World Academy of Science, Engineering and Technology
International Journal of Information and Communication Engineering
Vol:5, No:11, 2011

An Improved STBC Structure and Transmission Scheme for High Rate and Reliability in OFDMA Cooperative Communication

Hyoung-Muk Lim, Won-Jun Choi, Jae-Seon Yoon, Hyoung-Kyu Song

Abstract—Space-time block code(STBC) has been studied to get full diversity and full rate in multiple input multiple output(MIMO) system. Achieving full rate is difficult in cooperative communications due to the each user consumes the time slots for transmitting information in cooperation phase. So combining MIMO systems with cooperative communications has been researched for full diversity and full rate. In orthogonal frequency division multiple access (OFDMA) system, it is an alternative way that each user shares their allocated subchannels instead of using the MIMO system to improve the transmission rate. In this paper, a Decode-and-forward (DF) based cooperative communication scheme is proposed. The proposed scheme has improved transmission rate and reliability in multi-path fading channel of the OFDMA up-link condition by modified STBC structure and subchannel sharing.

Keywords—cooperation, improved rate, OFDMA, STBC.

I. Introduction

MANY researchers have studied various multiple antenna techniques to provide high reliability or high data rate in wireless communication [1]-[8]. It is not always practical that the receiver deploys multiple antenna in limited size and cost. So user cooperative communication system is very attractive for wireless communications. The users share their antennas each other to achieve high reliability or high data rate like multiple input multiple output(MIMO) system. But cooperative communications have a disadvantage that the transmission rate is decreased to transmit own signal for relaying in cooperation phase. To overcome the disadvantage of cooperative communication, it is proposed that modified space time block code (STBC) with increased transmission rate[4],[6]-[8]. In this paper, it is proposed that another modified STBC with 3/4 transmission rate by sharing subchannels of two users each other in orthogonal frequency division multiple access (OFDMA). It is shown that the system model of cooperative decode-and-forward (DF) In fig. (1).

II. OFDMA System Model

The OFDMA system consists of K orthogonal subcarriers and P active users. Each user accesses a subchannel which is a cluster of subcarriers. Each user is assigned to following subchannel K_p [8].

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Manuscript received April 19, 2005; revised January 11, 2007.

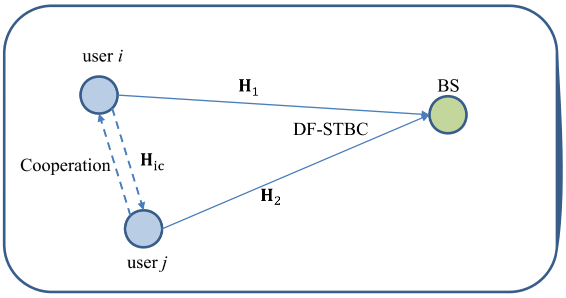

Fig. 1. Cooperative DF-STBC system model.

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

where k is subcarrier index and p is user index, respectively, and $N_{K_p} = K/P$ is the number of subcarriers assigned to each user. 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 goes through multi-path fading channel and the received signal at the base-station(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.

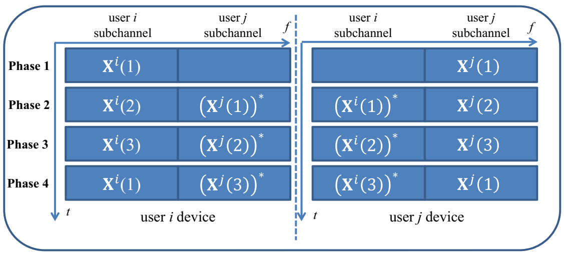

Fig. 2. Transmission procedure of proposed scheme.

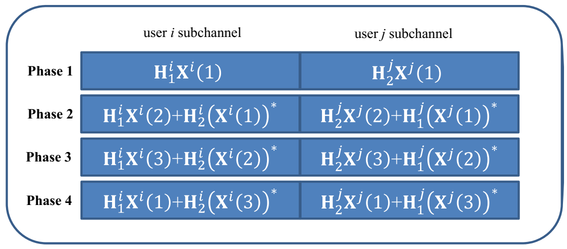

Fig. 3. Received signal at BS in frequency domain.

III. Cooperative Modified Space Time Block Code Structure With OFDMA Band Sharing

In this section, the new structure of STBC is proposed in DF cooperative communication for two users. It is assumed that the user with the best inter-user channel condition is already selected by the base station (BS) using the received signal to noise ratio (SNR) value. The inter-user channel condition means the relative difference of received signal's SNR value between the direct channel and the inter-user channel. It is considered that the subcarrier assignment of two users are same and each channel remains constant for the duration of one round of user cooperation (5 consecutive time slots). The basic transmission structures of the proposed scheme are described through the following equations.

$$\text{User } i = \begin{pmatrix} \overbrace{\mathbf{X}^i(1)}^{\text{user } i \text{ subchannel}} & \overbrace{null}^{\text{user } j \text{ subchannel}} \\ \mathbf{X}^i(2) & \left(\mathbf{X}^j(1)\right)^* \\ \mathbf{X}^i(3) & \left(\mathbf{X}^j(2)\right)^* \\ \mathbf{X}^i(1) & \left(\mathbf{X}^j(3)\right)^* \end{pmatrix}, \tag{5}$$

$$\text{User } j = \begin{pmatrix} \overbrace{null}^{\text{user } i \text{ subchannel}} & \overbrace{\mathbf{X}^j(1)}^{\text{user } j \text{ subchannel}} \\ \left(\mathbf{X}^i(1)\right)^* & \mathbf{X}^j(2) \\ \left(\mathbf{X}^i(2)\right)^* & \mathbf{X}^j(3) \\ \left(\mathbf{X}^i(3)\right)^* & \mathbf{X}^j(1) \end{pmatrix}, \tag{6}$$

where the row and column are respectively the time slot and user's subchannel, and $(\cdot)^*$ means "conjugate". In Eqs. (5) and (6), $\mathbf{X}^p$, $\mathbf{R}^p$, and $\mathbf{H}^p_{\{1,2,\text{ic}\}}$ 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 $\{H^p_{\{1,2,\text{ic}\}}(1), \cdots, H^p_{\{1,2,\text{ic}\}}(k), \cdots, H^p_{\{1,2,\text{ic}\}}(K_p)\}$.

Basically, the power of the second, the third and the forth transmitting signals in Eqs. (5) and (6) is 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 symbols from each other user and reconstruct symbols for DF according to Eqs. (5) and (6). The next symbols are transmitted through own subchannel and the reconstructed symbols are transmitted through the other user's subchannel. The BS receives the superposition signals from user i and j at each phase.

In this paper, 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. So, at the BS, the received signals for the user i in the frequency domain can be expressed as follows,

$$\mathbf{R}^i(1) = \mathbf{H}^i_1\mathbf{X}^i(1) + \mathbf{W}(1), \tag{7}$$

$$\mathbf{R}^i(2) = \mathbf{H}^i_1\mathbf{X}^i(2) + \mathbf{H}^i_2\mathbf{X}^i_{DF}(1) + \mathbf{W}(2), \tag{8}$$

$$\mathbf{R}^i(3) = \mathbf{H}^i_1\mathbf{X}^i(3) + \mathbf{H}^i_2\mathbf{X}^i_{DF}(2) + \mathbf{W}(3), \tag{9}$$

$$\mathbf{R}^i(4) = \mathbf{H}^i_1\mathbf{X}^i(1) + \mathbf{H}^i_2\mathbf{X}^i_{DF}(3) + \mathbf{W}(4), \tag{10}$$

where $\mathbf{X}^i_{DF}(\cdot)$ is the decoded and re-constructed symbols form subcarrier of the user j and $\mathbf{X}^i_{DF}(\cdot) = (\mathbf{X}^i(\cdot))^*$.

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

$$\hat{\mathbf{X}}^i(1) = \text{demodulation}(\mathbf{R}^i(1)). \tag{11}$$

$$\begin{aligned} \mathbf{X}^i(1) &\approx \hat{\mathbf{X}}^i(1) \\ \mathbf{H}^i_1 &\approx \hat{\mathbf{H}}^i_1 \\ \mathbf{H}^i_2 &\approx \hat{\mathbf{H}}^i_2, \end{aligned} \tag{12}$$

where $\hat{\mathbf{X}}^i(1)$ is the demodulated symbol, and $\hat{\mathbf{H}}^i_1$ and $\hat{\mathbf{H}}^i_2$ are estimated channels. $\hat{\mathbf{X}}^i(1)$ and estimated channel are approximated to Eq. (12) assuming that $\mathbf{R}^i(1)$ is demodulated perfect and the channel is estimated perfect. So $\left(\hat{\mathbf{X}}^i(1)\right)^* \mathbf{H}^i_2$ is combined at the BS. using $\left(\hat{\mathbf{X}}^i(1)\right)^* \mathbf{H}^i_2$ and Eq. (8), α_1 is derived as follows,

$$\begin{aligned} \alpha_1 &\equiv \mathbf{R}^i(2) - \left(\hat{\mathbf{X}}^i(1)\right)^* \mathbf{H}^i_2. \\ &= \mathbf{H}^i_1\mathbf{X}^i(2) + \mathbf{W}(2) \end{aligned} \tag{13}$$

β_2 is derived as follows,

$$\begin{aligned} \beta_2 &\equiv \mathbf{R}^i(3)(\mathbf{H}^i_1)^* - \alpha_1^*\mathbf{H}^i_2 \\ &= \left|\mathbf{H}^i_1\right|^2 \mathbf{X}^i(3) + \left(\mathbf{H}^i_1\right)^* \mathbf{W}(3) - \mathbf{H}^i_2\left(\mathbf{W}(2)\right)^*. \end{aligned} \tag{14}$$

β_1 is derived as follows,

$$\begin{aligned} \beta_1 &\equiv \mathbf{R}^i(4) - \hat{\mathbf{X}}^i(1)\mathbf{H}^i_1 \\ &= \mathbf{H}^i_2\left(\mathbf{X}^i(3)\right)^* + \mathbf{W}(4). \end{aligned} \tag{15}$$

α_2 is derived as follows,

$$\begin{aligned} \alpha_2 &\equiv \left(\mathbf{R}^i(3)\right)^* \mathbf{H}^i_2 - \beta_1\left(\mathbf{H}^i_1\right)^* \\ &= \left|\mathbf{H}^i_2\right|^2 \mathbf{X}^i(2) + \mathbf{H}^i_2\left(\mathbf{W}(3)\right)^* - \left(\mathbf{H}^i_1\right)^* \mathbf{W}(4). \end{aligned} \tag{16}$$

$\tilde{\mathbf{X}}^i(2)$ and $\tilde{\mathbf{X}}^i(3)$ are derived as follows,

$$\begin{aligned} \tilde{\mathbf{X}}^i(2) &= \alpha_1\left(\mathbf{H}^i_1\right)^* + \alpha_2 \\ &= \left(\left|\mathbf{H}^i_1\right|^2 + \left|\mathbf{H}^i_2\right|^2\right)\mathbf{X}^i(2) + \eta_2, \end{aligned} \tag{17}$$

TABLE I
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	Rayleigh fading multipath 8
Channel H_2	Rayleigh fading multipath 8
Channel H_{ic}	Rayleigh fading channel multipath 8 with dB gain

$$\begin{aligned}\tilde{\mathbf{X}}^i(3) &= (\beta_1)^* \mathbf{H}_2^i + \beta_2 \\ &= \left(\left|\mathbf{H}_1^i\right|^2 + \left|\mathbf{H}_2^i\right|^2\right)\mathbf{X}^i(3) + \eta_3,\end{aligned} \tag{18}$$

where η_2 and η_3 are the following noise elements, respectively.

$$\begin{aligned}\eta_2 &= \left(\mathbf{H}_1^i\right)^* \mathbf{W}(2) + \mathbf{H}_2^i (\mathbf{W}(3))^* - \left(\mathbf{H}_1^i\right)^* \mathbf{W}(4) \\ \eta_3 &= -\mathbf{H}_2^i (\mathbf{W}(2))^* + \left(\mathbf{H}_1^i\right)^* \mathbf{W}(3) + \mathbf{H}_2^i (\mathbf{W}(4))^* .\end{aligned} \tag{19}$$

In Eq. (18) and (19), the DF cooperative communication using modified STBC structure can get the channel diversity $\left(\left|\mathbf{H}_1^i\right|^2 + \left|\mathbf{H}_2^i\right|^2\right)$ and the transmission rate $3/4$.

IV. PERFORMANCE EVALUATION

In this section, it is shown that the error performance of the proposed cooperative scheme. OFDMA symbol is modulated by QPSK without channel coding, and Rayleigh fading channel is used for this simulation; the channel model has a characteristic of independent and identically distributed (i.i.d.) Rayleigh fading channel with 8 multipaths. The number of subcarriers is same as each user. It is assumed that the symbols of the first phase are decoded perfectly in the BS and the channel estimation is done completely. It is shown that the simulation parameters in the TABLE. I.

Fig. (4) shows the BER performance of the proposed scheme and the basic OFDMA system, according to the various inter-user channels at the SNR -3, 0, 3, and 10[dB]. The relative condition of the inter-user channel can be easily deteriorated because reconstructed symbols are corrupted by symbol decoding error in cooperation phase. The BER performance of proposed scheme is lower than basic OFDMA system in case of -3[dB] and 0[dB]. It is shown that the BER performance of proposed scheme is 5[dB] better than basic OFDMA system at 10^{-3} in case of 3[dB] and 8[dB] better than in case of 10[dB].

Fig. (5) shows the BER performance of the proposed scheme, the basic OFDMA system, and DF-STBC system with one relay at the inter-user channels 3[dB]. The BER performance of proposed scheme is 5[dB] lower than DF-STBC system at 10^{-3} because the noise is superposition to decode symbols and the error propagation is occurred by the added noise in the BS. But the transmission rate of the proposed scheme is 50 percent higher than DF-STBC system.

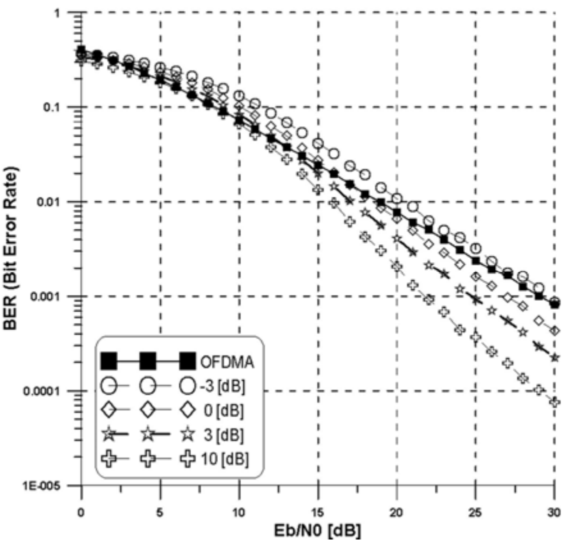

Fig. 4. BER performance of proposed scheme according to relative condition of inter-user channel (-3[dB], 0[dB], 3[dB], 10[dB]).

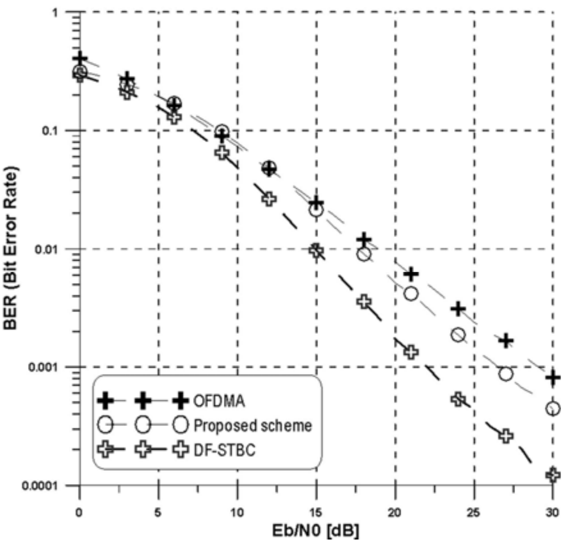

Fig. 5. BER performace of proposed scheme compares with simple OFDMA system and DF-STBC cooperative communication according to relative condition of inter-user channel (3[dB]).

V. CONCLUSION

To achieve high transmission rate in OFDMA system with DF-STBC structure, it is proposed that the modified STBC structure and user subchannel sharing. As a result, an OFDMA system adopting the proposed cooperative communication is higher rate than the previous DF-STBC cooperative communication. Therefore, this proposed scheme is very effective in the OFDMA system to satisfy reliability and high transmission rate at once.

However, the error performance of the proposed STBC structure is worse than the DF-STBC cooperative communication as shown in Fig. (5). Therefore, to satisfy various wireless communication environments, the modified STBC structure with noise cancellation will be worked.

ACKNOWLEDGMENT

This research is supported by the ubiquitous Computing and Network (UCN) Project, the Ministry of Knowledge and Economy(MKE) Knowledge and Economy Frontier R&D Program in Korea as a result of UCN's subproject 11C3-C2-10M and this research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology (No. 2010-0015785).

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