

# Cooperative CDD Scheme Based On Adaptive Modulation in Wireless Communication System

Seung-Jun Yu, Hwan-Jun Choi, Hyoung-Kyu Song

**Abstract**—Among spatial diversity scheme, orthogonal space-time block code (OSTBC) and cyclic delay diversity (CDD) have been widely studied for the cooperative wireless relaying system. However, conventional OSTBC and CDD cannot cope with change in the number of relays owing to low throughput or error performance. In this paper, we propose a cooperative cyclic delay diversity (CDD) scheme that use hierarchical modulation at the source and adaptive modulation based on cyclic redundancy check (CRC) code at the relays.

**Keywords**—Adaptive modulation, Cooperative communication, CDD, OSTBC.

## I. INTRODUCTION

HIGH quality multimedia services for future wireless communications need technologies that can provide increased throughput. The multi-input multi-output (MIMO) scheme significantly enhances system performance and robustness to the channel without the use of additional bandwidth and power consumption [1]. However, implementing multiple antennas at the terminals is impractical for most wireless applications due to the limited size or high cost. In order to overcome these problems, cooperative diversity has recently emerged and given considerable attention as an alternative way to achieve spatial diversity when the terminals 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 terminals as a virtual antenna array, realizing spatial diversity.

One way to provide spatial diversity is the use of orthogonal space time block code (OSTBC), which has been proposed in [5]. Using the code design of Alamouti scheme [6] with two relaying terminals, we can obtain full diversity gain and full rate. But, cooperative OSTBC has a rate loss in the case of more than two relaying terminals 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 gained a lot of interest, cyclic delay diversity (CDD) [7] 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.

A simple description of the dual-hop relaying protocol is following. In the first hop, the source broadcasts to the relays. In the second hop, the relays simply transmit sources signals in separated channels or transmit them using a space-time code to the destination. Consequently, the reliability of the communications is improved whereas the throughput might go down since the transmission is performed by two times. Conventional dual-hop scheme has used the same modulation method for the source and the relays. Given that the distances between the source and the relays are close, in other words, when the quality of the source-relays link is good, the usage of higher order modulation at the source improves total system throughput. However, in opposite case, bit error probability is increased through using higher order modulation. Therefore, we propose a cooperative CDD scheme that uses hierarchical modulation [8] at the source and adaptive modulation based on cyclic redundancy check (CRC) code at the relays. Accordingly, the bit error rate (BER) and throughput performances are improved by the proposed scheme.

## II. COOPERATIVE SYSTEM MODEL

In this section, we consider a dual-hop cooperative relay system with  $N+2$  terminals which is made up of a single source  $S$ , a single destination  $D$ , and all the other  $N$  terminals  $R_i$ ,  $i=1, 2, \dots, N$ , serving as the relays. A source  $S$  and relays  $R_i$  have a single antenna and a destination  $D$  has two antennas. We assume that communication takes place only over dual-hop links and there is no direct between  $S$  and  $D$ . The coefficient of the link between  $S$  and  $R_i$  is  $h_{i,s}$  and  $h_{j,i}$  is the coefficient of the link between  $R_i$  and  $j$ -th antenna at  $D$ , where  $j = 1, 2$ . It is assumed that each channel goes through Rayleigh fading and the link coefficients  $h_{i,s}$  and  $h_{j,i}$  are independent and identically distributed (*i.i.d*). Also, the channel state information (CSI) is known to  $D$  and the channels are supposed to be constant for three time slots. We assume a half-duplex channel, for which all terminals cannot transmit and receive symbols at the same time over the same frequency band.

## III. PROPOSED COOPERATIVE SCHEME

In this section, we propose the cooperative CDD scheme that uses hierarchical modulation at the source and adaptive modulation based on CRC code at the relays. Generally, the proposed DF scheme provides high throughput in good channel condition and maintain BER performance in bad channel condition. In order to adaptively transmit signals, we need to

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use CRC code. The proposed adaptive modulation uses hierarchical 16-QAM, which can be regarded as the combination of two QPSK modulations. The former 2 bits choose a position of large quadrant and the latter 2 bits determine a position of the small quadrant within the former 2 bits selected position. We name them hierarchical modulation class 1 (HM class 1) and class 2 (HM class 2), respectively. In conventional use of hierarchical 16-QAM, these distinctive classes enable a QPSK or a 16-QAM demodulator according to the channel quality. In contrast to that, we use hierarchical 16-QAM to let relays always demodulate with a 16-QAM demodulator. If CRC at any relay indicates failure of decoding, all relays discard the latter 2 bits. In voice and video signals, any most significant bits (MSBs) errors cause significantly more degradation in the symbol quality as compared to errors in the least significant bits (LSBs). Let us consider 4 bit data with 2 MSBs and LSBs. In hierarchical 16-QAM, groups of 2 MSBs are mapped to HM class 1 and groups of 2 LSBs are mapped to HM class 2, respectively. Hence, a very small performance drop is caused by omitting the latter 2 bits. For easier understanding of the proposed cooperative scheme, a simple cooperation example which considers 4 relays is provided. The proposed cooperative scheme may be operated using following steps. During two time slots, a source broadcasts hierarchically 16-QAM modulated symbols  $X_{12}$  and  $X_{34}$  to relays. The received symbols at relays in frequency domain are represented as

$$\begin{aligned} Y_{R_i,t} &= H_{R_i} X_{12} + N_{R_i,t}, \\ Y_{R_i,t+T} &= H_{R_i} X_{34} + N_{R_i,t+T}, \end{aligned} \quad (1)$$

where the subscript " $R_{i,t+kT}$ " stands for the  $(k+1)$ -th time slot component at the  $i$ -th relay,  $H_i$  represents the frequency responses of  $S$ - $R_i$  link, and  $N$  is a complex Gaussian random variable with zero mean and variance  $\sigma^2$ .

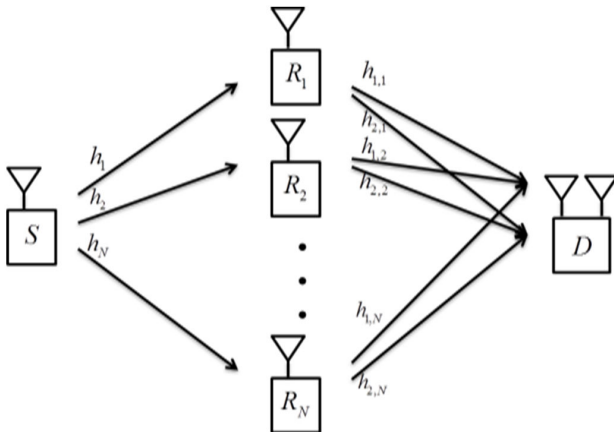


Fig. 1 Dual-hop cooperative wireless system

Each relay demodulates symbols with a 16-QAM demodulator and uses an adaptive modulation method according to the result of CRC verification. In order to do that,

all relays are supposed to share the CRC results causing a small overhead. If CRC indicates successful decoding at all relays, all relays modulate 4 bits with a QPSK modulator. If CRC at any relay indicates failure of decoding, all relays discard latter 2 bits. And then, each relay modulates former 2 bits with a BPSK modulator. Modulated symbols are implemented by using IFFT of size  $N_F$  in each relay. Each output of IFFT is cyclically shifted by a specific delay  $\delta_l$ .

The code design of the relay which has successful CRC decoding is

$$M_4 = \begin{pmatrix} X_{12,\delta_1} & X_{12,\delta_2} & X_{34,\delta_1} & X_{34,\delta_2} \\ -X_{34,\delta_1}^* & -X_{34,\delta_2}^* & X_{12,\delta_1}^* & X_{12,\delta_2}^* \end{pmatrix}, \quad (2)$$

where  $\delta_l$  denotes the cyclic delay length of the  $l$ -th relay in each group. An optimal cyclic delay  $\delta_l$  in each group is represented in [7]. At third time slot, the destination receives the space time coded symbols from relays. The received symbols in the frequency domain can be expressed as

$$\begin{aligned} Y_{D_n,t} &= H_{R_1,D_n} X_{12,\delta_1} + H_{R_2,D_n} X_{12,\delta_2} \\ &\quad + H_{R_3,D_n} X_{34,\delta_1} + H_{R_4,D_n} X_{34,\delta_2} + W_{D_n,t}, \\ Y_{D_n,t+T} &= -H_{R_1,D_n} X_{34,\delta_1}^* - H_{R_2,D_n} X_{34,\delta_2}^* \\ &\quad + H_{R_3,D_n} X_{12,\delta_1}^* + H_{R_4,D_n} X_{12,\delta_2}^* + W_{D_n,t+T}, \end{aligned} \quad (3)$$

where  $D_n$  is an index of the  $n$ -th destination antenna,  $H_{R_i,D_n}$  is the channel frequency response between  $R_i$  and the  $n$ -th destination antenna, and  $W_{D_n,t+T}$  is a complex Gaussian random variable with zero mean and variance  $\sigma^2$ . In the  $M \times 1$  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 [7] is as follows

$$H_k^e = \frac{1}{\sqrt{M}} \sum_{m=0}^{M-1} H_{R_m,k} e^{-j \frac{2\pi}{N_F} k \delta_m}. \quad (4)$$

Therefore, we can again express the received symbols in the frequency domain as follows

$$\begin{aligned} Y_{D_n,t} &= H_{R_{12},D_n} X_{12} + H_{R_{34},D_n} X_{34} + W_{D_n,t}, \\ Y_{D_n,t+T} &= -H_{R_{12},D_n} X_{34}^* + H_{R_{34},D_n} X_{12}^* + W_{D_n,t+T}. \end{aligned} \quad (5)$$

Finally, we can estimate each signal as follows

$$\begin{aligned} \hat{X}_{12} &= H_{R_{12},D_1}^* Y_{D_{1,t}} + H_{R_{34},D_1} Y_{D_{1,t+T}} \\ &\quad + H_{R_{12},D_2}^* Y_{D_{2,t}} + H_{R_{34},D_2} Y_{D_{2,t+T}}, \\ \hat{X}_{34} &= H_{R_{34},D_1}^* Y_{D_{1,t}} - H_{R_{12},D_1} Y_{D_{1,t+T}} \\ &\quad + H_{R_{34},D_2}^* Y_{D_{2,t}} - H_{R_{12},D_2} Y_{D_{2,t+T}}. \end{aligned} \quad (6)$$

This equation is the same as the Alamouti's STBC. In other words, even if the number of relays increases, our proposed scheme can be applied to existing system which two transmit antennas using Alamouti code without changing the receiver design.

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 128 and the cyclic prefix (CP) length is 32. For simulations, relays and two antennas at the destination terminal are used over 8-path Rayleigh fading channel. Fig. 2 and Fig. 3 show the BER performance of the proposed cooperative scheme with/without CRC, when the number of relays is 2 and 4. In the simulation, depending on the result of the CRC, relays adaptively transmit symbols. Consequently, throughput of the proposed scheme with CRC is slightly lower than that of the proposed scheme without CRC. However, the proposed scheme with CRC always shows higher BER performance than that of the proposed scheme without CRC.

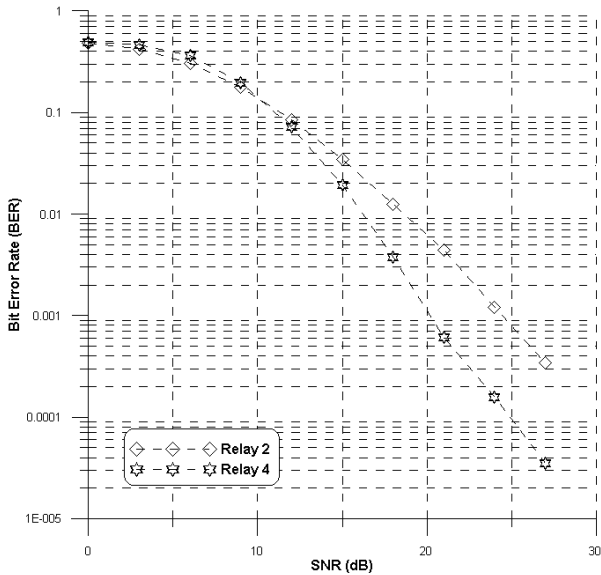


Fig. 2 The BER performance of the proposed cooperative scheme with CRC

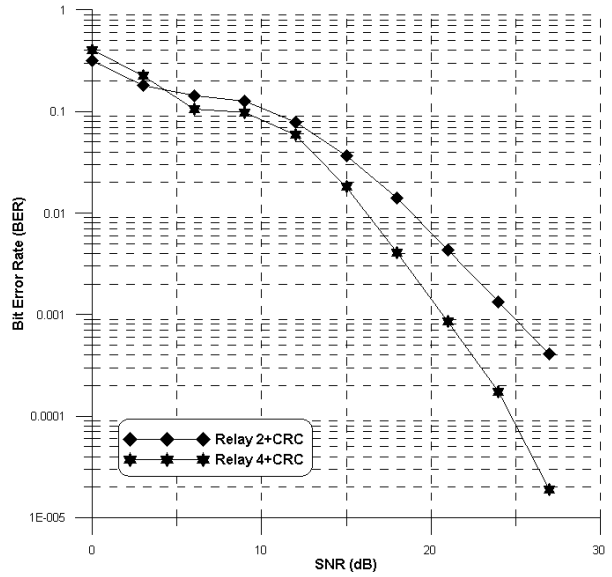


Fig. 3 The BER performance of the proposed cooperative scheme without CRC

V. CONCLUSION

In this paper, we proposed the cooperative CDD scheme which is combined with adaptive hierarchical modulation. The simulation results have shown that the performance of the proposed scheme is improved by increasing the number of relays. The increment of the number of relays appears to have significant impact on the performance because the diversity gain depends on the number of relays. In addition, the proposed scheme with CRC always shows higher BER performance than that of the proposed scheme without CRC. In particular, the proposed cooperative scheme guarantees reliable transmission for low SNR.

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