{k \in K_p} X^p(k) \exp\left(\frac{j2\pi kn}{K}\right). \quad (3)$$

The transmitted signal by each user undergoes multipath fading channel $H^p(k)$ and the received signal r_n in the BS can be briefly written as

$$r_n = \frac{1}{\sqrt{K}} \sum_{p=1}^{P} \sum_{k \in K_p} \left\{ H^p(k) X^p(k) \exp\left(\frac{j2\pi kn}{K}\right) + \omega_n(k) \right\}, \quad (4)$$

where $\omega_n(k)$ is the zero-mean additive white Gaussian noise (AWGN) with two sided power spectral density of σ^2. After Eq. (4) is transformed by the fast Fourier transform (FFT) from the time domain into the frequency domain, this received signal is equalized through 1-tap equalizer and is decoded. Therefore, the received signal for the proposed cooperation scheme is decoded in the frequency domain.

3. New Structure of Cooperative Transmission

In this letter, the transmission structure is modified and decoding process is changed in the receiver. Unlike the conventional scheme [9], the proposed scheme considers that decoding in the first phase is not perfect. The basic transmission structures of the proposed scheme are described through the following equations,

$$\text{User } i = \begin{pmatrix} \overbrace{\mathbf{X}^i(1)}^{\text{user } i \text{ sub-channel}} & \overbrace{null}^{\text{user } j \text{ sub-channel}} \\ \mathbf{X}^i(2) & \mathbf{X}^j(1) \\ \mathbf{X}^i(3) & \mathbf{X}^j(2) \\ null & \mathbf{X}^j(3) \end{pmatrix}, \quad (5)$$

$$\text{User } j = \begin{pmatrix} \overbrace{null}^{\text{user } i \text{ sub-channel}} & \overbrace{\mathbf{X}^j(1)}^{\text{user } j \text{ sub-channel}} \\ \mathbf{X}^i(1) & \mathbf{X}^j(2) \\ \mathbf{X}^i(2) & \mathbf{X}^j(3) \\ \mathbf{X}^i(3) & null \end{pmatrix}, \quad (6)$$

where the row and the column denote the time slot and the user's subchannel respectively.

Basically, the power of the second and the third transmitting signals in Eqs. (5) and (6) are already normalized by $1/\sqrt{2}$ like STBC because the total transmit power of cooperation-mode is the same as that of non-cooperation-mode.

In the first phase, the user i and j broadcast the first symbol. After the first phase, each user decodes the received symbols from the other user and reconstructs the symbols for DF according to Eqs. (5) and (6). The next symbols are transmitted through own sub-channel and the reconstructed symbols are transmitted through the other user's sub-channel. The BS receives the superposition signals from user i and j in each phase.

In this letter, it is considered that decoding process takes only user i since the received signals of the user i and j are decoded by same process. Therefore, in the BS, the received signals $\mathbf{R}^i(\cdot)$ for the user i in the frequency domain can be expressed as follows,

$$\mathbf{R}^i(1) = \mathbf{H}_1^i \mathbf{X}^i(1) + \mathbf{W}(1), \quad (7)$$

$$\mathbf{R}^i(2) = \mathbf{H}_1^i \mathbf{X}^i(2) + \mathbf{H}_2^i \mathbf{X}_{DF}^i(1) + \mathbf{W}(2), \quad (8)$$

$$\mathbf{R}^i(3) = \mathbf{H}_1^i \mathbf{X}^i(3) + \mathbf{H}_2^i \mathbf{X}_{DF}^i(2) + \mathbf{W}(3), \quad (9)$$

$$\mathbf{R}^i(4) = \mathbf{H}_2^i \mathbf{X}_{DF}^i(3) + \mathbf{W}(4), \quad (10)$$

where $\mathbf{X}_{DF}^i(\cdot)$ is the decoded and re-constructed symbol from sub-carrier of the user j. And $\mathbf{X}^p$, $\mathbf{R}^p$ and $\mathbf{H}_{\{1,2,\text{ic}\}}^p$ are the vector notations for $\left\{X^p(1), \cdots, X^p(k), \cdots, X^p(K_p)\right\}$, $\left\{R^p(1), \cdots, R^p(k), \cdots, R^p(K_p)\right\}$ and $\{H_{\{1,2,\text{ic}\}}^p(1), \cdots, H_{\{1,2,\text{ic}\}}^p(k), \cdots, H_{\{1,2,\text{ic}\}}^p(K_p)\}$.

The received signals of the user i can be decoded by the following combining rules,

$$\mathbf{X}^i(\cdot) = \mathbf{X}_{DF}^i(\cdot) + \epsilon_{DF}, \quad (11)$$

$$\mathbf{H}_1^i \approx \hat{\mathbf{H}}_1^i, \ \ \mathbf{H}_2^i \approx \hat{\mathbf{H}}_2^i, \quad (12)$$

$$\gamma_1 \equiv \frac{\mathbf{H}_2^i}{\mathbf{H}_1^i}, \ \ \gamma_2 \equiv \frac{\mathbf{H}_1^i}{\mathbf{H}_2^i}, \quad (13)$$

where ϵ_{DF} is error of DF which is occurred in the relay, and $\hat{\mathbf{H}}_1^i$ and $\hat{\mathbf{H}}_2^i$ are estimated channels. If it is assumed that the channels are perfectly estimated in order to know the theoretical performance for the first phase error, the estimated channels are approximated to Eq. (12).

In order to restore the signal, the α_1, α_2, β_1, and β_2 are derived as follows,

$$\begin{aligned} \alpha_1 &\equiv \mathbf{R}^i(2) - \mathbf{R}^i(1)\gamma_1 \\ &= \mathbf{H}_1^i \mathbf{X}^i(2) + \mathbf{W}(2) - \gamma_1 \mathbf{W}(1), \end{aligned} \quad (14)$$

$$\begin{aligned} \alpha_2 &\equiv \mathbf{R}^i(3) - \alpha_1\gamma_1 \\ &= \mathbf{H}_1^i \mathbf{X}^i(3) + \mathbf{W}(3) - \gamma_1 \mathbf{W}(2) + \gamma_1^2 \mathbf{W}(1), \end{aligned} \quad (15)$$

$$\begin{aligned} \beta_1 &\equiv \mathbf{R}^i(3) - \mathbf{R}^i(4)\gamma_2 \\ &= \mathbf{H}_2^i \mathbf{X}^i(2) + \mathbf{W}(3) + \gamma_2 \mathbf{W}(4), \end{aligned} \quad (16)$$

$$\begin{aligned} \beta_2 &\equiv \mathbf{R}^i(2) - \beta_1\gamma_2 \\ &= \mathbf{H}_2^i \mathbf{X}^i(1) + \mathbf{W}(2) - \gamma_2 \mathbf{W}(3) + \gamma_2^2 \mathbf{W}(4). \end{aligned} \quad (17)$$

$\tilde{\mathbf{X}}^i(1)$, $\tilde{\mathbf{X}}^i(2)$, and $\tilde{\mathbf{X}}^i(3)$ are variables used in order to decode the received signal and can be represented as follows,

$$\begin{aligned}\tilde{\mathbf{X}}^{\mathbf{i}}(1) &= \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \mathbf{R}^{\mathbf{i}}(1) + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \beta_2 \\ &= \left(\left|\mathbf{H}_1^{\mathbf{i}}\right|^2 + \left|\mathbf{H}_2^{\mathbf{i}}\right|^2\right)\mathbf{X}^{\mathbf{i}}(1) + \eta_1,\end{aligned} \tag{18}$$

$$\begin{aligned}\tilde{\mathbf{X}}^{\mathbf{i}}(2) &= \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \alpha_1 + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \beta_1 \\ &= \left(\left|\mathbf{H}_1^{\mathbf{i}}\right|^2 + \left|\mathbf{H}_2^{\mathbf{i}}\right|^2\right)\mathbf{X}^{\mathbf{i}}(2) + \eta_2,\end{aligned} \tag{19}$$

$$\begin{aligned}\tilde{\mathbf{X}}^{\mathbf{i}}(3) &= \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \alpha_2 + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \mathbf{R}^{\mathbf{i}}(4) \\ &= \left(\left|\mathbf{H}_1^{\mathbf{i}}\right|^2 + \left|\mathbf{H}_2^{\mathbf{i}}\right|^2\right)\mathbf{X}^{\mathbf{i}}(3) + \eta_3.\end{aligned} \tag{20}$$

By using the Eqs. (18), (19) and (20), the transmitted signal in the user is decoded. η_1, η_2, and η_3 are the following noise elements, respectively.

$$\begin{aligned}\eta_1 &= \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \mathbf{W}(\mathbf{1}) + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \mathbf{W}(\mathbf{2}) \\ &\quad - \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \gamma_2 \mathbf{W}(\mathbf{3}) + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \gamma_2^2 \mathbf{W}(\mathbf{4}) \\ \eta_2 &= -\left(\mathbf{H}_1^{\mathbf{i}}\right)^* \gamma_1 \mathbf{W}(\mathbf{1}) + \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \mathbf{W}(\mathbf{2}) \\ &\quad + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \mathbf{W}(\mathbf{3}) + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \gamma_2 \mathbf{W}(\mathbf{4}) \\ \eta_3 &= \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \gamma_1^2 \mathbf{W}(\mathbf{1}) - \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \gamma_1 \mathbf{W}(\mathbf{2}) \\ &\quad + \left(\mathbf{H}_1^{\mathbf{i}}\right)^* \mathbf{W}(\mathbf{3}) + \left(\mathbf{H}_2^{\mathbf{i}}\right)^* \mathbf{W}(\mathbf{4}).\end{aligned} \tag{21}$$

Equations (18), (19) and (20) show channel diversity of the proposed scheme. When the destination decodes the received symbol ($\mathbf{X}(1)$) in the first phase, the destination can achieve high diversity gain because two users transmit same symbol ($\mathbf{X}(1)$) through the independent channels ($\mathbf{H}_1, \mathbf{H}_2$). Because the independent channels can be secured by sufficient spaces between the users, the independence of the channels is not related to channel estimation. So it is assumed that the channels are independent in this letter. Therefore, the proposed scheme has the improved performance in the first phase.

4. Performance Evaluation

In this section, the BER performance of the proposed scheme is described as compared with the conventional scheme [9]. The symbols are modulated by QPSK without channel coding. To evaluate BER performance in fading channel, Rayleigh fading channel is used. The channel model has independent and identically distributed characteristic. The number of user is 2 in this simulation. The simulation parameters are shown in the Table 1.

Figure 2 shows the BER performance of the proposed and conventional scheme when the relative SNR of the inter-user channel is 10[dB]. The BER performance of the conventional scheme is degraded due to error occurred in the first phase. Assuming decoding method is same, the BER performance of the proposed scheme is better than the conventional scheme and the transmission rate of the proposed scheme is same as the conventional scheme (3/4 symbols per channel use).

Figure 3 shows the BER performance of the proposed scheme and the basic OFDMA system according to the relative SNR of inter-user channel (−5, −3, 0, 3, 10[dB]). In the

Table 1 Simulation parameters of proposed scheme.

Parameters	Value
Size of FFT	256
Cooperation users	2
Subcarriers in subchannel	128
Length of cyclic prefix	32
Channel H_1, H_2 and H_{ic}	8-path Rayleigh fading channel

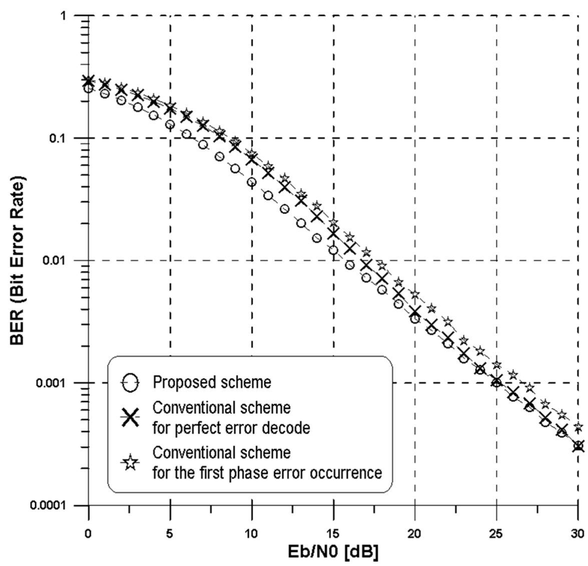

Fig. 2 BER performance of the proposed and the conventional scheme in case the relative SNR of the inter-user channel is 10[dB].

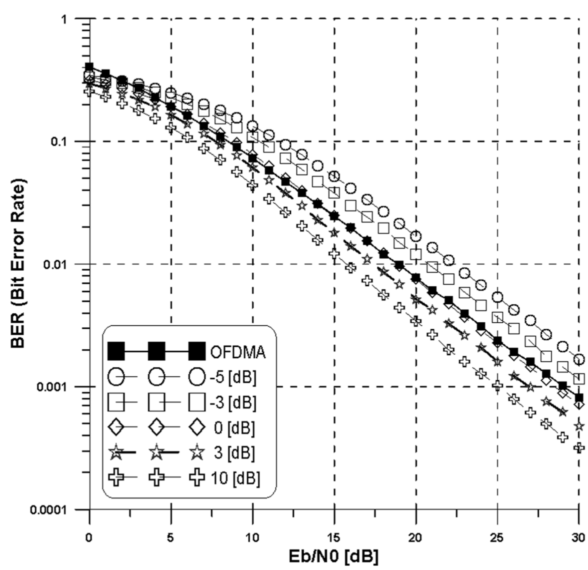

Fig. 3 BER performance of the proposed scheme compared with OFDMA system according to relative SNR of inter-user channel (−5, −3, 0, 3, 10[dB]).

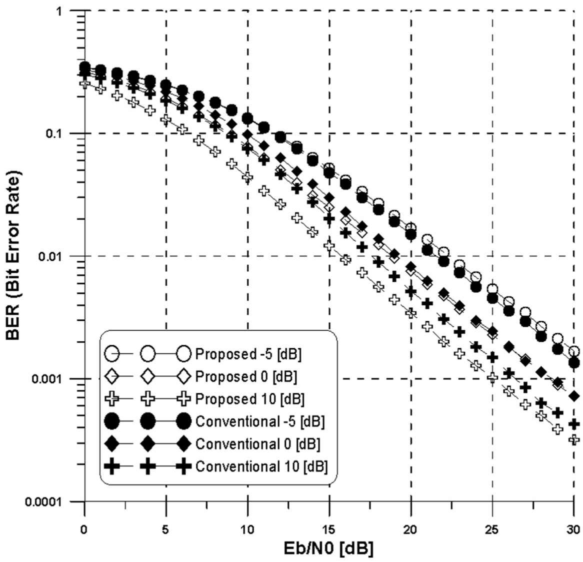

Fig. 4 BER performance of the proposed scheme compared with the conventional scheme to relative SNR of inter-user channel (−5, 0, 10[dB]).

basic OFDMA, there is one user and half of the total subcarriers are allocated for the user. The BER performance of the proposed scheme is better than the conventional scheme because of space diversity effects when the relative SNR of inter-user channel is higher than 0dB. However, the BER performance of the proposed scheme is lower than basic OFDMA system in case of −3[dB] and −5[dB]. The reconstructed symbols in the cooperation phase (first phase) can be easily corrupted when the channel condition between the users is poor.

Figure 4 shows the BER performance of the proposed and conventional scheme, according to the relative SNR of inter-user channel (−5, 0, 10[dB]). The BER performance of the proposed scheme is worse than the conventional scheme when the relative SNR of inter-user channel is −5dB. However, the BER performance of the proposed scheme is better than the conventional scheme in case of 10[dB]. Also, it is confirmed that BER performance of the proposed scheme is better than the conventional scheme when the relative SNR of inter-user channel is higher than 0[dB].

5. Conclusions

To achieve high throughput in OFDMA-based cooperative communication system, the conventional scheme modifies the structure of transmission symbols and allocates each sub-channel, which has half the total subcarriers. Therefore, the conventional scheme achieves higher throughput than the DF-STBC cooperative communication. However, the conventional scheme has worse BER performance than the DF-STBC cooperative communication. The proposed scheme improves the disadvantage of the conventional scheme in this letter.

The improvement of reliability means the improvement of BER performance in the cooperative communication. Because the proposed structure guarantees the channel diversity effects, the reliability of transmitted data is improved. Furthermore, the received signals can be well-decoded because of the channel diversity effects. In this letter, it is shown that the BER performance of the proposed scheme is better than the conventional scheme. Therefore the proposed signal structure is an efficient method to improve the reliability of received data in the cooperative communication.

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