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Cooperative CDD Scheme Based on Hierarchical Modulation in OFDM System

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Abstract**—**In order to achieve high data rate and increase the spectral efficiency, multiple input multiple output (MIMO) system has been proposed. However, multiple antennas are limited by size and cost. Therefore, recently developed cooperative diversity scheme, which profits the transmit diversity only with the existing hardware by constituting a virtual antenna array, can be a solution. However, most of the introduced cooperative techniques have a common fault of decreased transmission rate because the destination should receive the decodable compositions of symbols from the source and the relay. In this paper, we propose a cooperative cyclic delay diversity (CDD) scheme that use hierarchical modulation. This scheme is free from the rate loss and allows seamless cooperative communication.

Keywords**—**MIMO, Cooperative communication, CDD, Hierarchical modulation

I. Introduction

FOR next generation wireless systems offering high quality multimedia services, a wireless communication system which combats with impairments in the severe wireless environment is required to achieve better service quality and higher data rate. Recent research has shown that multiple input multiple output (MIMO) system has demonstrated the ability to transmit reliably and provide high throughput in rich multipath environment. It obtains diversity and multiplexing gain without increasing the total transmits power and bandwidth [1]. However, implementing multiple antennas at the devices is impractical for most wireless applications due to the limited size or high cost. In order to overcome these problems, cooperative communication has recently emerged and given considerable attention as an alternative way to achieve spatial diversity when the devices cannot afford to multiple transmit antennas [2]. This cooperative diversity was first studied in [3] and low complexity cooperative diversity protocols were proposed and analyzed in [4]. The main idea of cooperative diversity is to use multiple single antenna devices as a virtual antenna array and is to realize spatial diversity. In cooperative relay system, most of the MIMO diversity scheme can be easily applied by using multi-relays [5], [6].

One way to provide spatial diversity is the use of space time block code (STBC), which was proposed in [7]. Using the code design of Alamouti scheme [8] with two relaying terminals, we can obtain full diversity gain and full rate. But, cooperative STBC has a rate loss in the case of more than two devices due to orthogonal design of code and needs the quasi stationary multipath channel assumption for transmission of the specific number of symbols. Among other spatial diversity schemes which have gained a lot of interest, cyclic delay diversity (CDD) [9] transmits cyclically delayed signals in the time domain with different time delays through different antennas. It results in the randomization of the channel characteristics which makes it possible to achieve reduced correlation between neighboring subcarriers. That means CDD yields higher frequency selectivity and the improvement of error performance when channel coding is applied across subcarriers. However, the conventional cooperative scheme has rate-loss. In this paper, a cooperative CDD scheme based on hierarchical modulation [10] in OFDM system is proposed. By using hierarchical modulation, the proposed cooperative scheme can prevent rate-loss.

The rest of this paper is organized as follows. Section II gives cooperative system model. In Section III, we propose cooperative CDD scheme based on hierarchical modulation. In Section IV, the BER performance of the proposed scheme is evaluated and compared with conventional schemes. Lastly, we make a conclusion in Section V.

II. Cooperative System Model

In this section, we consider a cooperative relay system shown in Fig. 1. The system is made up of a single source S, a single destination D, and two relays R_i, i =1, 2. A source S and relays R_i have a single antenna and a destination D has two antennas. The coefficient of the link between S and R_i is h_{SRi}, and h_{RiDj}, is the coefficient of the link between R_i and the j-th antenna at D, where j = 1, 2. The coefficient of the link between S and D_j is h_{SDj}. It is assumed that each channel goes through Rayleigh fading and the link coefficients h is independent and identically distributed (*i.i.d*). Also, the channel state information (CSI) is known to a destination D.

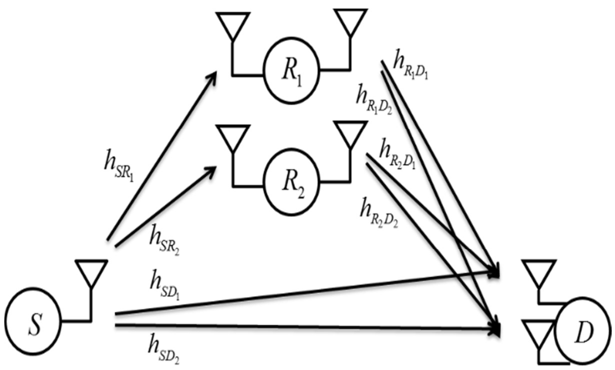

Fig. 1 A cooperative relay system

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III. Proposed Cooperative Scheme

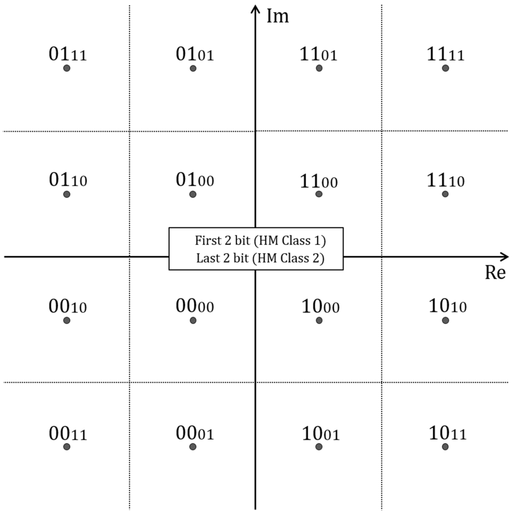

Fig. 2 The constellation for hierarchical modulation

In this section, we propose a cooperative CDD scheme based on hierarchical modulation in OFDM system. The conventional cooperative scheme has rate-loss. That problem can be solved as hierarchical modulation which is used in digital video broadcasting (DVB) system. Fig. 2 shows the constellation of hierarchical modulation. In conventional use of hierarchical modulation, these unique classes enable a destination to selectively demodulate symbols with QPSK or 16-QAM demodulators according to the channel condition. In contrast to that, the proposed scheme uses hierarchical modulation to let relays know the last 2 bits in advance.

For easier understanding about the proposed scheme, an example of the proposed cooperative CDD scheme is provided in Table I. At the first time slot, the source broadcasts a QPSK modulated symbol x_1. The relay and the destination demodulate it with QPSK demodulator. At the second time slot, the source broadcasts a hierarchically modulated symbol x_{23} and the relay 1 and 2 broadcast an estimated symbol $x_{1,\delta}$ that is a cyclically delayed symbol to achieve the diversity gain. The relay demodulates it with 16-QAM demodulator while the destination considers it as a QPSK symbol. The destination receives symbols x_{23}, $x_{1,\delta 1}$ and $x_{1,\delta 2}$. The received symbols at the destination are represented as:

$$\begin{aligned} Y_{D_1,t} &= H_{SD_1} X_{23} + H_{R_1D_1} \tilde{X}_{1,\delta_1} + H_{R_2D_1} \tilde{X}_{1,\delta_2} N_{D_1,t}, \\ Y_{D_2,t} &= H_{SD_2} X_{23} + H_{R_1D_2} \tilde{X}_{1,\delta_1} + H_{R_2D_1} \tilde{X}_{1,\delta_2} N_{D_2,t}, \end{aligned} \tag{1}$$

where D_j is an index of the j-th destination antenna, H_{SDj} is the channel frequency response between the source and the j-th destination antenna, $H_{Ri,Dj}$ is the channel frequency response between R_i and the j-th destination antenna, and $N_{Dj,t}$ is a complex Gaussian random variable with zero mean and variance σ^2. In the M × 1 CDD scheme, the cyclically delayed symbols from different relays have an effect on the destination as multipath in the channel model. For this reason, the practical transfer function of composite channel of the k-th subcarrier which is denoted in [9] is as:

$$H_k^e = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} H_{R_l,k} e^{-j\frac{2\pi}{N_F}k\delta_l}. \tag{2}$$

where N_F is the number of subcarriers, M is the number specific relay pairs, the normalization factor $\frac{1}{\sqrt{M}}$ is to keep the transmission power constant. If we apply this example to (2), the practical transfer function of signals $x_{1,\delta 1}$ and $x_{1,\delta 2}$ is given by

$$H_{R_{12}} = \frac{1}{\sqrt{2}} \left(H_{R_1} e^{-j\frac{2\pi}{N_F}k\delta_1} + H_{R_2} e^{-j\frac{2\pi}{N_F}k\delta_2} \right). \tag{3}$$

Therefore, we can again express the received signals in the frequency domain as:

$$\begin{aligned} Y_{D_1,t} &= H_{SD_1} X_{23} + H_{R_{12}D_1} \tilde{X}_1 + N_{D_1,t}, \\ Y_{D_2,t} &= H_{SD_2} X_{23} + H_{R_{12}D_2} \tilde{X}_1 + N_{D_2,t}. \end{aligned} \tag{4}$$

TABLE I
An Example of the Proposed Scheme

Time Slot	Source	Relay 1	Relay 2
t	x_1		
$t+T$	x_{23}	$\tilde{x}_{1,\delta_1}$	$\tilde{x}_{1,\delta_2}$
$t+2T$	x_{45}	$\tilde{x}_{3,\delta_1}$	$\tilde{x}_{3,\delta_2}$
$t+3T$	x_{67}	$\tilde{x}_{5,\delta_1}$	$\tilde{x}_{5,\delta_2}$

If the destination regards x_{23} as x_2, their structures are equal to 2x2 V-BLAST. The received signals in (4) can be transformed to a matrix-vector-notation as:

$$\begin{bmatrix} Y_{D_1,t} \\ Y_{D_2,t} \end{bmatrix} = \begin{bmatrix} H_{SD_1} & H_{R_{12}D_1} \\ H_{SD_2} & H_{R_{12}D_2} \end{bmatrix} \begin{bmatrix} \tilde{X}_2 \\ \tilde{X}_1 \end{bmatrix} + \begin{bmatrix} N_{D_1,t} \\ N_{D_2,t} \end{bmatrix}. \tag{5}$$

This equation is same as 2x2 V-BLAST. Because CDD scheme transforms MISO channel into SISO channel, we can reconstruct the original signal with simple V-BLAST detection algorithm. The linear scheme with zero-forcing (ZF) is used. The ZF Moore-Penrose pseudo-inverse matrix is as:

$$\mathbf{G}_{ZF} = \left(\mathbf{H}^H \mathbf{H} \right)^{-1} \mathbf{H}^H, \tag{6}$$

where $(\cdot)^H$ is the conjugate transpose operation. Finally, the estimated symbols are as:

$$\begin{bmatrix} \hat{X}_2 \\ \hat{X}_1 \end{bmatrix} = \mathbf{G}_{ZF} \begin{bmatrix} Y_{D_1,t} \\ Y_{D_2,t} \end{bmatrix}. \tag{7}$$

Although the first time slot of the proposed scheme causes rate-loss and hierarchical modulation causes a little performance degradation, the throughput of the proposed scheme becomes full rate after the first time slot and seamless relaying is possible by the proposed scheme.

IV. Simulation Results

In the cooperative model, we consider perfect synchronization and complete equalization. Moreover, the total power of the transmitting terminals is the same as the transmit power of a single hop transmission for pair comparison and all terminals have the same noise characteristics. Simulations are accomplished with following parameters. The fast Fourier transform (FFT) size is 256 and the cyclic prefix (CP) length is 32. For simulations, relays and two antennas at the destination terminal are used over 7-path Rayleigh fading channel. Fig. 3 shows the BER performance of the proposed scheme and cooperative V-BLAST schemes and cooperative CDD scheme. To show the difference of performance gap obviously, we consider that SNR of S – R channel is higher about 9 dB than R – D channel. In the simulation, the proposed scheme has 0.5dB gain better than the cooperative V-BLAST scheme at BER of 10^{-3}. The proposed scheme has 0.5dB performance degradation than STCDD scheme at the BER of 10^{-3} because hierarchical modulation causes performance degradation. Fig. 4 shows the BER performance of the proposed scheme and cooperative V-BLAST schemes and cooperative CDD scheme. To show the difference of performance gap obviously, we consider that SNR of S – R channel is higher about 9 dB than R – D channel. In the simulation, the proposed scheme has 0.5dB gain better than the cooperative V-BLAST scheme at BER of 10^{-4}. The proposed scheme has 0.4dB performance degradation than STCDD scheme at the BER of 10^{-4} because hierarchical modulation causes performance degradation. According to simulation result, the proposed scheme has better BER performance than cooperative V-BLAST scheme but has a little performance degradation than the cooperative CDD scheme.

V. Conclusion

In this paper, we proposed the cooperative CDD scheme based on hierarchical modulation in OFDM system. The simulation result shows that the proposed scheme outperforms than the cooperative V-BLAST scheme. However, there is slight performance degradation compared to the cooperative CDD scheme because hierarchical modulation causes performance degradation. The proposed scheme can be free from the loss of transmission rate due to the transmission of the source's latter symbols to the relays in advance.

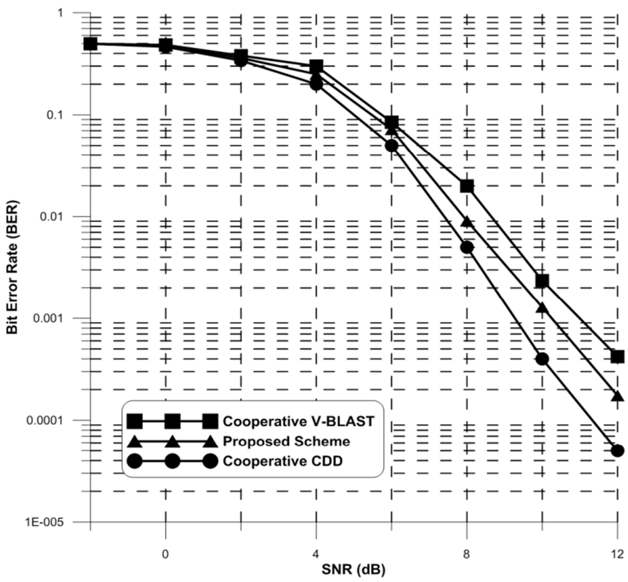

Fig. 3 The BER performance of the proposed scheme, cooperative V-BLAST scheme and cooperative CDD scheme

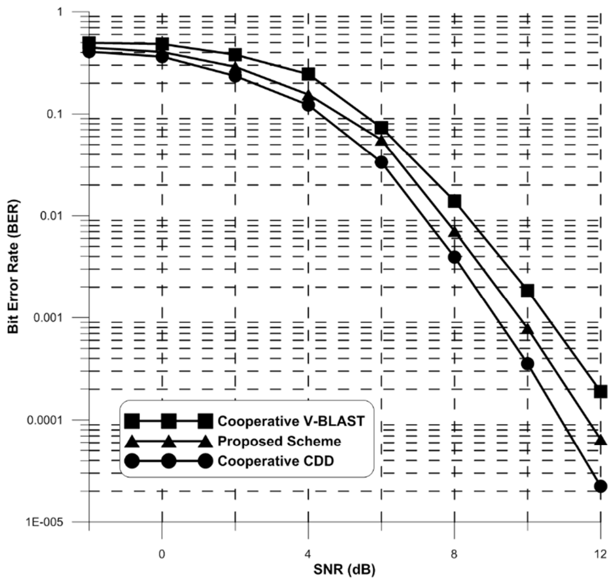

Fig. 4 The BER performance of the proposed scheme, cooperative V-BLAST scheme and cooperative CDD scheme

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