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An Improved Transmission Scheme in Cooperative Communication System

Seung-Jun Yu, Young-Min Ko, Hyoung-Kyu Song

Abstract**—**Recently developed cooperative diversity scheme enables a terminal to get transmit diversity through the support of other terminals. However, most of the introduced cooperative schemes 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 order to achieve high data rate, we propose a cooperative scheme that employs hierarchical modulation. This scheme is free from the rate loss and allows seamless cooperative communication.

Keywords**—**Cooperative communication, hierarchical modulation, high data rate, transmission scheme.

I. Introduction

MULTIPLE input multiple output (MIMO)-orthogonal frequency division multiplexing (OFDM) systems are considered to be a promising solution to enhance the performance in rich scattering wireless channel. MIMO-OFDM systems can offer diversity and multiplexing gain without increasing total transmit power and bandwidth [1], [2]. Cyclic delay diversity (CDD) [3] and space time block code (STBC) [4], [5] are representative MIMO spatial diversity schemes, and Vertical Bell Laboratories layered space-time (V-BLAST) [6] is typical MIMO multiplexing scheme. 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 [7]. This cooperative diversity was first studied in [8] and low complexity cooperative diversity protocols were proposed and analyzed in [9]. 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 schemes can be easily applied by using multi-relays [10], [11]. However, the conventional cooperative schemes have rate-loss.

In this paper, an improved transmission scheme based on hierarchical modulation [12] in cooperative is proposed to achieve high data rate. By using hierarchical modulation, the proposed cooperative scheme can be free from the rate loss and allow seamless cooperative communication.

The rest of this paper is organized as follows. Section II gives two-relay cooperative system and hierarchical modulation. In Section III, we propose an improved transmission scheme based on hierarchical modulation in cooperative system. In Section IV, the performances of the proposed scheme are evaluated and compared with conventional schemes. Lastly, we make a conclusion in Section V.

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II. System Model

A. Two-Relay Cooperative System

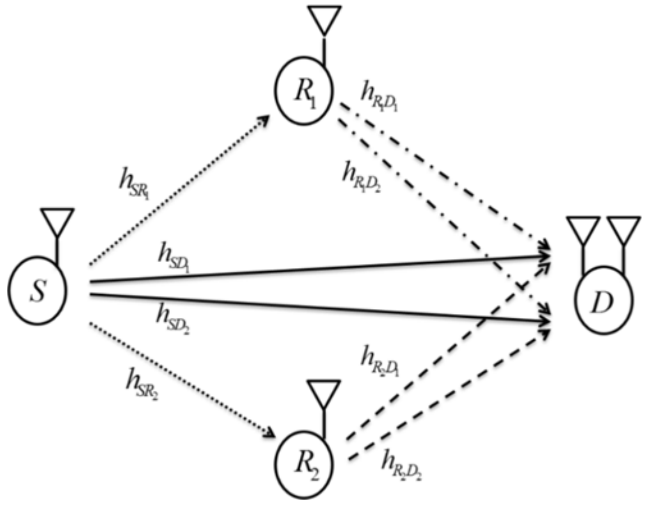

Fig. 1 Two-relay cooperative system

In this section, we consider two-relay cooperative system model as shown in Fig. 1. Two-relay cooperative system consists of a source S, two relays R_i and a destination D, where i = 1, 2. A source S and two relays R_i have a single antenna and a destination D has two antennas. This system is based on orthogonal frequency division multiplexing (OFDM) transmission technique. The l^{th} OFDM symbol at time t as:

$$y_{l,t} = \frac{1}{\sqrt{N_F}} \sum_{k=0}^{N_F-1} X_{l,k} e^{-j\frac{2\pi}{N_F}kt}, \quad (1)$$

where N_F is the number of subcarriers and k is an index of subcarrier.

The channel coefficient of the link between S and R_i is represented h_{SRi} and the one between R_i and the j-th antenna at D, where j = 1, 2, is represented h_{RiDj}. The channel coefficient of the link between S and D_j is represented h_{SDj}. It is supposed that each channel undergoes Rayleigh fading and the coefficient of h_{SRi}, h_{RiDj} and h_{SDj} is independent and identically distributed ($i.i.d$). We suppose the half-duplex channel and assume that the channel state information (CSI) is known to a destination *D*.

B. Hierarchical Modulation

We consider hierarchical modulation with Gray code mapping as shown in Fig. 2. It can be viewed as the combination of two quadrature phase shift keying (QPSK) modulation with two levels of hierarchy: high-priority bits, which are to be assigned to the bit stream that requires a higher level of protection and low-priority bits, which are to be assigned to the bit stream for which a low level of protection is acceptable.

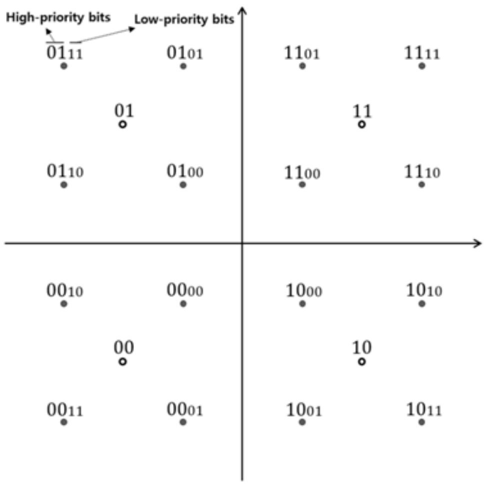

Fig. 2 An example of hierarchical modulation

III. Proposed Scheme

In this section, we propose an improved transmission scheme based on hierarchical modulation in cooperative system. The conventional cooperative scheme has rate-loss. That problem can be solved as hierarchical modulation in [7].

TABLE I
Code Design of The Proposed Scheme

t	S	R_1	R_2
t	x_{12}		
$t+T$	x_{34}	$\tilde{x}_{2,\delta_1}$	$\tilde{x}_{2,\delta_2}$
$t+2T$	x_{56}	$\tilde{x}_{4,\delta_1}$	$\tilde{x}_{4,\delta_2}$
$t+3T$	x_{78}	$\tilde{x}_{6,\delta_1}$	$\tilde{x}_{6,\delta_2}$

For easier understanding about the proposed scheme, code design of the proposed scheme is provided in Table I. At the first time slot, the source broadcasts a hierarchically modulated symbol x_{12}. Two relays demodulate it with 16-QAM demodulator. The destination demodulate it with QPSK demodulator. At the second time slot, the source broadcasts a hierarchically modulated symbol x_{34} and relay R_1 and R_2 broadcast estimated symbols $x_{2,\delta 1}$, $x_{2,\delta 2}$ that are cyclically delayed symbols to obtain the diversity gain. The received symbols at the destination are represented as:

$$\begin{aligned} Y_{D_1,t} &= H_{SD_1}X_{34} + H_{R_1D_1}\tilde{X}_{2,\delta_1} + H_{R_2D_1}\tilde{X}_{2,\delta_2} + N_{D_1,t}, \\ Y_{D_2,t} &= H_{SD_2}X_{34} + H_{R_1D_2}\tilde{X}_{2,\delta_1} + H_{R_2D_2}\tilde{X}_{2,\delta_2} + N_{D_2,t}, \end{aligned} \quad (2)$$

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 2 × 1 CDD scheme, the cyclically delayed symbols from different relays have an effect on the destination as multipath in the channel model. The channel transfer function of H_{R1} and H_{R2} is as:

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

Therefore, the received signals in the frequency domain is as:

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

If the destination regards x_{34} as x_3, their structures are equal to 2 x 2 V-BLAST. The received signals in (4) can be transformed to a matrix notation as:

$$\begin{bmatrix} Y_{D_1,t} \\ Y_{D_2,t} \end{bmatrix} = \begin{bmatrix} H_{SD_1} & H_{R_{12}D_1} \\ H_{SD_2} & H_{R_{12}D_2} \end{bmatrix} \begin{bmatrix} \tilde{X}_3 \\ \tilde{X}_2 \end{bmatrix} + \begin{bmatrix} N_{D_1,t} \\ N_{D_2,t} \end{bmatrix} \quad (5)$$

Because MISO channel converts into SISO channel by CDD scheme, we can reconstruct the original signals with V-BLAST detection algorithm. The destination uses Minimum Mean Square Error (MMSE) detection algorithm. The MMSE Moore-Penrose pseudo-inverse matrix is as:

$$\mathbf{G}_{MMSE} = \left(\mathbf{H}^H\mathbf{H} + \sigma^2\mathbf{I} \right)^{-1} \mathbf{H}^H \quad (6)$$

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

$$\begin{bmatrix} \hat{X}_3 \\ \hat{X}_2 \end{bmatrix} = \mathbf{G}_{MMSE} \begin{bmatrix} Y_{D_1,t} \\ Y_{D_2,t} \end{bmatrix} \quad (7)$$

Although hierarchical modulation causes degradation of BER performance, seamless relaying is possible by the proposed scheme.

IV. Simulation Results

In this section, we consider following parameters to evaluate the performance of proposed scheme. Simulation parameters: FFT size N_F = 256, length of cyclic prefix (CP) = 32, 1/3 rate convolutional encoder with constraint length 7. We performed computer simulations over 7-path Rayleigh fading channel to verify the performance of the proposed scheme compared with conventional schemes from the viewpoint of BER and throughput performance.

Fig. 3 shows BER performance of conventional cooperative schemes and proposed cooperative scheme. In Fig. 3, we assume that SNR of S – R channel is higher about 9 dB than R – D channel to show the difference of performance gap obviously. Because the proposed cooperative obtain diversity gain due to two relays using CDD scheme, the proposed scheme has 0.6dB gain better than the cooperative V-BLAST scheme at BER of 10^{-3}. Because hierarchical modulation causes the degradation of performance, the cooperative CDD scheme has 0.7dB gain better than the proposed scheme at BER of 10^{-3}.

Fig. 4 shows throughput performance of conventional cooperative schemes and proposed cooperative scheme. In the simulation, the throughput is calculated as:

$$T = (1-E) \times L \times R \quad (8)$$

where T is throughput, E is bit error rate, L is transmission bits and R is transmission rate, respectively. In Fig. 4, the proposed scheme outperforms than the conventional cooperative schemes because of the use of hierarchical modulation.

V. CONCLUSION

In this paper, we proposed an improved transmission scheme based on hierarchical modulation in cooperative communication system. The proposed scheme can be free from the loss of transmission rate due to hierarchical modulation. The result of BER simulation shows that the proposed scheme has 0.6dB better than conventional cooperative V-BLAST scheme. The result of Throughput shows that the proposed scheme outperforms than the conventional cooperative schemes.

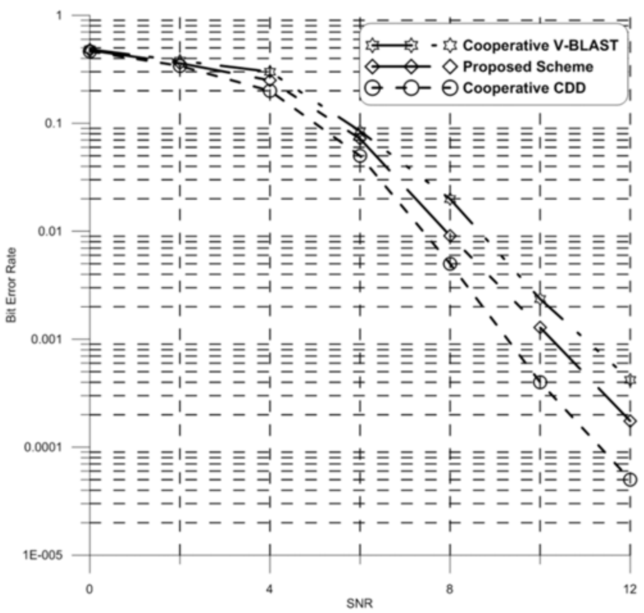

Fig. 3 BER performance of conventional schemes and proposed scheme when SNR gap is set to 9 dB

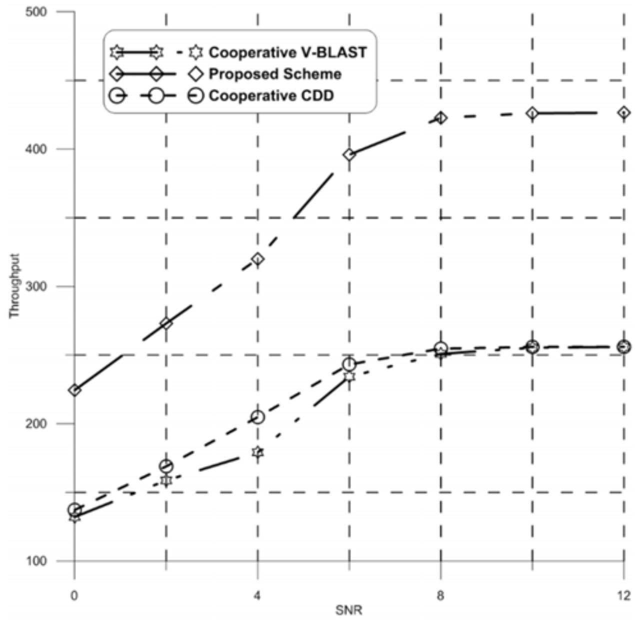

Fig. 4 Throughput performance of conventional schemes and proposed scheme when SNR gap is set to 9 dB

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