An Adaptive Cooperative Scheme for Reliability of Transmission Using STBC and CDD in Wireless Communications

Hyun-Jun Shin, Jae-Jeong Kim, Hyoung-Kyu Song

***Abstract*—**In broadcasting and cellular system, a cooperative scheme is proposed for the improvement of performance of bit error rate. Up to date, the coverage of broadcasting system coexists with the coverage of cellular system. Therefore each user in a cellular coverage is frequently involved in a broadcasting coverage. The proposed cooperative scheme is derived from the shared areas. The users receive signals from both broadcasting station and cellular station. The proposed scheme selects a cellular base station of a worse channel to achieve better performance of bit error rate in cooperation. The performance of the proposed scheme is evaluated in fading channel.

***Keywords*—**Cooperative communication, diversity, STBC, CDD, channel condition, broadcasting system, cellular system.

I. Introduction

BROADCASTING system has been used for TV and radio services and cellular system communicates with users. In broadcasting system, a base station transmits signals to users in its coverage through downlink and the users are not needed to have a connection for signal reception. The requirement without a connection is advantageous for transmission in terms of overload of system. However, broadcasting system transmits without receiving feedback signals from users. Transmission without feedback information is disadvantageous for flexibility of communications and broadcasting system is impossible to change transmission scheme by channel condition. Broadcasting system continues to transmit signals until the system discontinues transmission without changing transmission scheme.

Otherwise, in cellular system, a base station transmits signals to users and they transmit their signals to the base station. Cellular system requires a connection for communications between a base station and a user. The base station receiving feedback information is available to change transmission scheme by channel condition between itself and a user.

In this paper, a scheme is proposed that a broadcasting system cooperates with a cellular system for the high bit error rate of users. By cooperation, the both advantages are applied to the proposed scheme [1]-[3]. The proposed scheme achieves high bit error rate (BER) using space-time block code (STBC) and cyclic delay diversity (CDD). STBC doubles diversity order and improves the reliability of signals by combining received signals at receiver. CDD is a simple approach to obtain spatial diversity based on orthogonal frequency division multiplexing (OFDM) [4]-[6]. A hybrid multiple-input multiple-output (MIMO) detection scheme is employed for reliability. The detection scheme orders the priority of detection of received signals [7]-[9].

The remaining sections are organized as follows. Section II presents a system and channel model, Section III proposes a cooperative transmission scheme for improvement of BER performance, Section IV shows simulation results and Section V presents the conclusion of the proposed scheme.

II. System and Channel Model

In this section, a broadcasting system and a cellular system are considered for the proposed scheme. In broadcasting coverage, cellular coverage is concatenated with other cellular coverage. A broadcasting station (BS) with one antenna transmits signals to each user who has two antennas. Cellular station (CS) with one antenna transmits signals to the each user. Base stations transmit their signals in a cooperative scheme selected by channel condition [10]. The proposed system assumes that the transmitted signals experience Rayleigh fading and the channel from the base stations to users is stable for the transmission of one STBC. A complex Gaussian random noise is added to the transmitted signals by receiver. The received signal vectorYis as follows,

$$\mathrm{Y} = \mathrm{HPX} + \mathrm{w}, \qquad (1)$$

where a received signal Y is a complex vector, H is the complex channel matrix, P is the allocation of the transmission power, $\mathbf{X}$ is a transmitted complex OFDM symbols and $\mathbf{w}$ is an additive white complex Gaussian noise (AWGN) vector with zero mean and σ^2 variance.

III. Proposed Cooperative Scheme

In this section, a cooperative transmission scheme is proposed for improvement of BER. Fig. 1 shows the system model of the proposed scheme. If users are in the concatenated coverage of a BS and CSs, users are possible to communicate with CSs more than one CS. Since transmitted signals from base stations are attenuated through each channel, the performance of the cooperative scheme with one BS and one CS is low BER at receiver.

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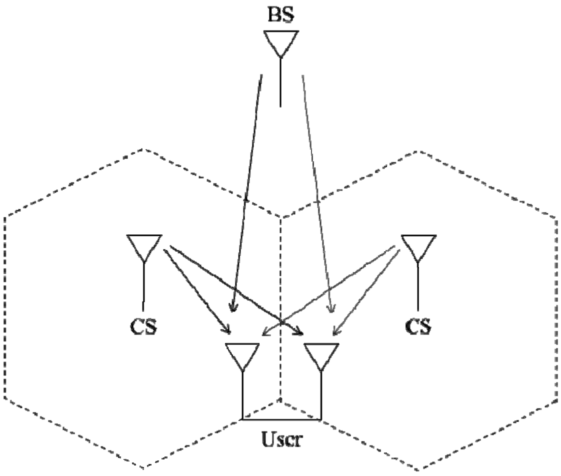

Fig. 1 System and channel model for cooperation

The proposed cooperative scheme is possible to achieve high BER. Users who receive signals from the base stations estimate channel condition between the base stations and themselves and transmit the feedback information to CSs. And CSs share the feedback information with BS.

TABLE I
TRANSMISSION SEQUENCE FOR STBC AND CDD WITH BROADCASTING STATION

Time Slot	Broadcasting Station	Cellular Station1	Cellular Station2
t_1	a_1	$-a_2^*$	$a_{1,CDD}$
t_2	a_2	a_1^*	$a_{2,CDD}$

If the channel condition from BS to a user is bad, BS in Table I transmits signals cooperating with CBS1 in STBC and CS2 simultaneously transmits signals in CDD with BBS signals. It has the advantages of diversity gain using cooperation. The received signals are expressed as follows,

$$\begin{aligned} b_{1,1} &= a_1 h_{1,1} - a_2^* h_{2,1} + a_{1,CDD} h_{3,1}, \\ b_{2,1} &= a_2 h_{1,1} + a_1^* h_{2,1} + a_{2,CDD} h_{3,1}, \\ b_{1,2} &= a_1 h_{1,2} - a_2^* h_{2,2} + a_{1,CDD} h_{3,2}, \\ b_{2,2} &= a_2 h_{1,2} + a_1^* h_{2,2} + a_{2,CDD} h_{3,2}, \end{aligned} \quad (2)$$

where $b_{i,j}$ denotes the received signal at the i-th time slot on the j-th receiving antenna, a_i is the transmitted signal from BS and CS1, $h_{i,j}$ denotes the channel from the i-th base station to the j-th antenna of users and $a_{i,CDD}$ denotes the transmitted signal from the CS2 with CDD signal of BS.

For orthogonality, the received signals at the second time slot in Table are conjugated and the complex-conjugated signals are expressed as follows,

$$\begin{aligned} b_{1,1} &= a_1 h_{1,1} - a_2^* h_{2,1} + a_{1,CDD} h_{3,1,} \\ b_{2,1}^* &= a_2^* h_{1,1}^* + a_1 h_{2,1}^* + a_{2,CDD}^* h_{3,1,}^* \\ b_{1,2} &= a_1 h_{1,2} - a_2^* h_{2,2} + a_{1,CDD} h_{3,2}, \\ b_{2,2}^* &= a_2^* h_{1,2}^* + a_1 h_{2,2}^* + a_{2,CDD}^* h_{3,2}^*. \end{aligned} \quad (3)$$

and the matrix of the received signals is expressed as follows,

$$\begin{bmatrix} b_{1,1} \\ b_{2,1}^* \\ b_{1,2} \\ b_{2,2}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} + e^{j\theta} h_{3,1} & -h_{2,1} \\ h_{2,1}^* & h_{1,1}^* + e^{-j\theta} h_{3,1}^* \\ h_{1,2} + e^{j\theta} h_{3,2} & -h_{2,2} \\ h_{2,2}^* & h_{1,2}^* + e^{-j\theta} h_{3,2}^* \end{bmatrix} \begin{bmatrix} a_1 \\ a_2^* \end{bmatrix}, \quad (4)$$

where $e^{\pm j\theta}$ denotes a CDD component. The transmitted signals from BS obtain the diversity gain by the cyclic delayed signals from CS2.

TABLE II
TRANSMISSION SEQUENCE FOR STBC AND CDD WITH CELLULAR STATION

Time Slot	Broadcasting Station	Cellular Station1	Cellular Station2
t_1	a_1	$-a_2^*$	$-a_{2,CDD}^*$
t_2	a_2	a_1^*	$a_{1,CDD}^*$

If the channel condition between CS1 and users is bad, BS in Table II transmits signals cooperating with CS1 in STBC and CS2 simultaneously transmits signals in CDD with CS1 signals. The received signals are expressed as follows,

$$\begin{aligned} b_{1,1} &= a_1 h_{1,1} - a_2^* h_{2,1} - a_{2,CDD}^* h_{3,1}, \\ b_{2,1} &= a_2 h_{1,1} + a_1^* h_{2,1} + a_{1,CDD}^* h_{3,1}, \\ b_{1,2} &= a_1 h_{1,2} - a_2^* h_{2,2} - a_{2,CDD}^* h_{3,2}, \\ b_{2,2} &= a_2 h_{1,2} + a_1^* h_{2,2} + a_{1,CDD}^* h_{3,2}, \end{aligned} \quad (5)$$

where $a_{i,CDD}$ denotes the transmitted signal from the CS2 with CDD signal of CS1. For orthogonality, the received signals at the second time slot in Table II are conjugated and the complex-conjugated signals are expressed as follows,

$$\begin{aligned} b_{1,1} &= a_1 h_{1,1} - a_2^* h_{2,1} - a_{2,CDD} h_{3,1}, \\ b_{2,1}^* &= a_2^* h_{1,1}^* + a_1 h_{2,1}^* + a_{1,CDD}^* h_{3,1}^*, \\ b_{1,2} &= a_1 h_{1,2} - a_2^* h_{2,2} - a_{2,CDD} h_{3,2}, \\ b_{2,2}^* &= a_2^* h_{1,2}^* + a_1 h_{2,2}^* + a_{1,CDD}^* h_{3,2}^*. \end{aligned} \quad (6)$$

and the matrix of the received signals is expressed as follows,

$$\begin{bmatrix} b_{1,1} \\ b_{2,1}^* \\ b_{1,2} \\ b_{2,2}^* \end{bmatrix} = \begin{bmatrix} h_{1,1} & -(h_{2,1} + e^{-j\theta} h_{3,1}) \\ h_{2,1}^* + e^{+j\theta} h_{3,1}^* & h_{1,1}^* \\ h_{1,2} & -(h_{2,2} + e^{-j\theta} h_{3,2}) \\ h_{2,2}^* + e^{+j\theta} h_{3,2}^* & h_{1,2}^* \end{bmatrix} \begin{bmatrix} a_1 \\ a_2^* \end{bmatrix}. \quad (7)$$

The signals transmitted from CS1 obtain the diversity gain by the cyclic delayed signal from CS2.

The proposed cooperative scheme selects one out of two transmission schemes for reliability of transmitted signals. A criterion for selection of the proposed scheme is comparison of the channel condition between BS and a user with the channel condition between CS1 and a user. The selection for diversity gain depends on norm value of the channel. The norm value is a magnitude of the channel. If the norm value of the channel between BS and a user is lower than between CS1 and a user, CS2 cooperates with BS in CDD scheme to improve the performance of BER of the worse channel. And if the norm value of the channel between CS1 and a user, CS2 cooperates with CS1 in CDD scheme. CS2 cooperates adaptively with other base stations to improve performance of BER of the worse channel.

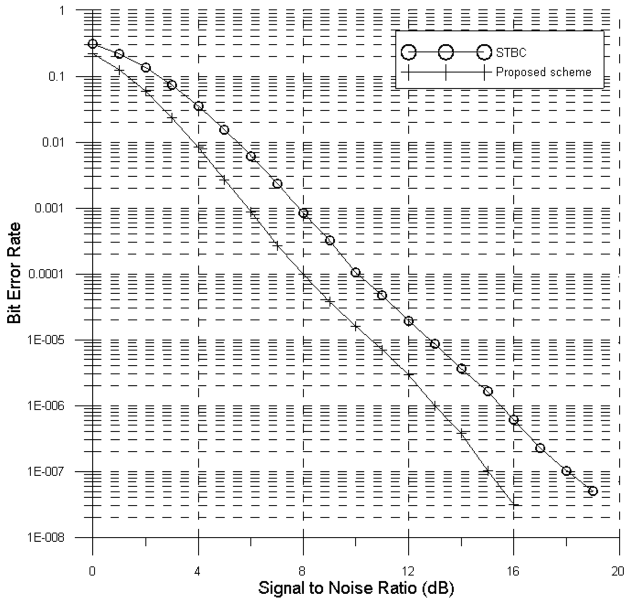

Fig. 2 BER performance of 2 transmission schemes

Minimum mean square error (MMSE) is used in pseudo inverse matrix for detection of the received signals from base stations. MMSE estimator minimizes the mean square error (MSE) quantifying the difference between the estimated values and the true values. The MMSE matrixM is denoted as

$$\mathrm{M}_{mmse} = \mathrm{inv}(\mathrm{H}^{\mathrm{H}}\mathrm{H} + \sigma^2\mathrm{I})\mathrm{H}^{\mathrm{H}}, \quad (8)$$

where inv(·) transforms a matrix into an inverse matrix, $\sigma^2$is a noise variance, I is a unit matrix and $(\cdot)^{\mathrm{H}}$ is a conjugate transpose operation. The MMSE matrix M_{mmse} is calculated with the channel matrix H to detect the received signals.

IV. Simulation Results

In this section, the performance of the proposed scheme is presented in terms of signal to noise ratio (SNR) and BER. The transmitted signals are encoded in convolutional coding with the code rate 1/2, modulated in quadrature phase shift keying (QPSK) and based on OFDM with a fast Fourier transform (FFT) size of 256. The system assumes that the path length of Rayleigh fading channel is 7 and the power allocation at each base station is uniform.

Fig. 2 shows the BER performance of the transmission schemes. If the channel condition between a base station and a user is bad, i.e., SNR is low, the proposed scheme obtains a 2 dB gain than STBC scheme at a BER of 10^{-3}.

V. Conclusion

The proposed scheme adaptively applies the CDD scheme to a base station in worse channel condition than another base station. By using the proposed scheme, broadcasting and cellular systems achieve better performance of BER. In practice, since cellular systems almost consist of concatenated cells with adjacent cells, broadcasting and cellular operators are available to employ the proposed scheme in existing systems for the improvement of BER performance. Simulation results show that the performance of the proposed cooperative scheme is better than STBC scheme in terms of BER.

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