The Study on Cooperative Relay Coding in Multicarrier System

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Abstract

Cooperative relay systems represent a promising solution overcoming the drawbacks of non-line-of-sight (NLOS) propagation in future wireless communications. In this paper, we propose a cooperative relay coding which uses adaptive hierarchical modulation based on cyclic redundancy check (CRC) and cyclic delay diversity (CDD). In the proposed scheme, the system consists of multiple single-antenna terminals acting as relays and cooperating to provide spatial diversity. Also, cyclic shift is introduced at the relays to increase the frequency selectivity in the relay channels. To exploit a highly selective channel, convolutional code is employed together with orthogonal frequency division multiplexing (OFDM). The proposed scheme is evaluated in terms of the bit error rate (BER).

Keywords: *OFDM, relays, hierarchical modulation, cyclic delay diversity*

1. Introduction

Orthogonal frequency division multiplexing (OFDM) has been one of the most promising technologies in wireless communications [1]. In OFDM systems, the high-rate serial data stream is divided into a group of low-rate substreams to increase the symbol duration of OFDM symbol with respect to the number of subcarriers. Since each subcarrier goes through a flat fading channel, the OFDM receiver is relatively uncomplicated. As a result, the OFDM systems yield the robustness to frequency selective fading and high spectral efficiency.

Multiple-input multiple-output (MIMO) systems employ several antennas at the transmitter and receiver to provide a multiplexing gain which increases the channel capacity and a diversity gain which improves the link reliability. However, due to size, cost and complexity limitation, most of the practical wireless terminals may not be able to support multiple antennas [2].

In order to get over these constraints, the cooperative communication systems have been proposed in [2-3]. The main idea of this class of communication schemes is that single-antenna terminals in a multi-user environment share their antenna and create a virtual MIMO system to increase the quality of service by cooperation. In cooperative systems, we can obtain spatial diversity through MIMO diversity schemes which can be easily applied by using multiple relays [4-5]. In case of single antenna at each terminal, it may not be possible that a cooperative system obtains multiplexing gain. However, the destination in the uplink system is easily equipped with multiple antennas. Therefore, we can increase throughput in the destination with multiple antennas by using MIMO multiplexing scheme such as Vertical Bell Laboratories layered space-time (V-BLAST) which has demonstrated very high spectral efficiencies [6]. In this paper, we adapt adaptive hierarchical modulation and cyclic delay diversity (CDD) to be combined with V-BLAST in multi-user relay systems. In the proposed

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scheme, we use hierarchical modulation [7] which is applied in digital video broadcasting (DVB) system at the source and adaptive modulation based on cyclic redundancy check (CRC) code at the relays. Also, multiple relays with a single antenna share their resources and exploit spatial diversity and multiplexing gain. For the cooperative effect to be more advantageous, CDD is adopted in cooperative transmission of relays. CDD yields the frequency selectivity in the relay channel which can be exploited at the destination. Consequently, the bit error rate (BER) performance is improved by the proposed scheme.

The rest of this paper is organized as follows. Section 2 describes cooperative system model. In Section 3, we present the proposed scheme. After simulation results in Section 4, we conclude in Section 5.

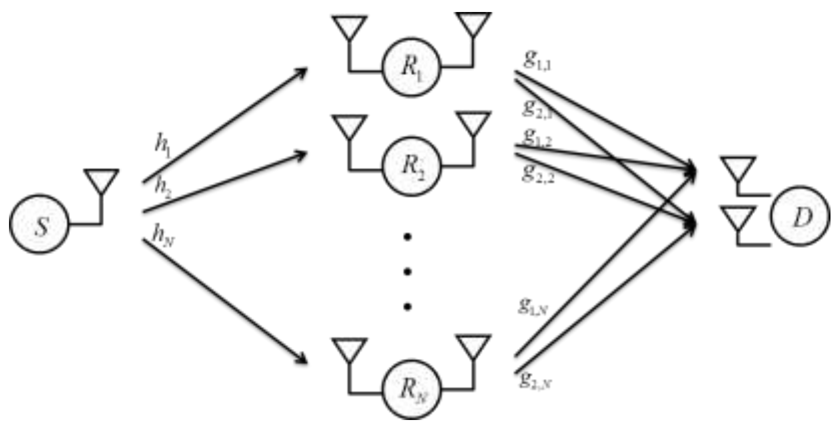

Figure 1. Dual-hop Cooperative Relay System

2. Cooperative System Model

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,...,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, and $g_{j,i}$ 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, and $g_{j,i}$ 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.

3. Proposed Cooperative Scheme

In this section, we propose the cooperative CDD scheme which is combined with adaptive hierarchical modulation. CDD transmits cyclically delayed symbols in the time domain with different time delays through different antenna [5]. It is a very simple and superior method to improve frequency selectivity, thereby randomizing the channel response.

The proposed adaptive modulation uses hierarchical 16-QAM [7], 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.

To improve the system performance, we combine a cooperative CDD scheme with adaptive hierarchical modulation based on CRC code at relays. Figure 1 shows the structure of a dual-hop cooperative relay system with *N* relays. For easier understanding of the proposed cooperative scheme, a simple cooperation example which considers 4 relays is provided. Relays can be divided into two groups and each group has two relays in each group. Relays are selected randomly when relays are divided into groups. In this example, R_1 and R_2 are selected for a group and R_3 and R_4 are selected for the other group.

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

$$\begin{aligned} Y_{R_i,t} &= H_i X_{12} + N_{R_i,t}, \\ Y_{R_i,t+T} &= H_i X_{34} + N_{R_i,t+T}, \end{aligned} \tag{1}$$

where the subscript "R_{i+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 σ^2.

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 16-QAM 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 QPSK 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 δ_l.

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

$$Q_4 = [X_{12,\delta_1}\ X_{12,\delta_2}\ X_{34,\delta_1}\ X_{34,\delta_2}], \tag{2}$$

where δ_l denotes the cyclic delay length of the *l*-th relay in each group. An optimal cyclic delay δ_l in each group is represented in [5]. 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

$$Y_n = G_{n,1}X_{12,\delta_1} + G_{n,2}X_{12,\delta_2} + G_{n,3}X_{34,\delta_1} + G_{n,4}X_{34,\delta_2} + W_n, \tag{3}$$

where n is an index of the n-th destination antenna, $G_{n,l}$ is the channel frequency response between R_i and the n-th destination antenna, and W_n is a complex Gaussian random variable with zero mean and variance σ^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 [5] is as follows

$$G_n = \frac{1}{\sqrt{M}} \sum_{l=1}^{M} G_{n,l}(k) \times e^{-j\frac{2\pi}{N_F}k\delta_l}. \tag{4}$$

Therefore, we can conclude that CDD effectively transforms the multiple-input single-output (MISO) channel into single-input single-output (SISO) channel with increased frequency selectivity. The received signal can be transformed to a matrix-vector-notation as follows

$$\begin{bmatrix} Y_1 \\ Y_2 \end{bmatrix} = \begin{bmatrix} G_{1,12} & G_{1,34} \\ G_{2,12} & G_{2,34} \end{bmatrix} \begin{bmatrix} X_{12} \\ X_{34} \end{bmatrix} + \begin{bmatrix} N_1 \\ N_2 \end{bmatrix}. \tag{5}$$

This equation is identical as 2 × 2 V-BLAST. Even though the number of relays is increased, the proposed cooperative scheme can be applied to 2 × 2 V-BLAST system without changing the design of the destination terminal. Thus, we can reconstruct the original symbols with simple V-BLAST detection algorithms. In this paper, the linear detection scheme with MMSE is used.

4. 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, 2~6 relays and two antennas at the destination terminal are used over 7-path Rayleigh fading channel.

Figure 2 shows the BER performance of the cooperative CDD scheme according to the number of relays as a function of signal to noise power ratio (SNR). To show the difference of performance gap obviously, we consider that SNR of *S-R* link is higher about 9 dB than that of *R-D* link. The performance in accordance with the number of relays appears to have a significant impact because the diversity gain depends on the number of relays.

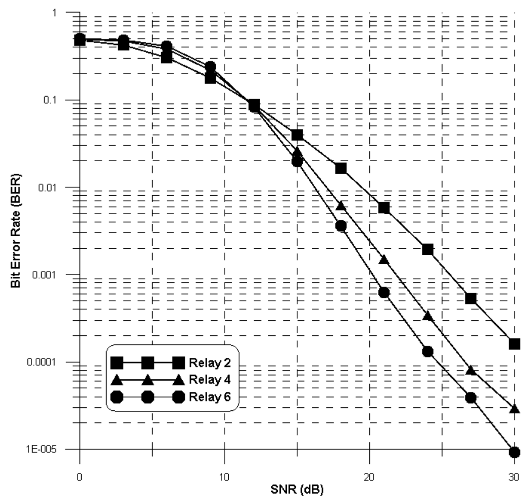

Figure 2. The BER Performance According to the Number of Relays

5. 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.

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