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Coded cooperation using Reed Solomon codes in slow fading channel

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Abstract: The coded cooperative communication technique utilizes single antenna mobiles in a multi-user environment that share their antennas and incorporate channel coding schemes in order to achieve transmit diversity. This letter presents a new coded cooperation system based on Reed Solomon codes. The RS codes are very effective in correcting random symbol errors and random burst errors over fading channels. The new coded cooperation system splits the data into two frames, using a vector arithmetic operation. The performance of the new system as compared to the coded cooperation system that utilizes the Rate-Compatible Punctured Convolutional (RCPC) coded cooperation is significantly superior with improvement for full diversity gain is around 10 dB under variety slow fading channel conditions.

Keywords: coded cooperation, cooperative diversity, user cooperation, slow fading channels

Classification: Science and engineering for electronics

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1 Introduction

In wireless networks, signal fading arising from multipath propagation impair the channel and can be mitigated via the use of diversity [1]. Transmit diversity is particularly attractive as it can be combined with other forms of diversity. Unfortunately, this powerful technique cannot be implemented to mobile units directly due to their size constrain. Instead of using the multiple inputs multiple output (MIMO) technique, the same spatial diversity gain can achieved through cooperative diversity [2, 3, 4]. The base station receives multiple versions of the original message from a single source via one or more partners. Then, it combines these multiple versions data in order to obtain a more reliable estimate of the transmitted message.

In the conventional technique of cooperative communication, a cooperating user repeats the received data from its partner via either forwarding or hard detection as presented in [5]. Different method for cooperation has been proposed that utilizes channel coding scheme known as coded cooperation as presented in [2, 6, 7, 8]. In coded cooperation, the codeword of each user is partitioned into two subframes. One of the subframes is transmitted via the user, and the other via the partner. Hunter and Nosratinia in [5, 6] propose a coded cooperation scheme using convolution codes. In their work, the rate compatible punctured convolution codes (RCPC) are employed to split the encoded message into two codeword parts. Whenever cooperation is not possible, the users automatically revert to the non-cooperative mode.

In this letter, a new coded cooperation system is introduced based on RS codes channel coding scheme. The RS codes are very effective in correcting random symbol errors and random burst errors over fading channels. The code symbols for the two frames may be selected through puncturing using a mask vector that divides the parity check (P) into two parts, which differs from the use of RCPC method presented in [9]. Simulation results of the new system over the slow fading channel show 10 dB improvement in term diversity gain as compare to the work in [9].

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2 RS coded cooperation method

The proposed scheme is based on RS channel coding scheme, where each encoded codeword on a user is partitioned into two frames and are transmitted in two phases. The first frames (N_1) are transmitted directly from users to the base station. Then, the second frames (N_2) are transmitted via partners to the base station. The level of cooperation is defined as N_2/N x 100%. Fig. 1 illustrates part of RS coded cooperation system from a single user's point of view. The user's original message has length of ($K = 680\,bits$) are encoded using RS codes to produce the intermediate encoded output data $N = 2K + P$ with the overall code rate of 1/4. Then, the parity-check data P of length $P = 1360\,bits$ is punctured into two parts i.e. P_1 and P_2 where $P = P_1 + P_2$. The first and second frames are given as $N_1 = K + P_1$ and $N_2 = K + P_2$ respectively. The parity-check data P is split into two parts using the vector arithmetic operation as shown below;

Let the parity-check P be a vector of length $(N - K)$, $\overline{P} = \{a_1, a_2, \ldots\ldots, a_{N-K}\}$

Let a vector M be a masking vector of length $(N - K)$, with fixed component value of

$\overline{M} = \{m_1, m_2, \ldots\ldots, m_{N-K}\}$ where $m_i = \{1, 0\}$ for all $(0 < i \leq N - K)$

For the sake of convenient, the vector arithmetic operation is handled in matrix form, and we express the vector M as a matrix of size $(N - K))$ by $(N - K))$ and fill in $(N - K - 1))$ row of zeros to the matrix;

$$M = \begin{bmatrix} m_1 & m_2 & m_3 \ldots\ldots & m_{N-K} \\ 0 & 0 & 0 & 0 \\ . & & & \\ . & & & \\ . & & & \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Then vector $\overline{P_1}$ is obtained from $P_1 = P \times M$ Thus,

$$P_1 = [a_1 a_2 \ \ldots\ldots a_{N-K}] \times \begin{bmatrix} m_1 & m_2 & m_3 \ldots\ldots & m_{N-K} \\ 0 & 0 & 0 & 0 \\ . & & & \\ . & & & \\ . & & & \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{1}$$

Therefore, the elements in vector $\overline{P_1}$ are the actual content of parity-check data P_1. The parity-check data for P_2 is obtained in the same way, except that the vector M is complemented prior the multiplication matrix operation.

When preparing for transmission of the second frames (N_2), the users have no knowledge of whether their first frames (N_1) have been correctly decoded by their partners. As a result, there are four possible cooperative cases for the transmission of the second frames (N_2).

In Case 1, both users can successfully decode each other. Therefore, every user will re-encode and transmit its second frame (N_2) or their partner's data

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to the base station. This results in full cooperative scenario. Error Correction Capability *(ECC)* depend on number of errors detected during decoding of the codeword when ECC is -1 indicates that the block detected more errors than it could correct using the coding scheme. An (N, K) Reed-Solomon code can correct up to floor *((N-K)/2)* symbol errors (not bit errors) in each codeword [10].

In Case 2, both users are unable to decode their partner's second frames (N_2), and therefore the system reverts to the non-cooperative case. In Case 3, the User 2 can successfully decode User 1 data, but User 1 is unable decode User 2's data. Therefore, User2 sends its partner second frame data. User 1 sends its own second frame data. These two independent copies of User 1's data are optimally combined using Maximum Ratio Combining (MRC) [11]. Case 4 is identical to Case 3 with the role of User 1 and User 2 is reversed.

Clearly the base station must know which one of these four cases has occurred in order to correctly decode the received data. Two additional control bits are used to indicate one of these cases in the base station.

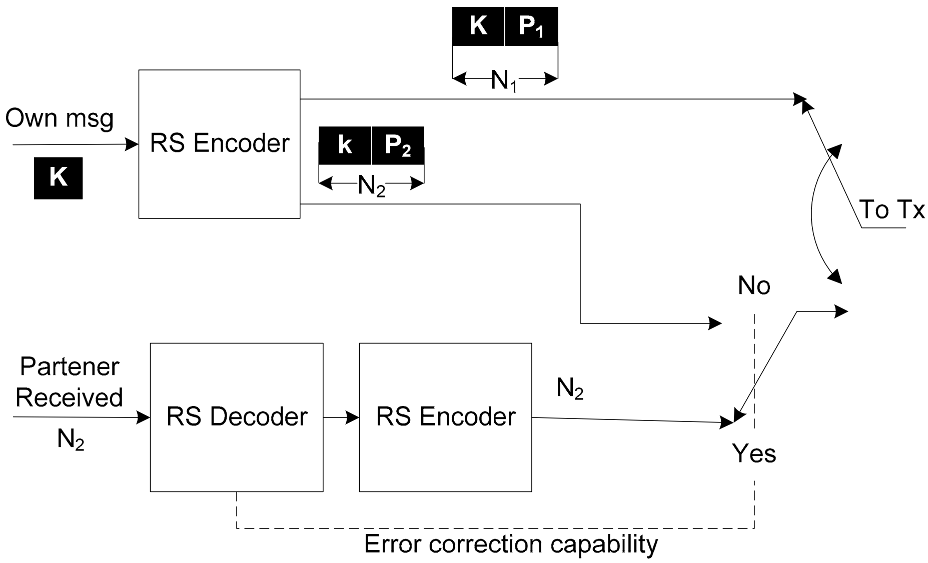

Fig. 1. RS coded cooperation system from a single user point of view.

When the system exhibits cooperation of case 1, the base station will receive two same copies of the original message. One message is from frame 1 and other from frame 2 from the partner, and they are combined using MRC technique. In case 3 of cooperation, the base station received three copies of the original message. Two copies from User 1 (one is the first frame of User 1 and the other is the second frame of User 1). The third copy is from the second frame of User 2.

Fig. 2 illustrates the implementation of the RS coded cooperation system with a base station. The received copies of the message from frame 1 and 2 are combined using MRC, and the information bits are decoded using the RS decoder. The input data to the RS decoder has the length of $N = K + P_1 + P_2$

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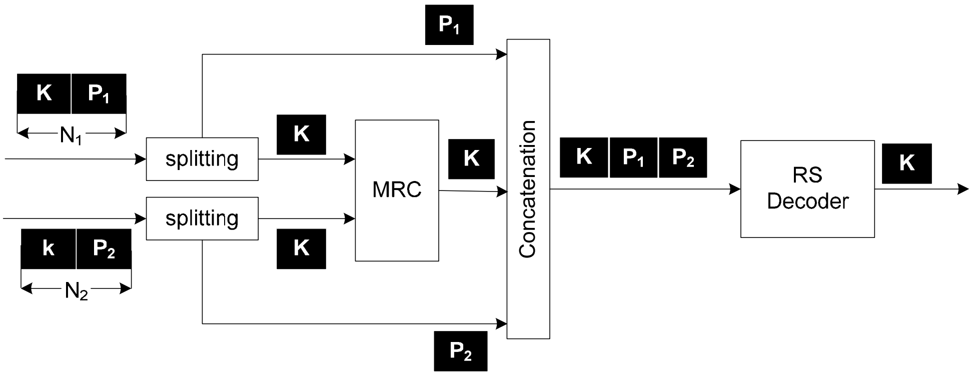

Fig. 2. A base station implementation of RS coded cooperation scheme.

which output the original message of length K.

3 Simulation results

Fig. 3 compares the performance the new RS coded cooperation system with the RCPC coded cooperation system as presented in [9]. This comparison serves to illustrate the advantage the new RS coded cooperation system over the previously proposed repetition-based schemes. The overall code rate used for both coded cooperation systems is $R = 1/4$.

Fig. 3 shows the comparison of the simulated BER for slow Rayleigh fading, equal uplink channel SNR, and inter-user channels with 10 dB and 20 dB

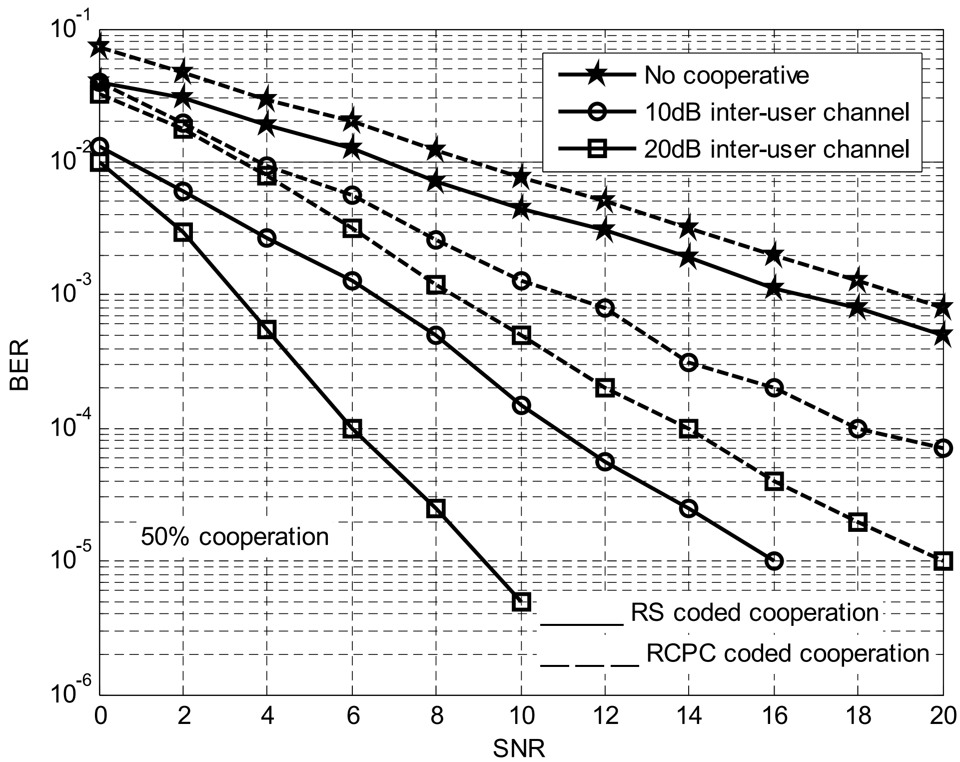

Fig. 3. Comparison of RS coded cooperation with RCPC coded cooperation under slow Rayleigh fading.

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SNR. Although the difference between the performances of the two systems in case of no cooperation is more than 2 dB, the new RS Coded cooperation maintains its superiority up to 4 – 8 dB at 30% level of cooperation. The performance improvement is 4 – 10 dB at 50% level of cooperation over RCPC Coded cooperation for 0 – 20 dB uplink channel SNR. The level of cooperation that achieves the best performance for coded cooperation varies between 50% and 30%, depending on the channel conditions.

4 Conclusions

This letter presents the new method for coded cooperative communication, system using RS codes. Diversity is achieved by partitioning a user's parity code into two parts. Each user receives the first codeword partition from the partner, and upon successful decoding ECC, it transmits the second codeword partition. The two partitions are thus received at the base station through independent fading channels. The numerical results explicate that the new RS coded cooperation system is significantly outperform the pervious work by Hunter in [9].

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