An Efficient Space-Time Coded Cooperation Protocol for Wireless Communication

Ji-Hwan Park · Hyung-Yun Kong

Abstract

This paper proposes a new cooperative protocol in which Alamouti's scheme is applied to exploit the advantages of both coded cooperation and Alamouti's scheme. It not only has better than direct transmission but also coded cooperation at appropriate cooperation levels. Simulation results show that the proposed protocol can save approximately 6~7 dB of transmit power to achieve the target BER(Bit Error Rate) compared with coded cooperation. Furthermore, the performance of the proposed protocol does not significantly depend on the qualities of inter-user channels.

Key words : Coded Cooperation, Alamouti's Scheme, STBC, Spatial Diversity, Rayleigh Fading.

Ⅰ. Introduction

Signal fading due to multipath propagation is a serious problem in wireless communication and diversity is considered an effective tool for combating multipath fading, which causes random variations of the signal levels at the mobile units during a communication section[1]. Diversity is achieved by transmitting affectively or processing independently faded copies of the signal. Recently, cooperative diversity has attracted great interest in research community[2]~[5]. The basic concept of cooperative networks is that several single-antenna relays assist the source in the transmission of the signal to the destination. For example, there are various cooperative transmission protocols in which to classify some of the most popular protocols such as: amplify-and-forward(AF), decode-and-forward(DF), hybrid decode-and-forward(HDF) and coded cooperation. In these protocols, the relays repeat the received signal except in coded cooperation[6],[7], where the codeword is partitioned into two subframes; one subframe is transmitted by the source and the other by the relay. Thus, coded cooperation can provide significant performance gains for a variety of channel conditions. Performance gains can be obtained by employing different code rates through compatible codes[8]. However, this scheme could not get any benefit and shows its strength when the uplink's channel are fast fading channel and when its partner fails in decoding.

In this paper, the authors introduce an extension to coded cooperation that significantly improves the performance under the same conditions by applying Alamouti's scheme[9]. This proposed protocol not only offers better performance at a low SNR regime but also at a high SNR regime compared with that of coded cooperation. In addition, it diminishes the effect of inter-channel quality on the system performance.

An outline of the remainder of the paper is as follows. Section 2 presents the cooperative system models. In Section 3, the protocol for coded cooperation with the application of Alamouti's scheme is described. Section 4 compares the BER performance of the proposed protocol with other methods and Section 5 offers conclusions.

Ⅱ. System Models

As illustrated in Fig. 1, the system under consideration consists of two users(users A and B) and one destination (denoted as user D) where information is transmitted

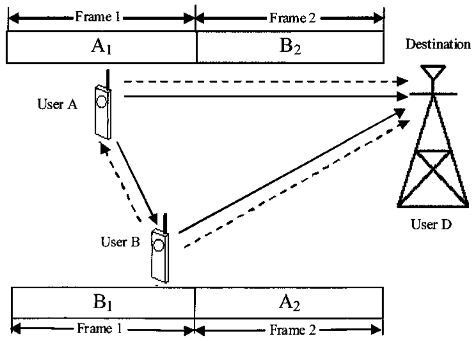

Fig. 1. Coded cooperation implementation for a system using TDMA.

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from user A to the destination with the assistance of user B. All terminals are equipped with a single-antenna transceiver and share the same frequency band. The modulation is assumed to be binary phase shift keying (BPSK). Each node can cooperate with another node (the partner) to transmit information to the destination. For the sake of exposition, it is assumed that the channels between users(inter-user channels) and those from each user to the destination(uplink channels) are mutually independent and are subjected to Rayleigh fading plus additive white Gaussian Noise(AGWN). It is also assumed that a slowly fading channel stays constant during a one-frame period and changes independently to the next. Lastly, it is assumed that each terminal knows the channel state information(CSI) perfectly and all receivers can achieve perfect timing and carrier synchronization.

Ⅲ. Description of Cooperative Technique

3-1 Overview of Coded Cooperation

Coded cooperation functions by sending each terminal's codeword via two independent fading paths. The basic concept of coded cooperation is that each terminal attempts transmit incremental redundancy to its partner. Each terminal segments its data into coded transmit blocks consisting of N code symbols, with the allocated rate R[b/s/Hz] for each block. Terminals cooperate by dividing the transmission of each N-symbol block over two sub-frames. In the first subframe, each terminal transmits a rate- $R/\alpha(0<\alpha\leq 1)$ codeword including $N_1=\alpha N$ symbols. The parameter α is defined as the degree of cooperation, or the portion that the N total channel symbols allocated for the first frame. If the terminal successfully decodes the received subframe from its partner, then in the second sub-frame, it will transmit N_2 additional parity symbols for the partner's data, $N_1+N_2=N$. Otherwise, the terminal transmits N_2 additional parity symbols for its own data or remains idle. The drawback of coded cooperation is that the destination can only receive a powerful codeword when the cooperation between the two terminals is successful. Two sub-frames from the terminal and its partner can be combined to generate a low rate codeword before decoding by a Viterbi decoder. When the decoding status at the partner is unsuccessful, the system performance is severely degraded compared with direct transmission. It is the reason why coded cooperation depends so much on the SNR of inter-channels.

3-2 Proposed Coded Cooperation

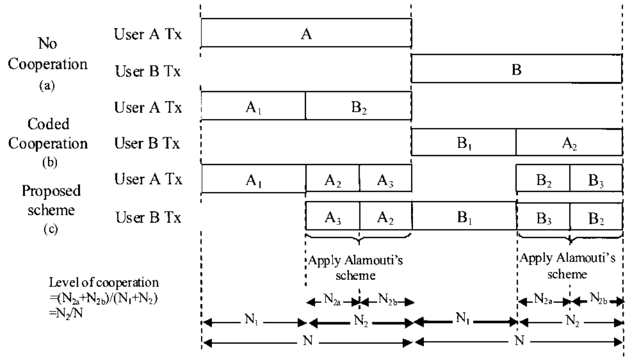

Fig. 2. TDM scheduling for the proposed protocols.

Protocol design was based on the thought that a protocol should not always allow the destination to receive a powerful codeword without considering the decoding status of its partner. By applying the simple and efficient space time block code introduced by Alamouti[9] in the second subframe, more space-time diversity can be exploited when the cooperation process is successful. Fig. 2, describes and compares the signaling scheme of the proposed protocol with those of coded protocol and direct transmission. As in Fig. 2c, both the user and its partner concurrently transmit data under the space time block code(STBC) form to the destination when the partner can decode the user's data correctly. However, the crucial issue is that the data transmission of the user is not affected by the decoding process of its partner. It means that the user continues transmitting with the same data in the same form without acknowledgment regarding the success of the partner's decoding process is successful or not. In this way, the destination always receives a powerful codeword. This is a difference between the proposed protocol and the coded protocol and results in the proposed protocol having less dependence on the quality of the inter-channel. Another advantage of this protocol is that it can improve the reliability of the incremental redundancy due to the spatial diversity of Alamouti's scheme.

The two users cooperate by dividing the transmission of their N-bits codewords into two successive time segments or subframes, like coded cooperation. In the first subframe, each user transmits a rate $R_1>R$ codeword $N_1=K/R_1$. The higher rate code can be obtained by the puncturing process from the original codeword[8]. At the end of the first subframe, each user attempts decode its partner's first subframe. As a result, there are two possible cases in the partner's node:

- Case 1: They successfully decode the partner's rate R_1 codewords. They will simultaneously transmit the second subframes under a form of Alamouti's scheme. To apply this scheme, the second subframe is divided into two equal parts by the puncturing process. For fairness in comparison among the examined protocols, the total transmit power of the proposed protocol must be equal to those of coded cooperation and direct transmission. To satisfy this requirement, the total transmit power in the second frame is divided by two, one part for it and the other part for its partner.

- Case 2: The partner cannot recover the information correctly so it will be remain silent in the next two subframes while the user still transmits N_{2a} and N_{2b} to the destination.

The Viterbi decoder at the destination will decode to recover the original data. The advantage of this proposed protocol is that the destination always receives a powerful codeword, so it doesn't need to de-puncture (insert zeros) in cases where the partner decodes unsuccessfully like coded cooperation's case.

Ⅳ. Simulation Results and Discussion

Coded cooperation was implemented using a family of rate compatible punctured convolutional codes(RCPC codes) with memory M=4, polynomial generator(5 7 7 7)[1] and a 16-bit CRC code with the generator polynomial 1593516(hexadecimal number). The puncturing process is carried out for 50 % cooperation where the puncturing period P=4 and the puncturing table [1 1 0 0] for N_1 and [0 0 1 1] for N_2 in case of coded cooperation. In the proposed protocol, the punctured matrices were as follows: [1 1 0 0] for N_1, [0 0 1 0] for N_2 and [0 0 0 1] for N_{2b}. The source data block size is 128 bits.

In case of coded cooperation, the level of cooperation is defined as N_2/N, the percentage of the total bits per source block that the user transmits for its partner. In the proposed protocol, it is easy to calculate the level cooperation as $(N_{2a}+N_{2b})/N$. For fairness of comparison, the transmit power of each user should satisfy the following equation:

$$P_1=2P_2=P \tag{1}$$

where P_i is the transmit power of each user at time period i with $i\in\{1, 2\}$ and P is transmit power of direct transmission.

In Figs. 3~6, the effect of the level of cooperation on a system's performance is studied and the performance of coded cooperation is compared with that of the proposed protocol. These cases of cooperation levels at 25 %, 33 % and 50 % with average inter-user channel SNR of 0 dB, 10 dB and 20 dB respectively, are considered. Fig. 3 shows that the proposed protocol is ineffective at the 25 % cooperation level; its performance worsens more than that of coded cooperation in all SNR regimes. However the situation changes when the cooperation level is increased to 33 % and 50 %.

When the cooperation level is small, the proposed scheme cannot achieve any benefit from spatial diversity. However, when the cooperation level is increased, the performance of the proposed protocol is better and it outperforms coded cooperation because it exploits all of the spatial and time diversity. In addition, it remarkably diminishes the dependence of performance on the quality of inter-channels. When average received SNR at a destination is greater than 4 dB, the proposed scheme is better than coded cooperation when the SNRs of

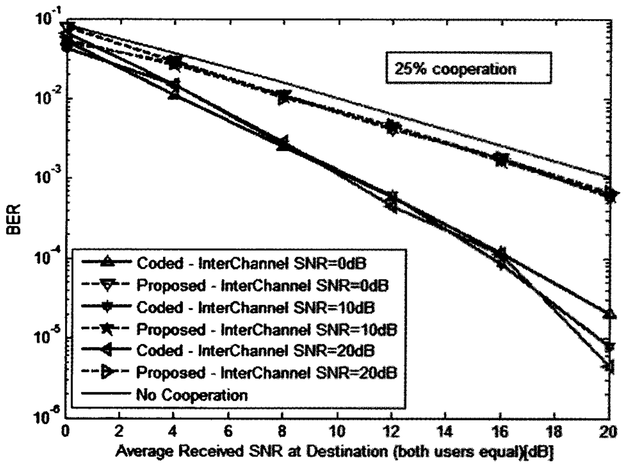

Fig. 3. Performance in slow Rayleigh fading with 25 % cooperation, equal uplink SNR, and reciprocal inter-user channels.

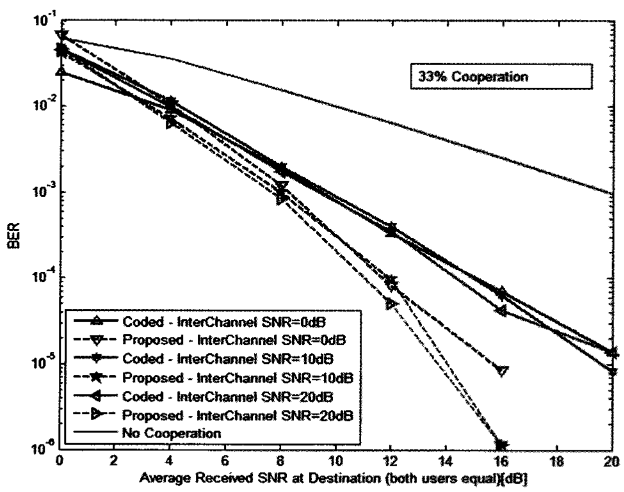

Fig. 4. Performance in slow Rayleigh fading with 33 % cooperation, equal uplink SNR, and reciprocal inter-user channels.

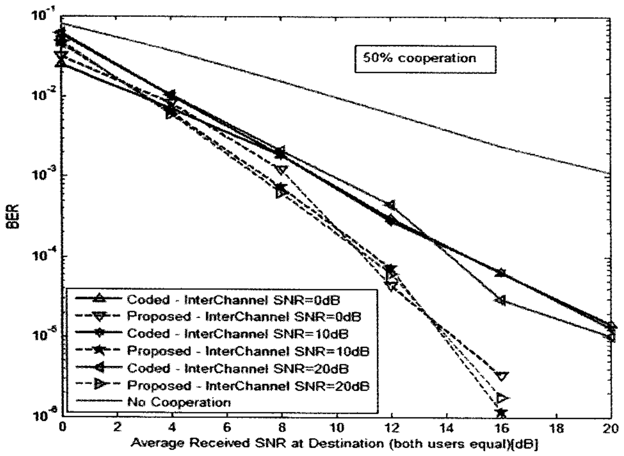

Fig. 5. Performance in slow Rayleigh fading with 50 % cooperation, equal uplink SNR, and reciprocal inter-user channels.

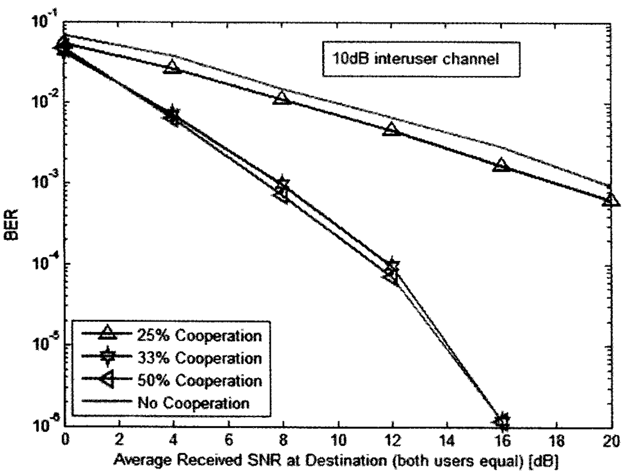

Fig. 6. Comparison of 25 %, 33 % and 50 % cooperation of proposed protocol in slow Rayleigh fading equal uplink SNR with 10 dB inter-user channels.

inter-user channels are 0 dB, 10 dB and 20 dB. The level of cooperation that achieves the best performance for the proposed protocol varies around 50 % and depends on the inter-user channel qualities. The simulation is very different with coded cooperation because no-gain can be achieved when the cooperation level is 25 %.

In Fig. 7, the performance of the proposed and the existing cooperative protocols are compared. The amplify-and-forward protocol is used as a baseline because it achieves full diversity[6]. For fairness of comparison, only a rate 1/2 convolutional code is used for amplify-and-forward because relay helps source forwarding of its data, resulting in an overall rate of 1/2. The level of cooperation of the AF protocol is fixed at 50 %. Fig. 7 confirms that the proposed protocol achieves full diversity and achieves better performance than AF in all

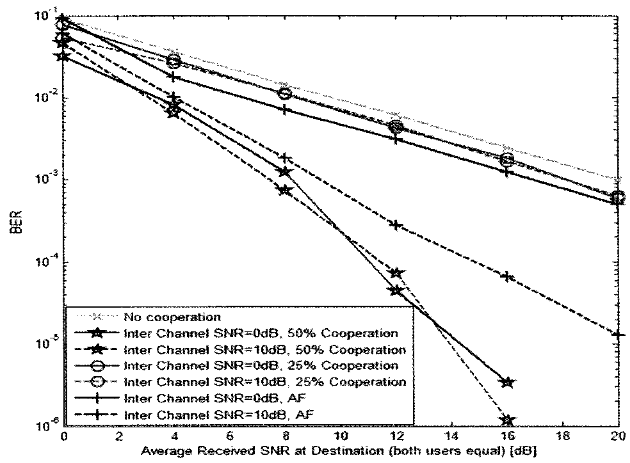

Fig. 7. Comparison of proposed protocol with amplify-and-forward.

SNRs. The advantage of proposed protocol is that it is more dominant at high SNRs compared with AF. To get BER at 10^{-5}, the protocol only needs transmit power if approximately 13 dB, but the AF protocol consumes more than 20 dB. It is obvious that approximately 7 dB of transmit power is saved if the proposed protocol is used.

V. Conclusion

The author proposed a new protocol that Alamouti's scheme in coded cooperation to get full diversity of order. With the same transmit power and assigned time slot, better performance can be achieved than with coded cooperation at all low and high SNR regimes because all of the time diversity and spatial diversity is exploited by the protocol with no additional resource requirement. The simulation results demonstrated the effectiveness of this scheme. With the results presented, the author realize that both cooperative users benefit from this cooperation because the scheme outperforms not only the direct transmission under any qualities of individual channels (S-D channel) or (R-D channel) and inter-user channel but also AF and coded cooperation. It is thought that with its performance and advantages, the proposed protocol can replace coded cooperation and can be applied in any type of wireless network such as a cellular base system, wireless sensor network, or ad-hoc network.

The evaluation of the maximum possible throughput of the proposed scheme is important. However, to evaluate the throughput of the proposed scheme a cross-layer analysis of the physical layer and the data-link layer is required. The throughput analysis will be addressed in future work.

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