Extended Low-density Parity-check Codes for Cooperative Diversity

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Abstract: Cooperative diversity or user cooperation achieves the diversity gain without adding physical antennas to the users. The users work in cooperative fashion using their single antennas to create a virtual multiple-input multiple-output (MIMO) antenna system. The diversity gain achieved by cooperative diversity can be further improved using error correction codes. Low-density parity-check (LDPC) codes are linear block codes with good error correction capabilities. We present a novel approach using extended LDPC codes to increase the diversity gain in cooperative diversity.

1 INTRODUCTION

Wireless communications face the challenges of channel impairments and fading that severely degrade the capacity of wireless channels. Numerous spatial diversity techniques have been in use to combat channel impairments and fading. One such technique is cooperative diversity in which the users or mobile stations cooperate using their single transmitting antenna in a particular scenario to exploit the availability of good channels from users to base stations or destination. In cooperative diversity, generally, the destination receives multiple packets for the same data from independent channels creating a virtual multiple-input multiple-output channel. Cooperative diversity cannot guarantee error free transmission, therefore, error control coding techniques are applied in cooperative scenario.

User cooperation diversity has been used to achieve diversity gain using the partners transmitting antennas (Sendonaris et al., 2003a), (Sendonaris et al., 2003b). If the channel with one user to the destination is bad, then the channels from other users, called partners, can be used to send the packet to the destination. The destination receives two packets of the same data from two independent channels that may not be noisy or in deep fade at the same time. The destination provides decoding by maximal ratio combining on both packets received and thus achieving spatial diversity gain in simple repetition schemes. In coded cooperative diversity or cooperation diversity through coding (Hunter and Nosratinia, 2006), rate-compatible convolutional (RCPC) codes were used jointly with cooperation. We extend the coded cooperative diversity work using extended LDPC codes.

Low-density parity-check (LDPC) codes were invented by Gallager in his Ph.D. work (Gallager, 1962) in 1960. LDPC codes belong to the class of linear block codes. These codes were ignored due to lack of appropriate hardware in 1960s. These codes were rediscovered by MacKay (MacKay, 1999) and others. These codes have become more practical due to the advancements in transistor technology leading to high computational power of the hardware. These codes have gain attention due to their near-capacity performance. These codes can be modified to achieve rate-compatibility. Extended LDPC codes were introduced in (Bi and Perez, 2006; Li and Narayanan, 2002; Yazdani and Banihashemi, 2004) to achieve lower rate codes from high rate codes. A joint and efficient design for puncturing and extension is discussed in (Li and Narayanan, 2002) which is preferred in cooperative scenario for its rate adaptability.

The paper is organized as follows: In section 2, we introduce the coded cooperative diversity. In section 3, we propose the extended LDPC codes for cooperative diversity. The simulation results for the proposed extended codes for cooperative diversity are presented in section 4. The last section concludes the paper.

2 CODED COOPERATIVE DIVERSITY

We assume a time-division based system with two terminals T_1 and T_2 as users and one terminal T_3 as des-

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tination. The channels for T_1 and T_2 transmission are assumed to be orthogonal in time. The codeword N is divided into two weaker codewords denoted by N_1 and N_2. The frame transmission for N is divided into two time slots. The first time slot is reserved for each user's own data. For the user T_1, $N_1^{T_1}$ is transmitted to the destination T_3 and to the partner T_2 where $N_1^{T_1}$ is the first codeword for user T_1. Similarly, T_2 sends the codeword $N_1^{T_2}$ to T_1 and T_3. Both T_1 and T_2 check the integrity of data received by applying cyclic redundancy check (CRC). The transmission in the second time slot is determined by the success or failure of decoding of these packets received in the first time slot for each user. The four cases that arise after the first time slot transmission are shown in Fig. 1. In

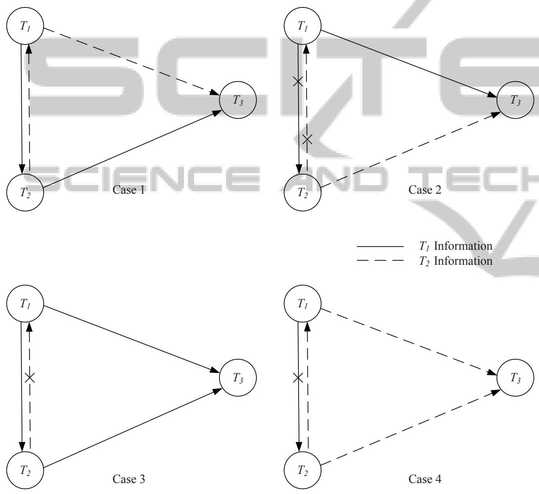

Figure 1: Four cooperative diversity cases based on transmission in second time slot.

case 1, both users successfully decodes the packet received from their partners. Therefore, T_1 will send $N_2^{T_2}$ for T_2 and T_2 will send $N_2^{T_1}$ for T_1 in the second time slot. In case 2, both users fail to decode their partners transmission and continue to send their own second codeword N_2 in the second time slot. In case 3, T_1 fails to decode the transmission from T_2. In this case, both users will transmit $N_2^{T_1}$ for T_1. In case 4, T_2 fails to decode the transmission from T_1. In this case, both users will transmit the codeword $N_2^{T_2}$ for T_2.

3 EXTENDED LDPC CODES

LDPC codes are defined by their parity-check matrix $\mathbf{H}$ with $\mathbf{G}.\mathbf{H}^\mathbf{T} = \mathbf{O}$ where $\mathbf{G}$ is called the generator matrix and $\mathbf{O}$ is an all zero matrix. The regular LDPC codes have constant row and column weight. In this work, we will use regular LDPC codes with column weight 3 and row weight 6, denoted as (3,6) regular code. The (3,6) regular code has the best error correction capabilities in the class of regular LDPC codes. Rate-compatible design is required to generate codewords of different lengths. The design of (Li and Narayanan, 2002) is capable of embedding higher rate codewords in lower rate codewords. We exploit this design to be used in coded cooperative diversity. We design the extended parity-check matrix according to the following definitions of matrices

$$\mathbf{H}_2 = \begin{bmatrix} \mathbf{H}_1 & \mathbf{O} \\ \mathbf{A} & \mathbf{B} \end{bmatrix}_{m' \times n'} \tag{1}$$

where $m = n - k$, $m' = n' - k$ and $\mathbf{H}_1$ is the (3,6) regular parity-check matrix of dimensions $m \times n$ for the mother code of rate $R = k/n$. To extend the code rate to $R' = k/n'$, the extra parity bits in the extended codewords will be $e_{bits} = n' - n$ where n' is the size of extended codeword for rate R'. The $\mathbf{O}$ matrix is an all zero matrix of size $k \times e_{bits}$ or $k \times (n' - n)$. The $\mathbf{A}$ matrix is a very sparse matrix of size $(n' - n) \times n$ with at least one 1 in each row. The $\mathbf{B}$ matrix has dimensions $(n' - n) \times (n' - n)$ with column weight 3.

The systematic form of $\mathbf{H}_1$ is

$$\mathbf{H}_1 = \begin{bmatrix} \mathbf{P}_1^\mathrm{T} & \mathbf{I}_{n-k} \end{bmatrix}_{m \times n} \tag{2}$$

where $\mathbf{P}^\mathrm{T}$ is the transpose of $\mathbf{P}$. The systematic form of $\mathbf{H}_2$ is given by

$$\mathbf{H}_2 = \begin{bmatrix} \mathbf{P}_1^\mathrm{T} & \mathbf{I}_{n'-k} \\ \mathbf{P}_2^\mathrm{T} & \end{bmatrix}_{m' \times n'} \tag{3}$$

The $\mathbf{O}$ matrix ensures that the higher rate codewords are embedded in extended lower rate codewords by keeping the integrity of $\mathbf{P}_1^\mathrm{T}$. The generator matrix for $\mathbf{H_1}$ and $\mathbf{H_2}$ becomes

$$\mathbf{G}_1 = \begin{bmatrix} \mathbf{I}_k & \mathbf{P}_1 \end{bmatrix}_{k \times n} \tag{4}$$

and

$$\mathbf{G}_2 = \begin{bmatrix} \mathbf{I}_k & \mathbf{P}_1 & \mathbf{P}_2 \end{bmatrix}_{k \times n'} \tag{5}$$

respectively, where $\mathbf{P}_1$ has dimensions $k \times (n - k)$ and $\mathbf{P}_2$ has dimensions $k \times (n' - n)$.

We exploit this design of extended LDPC codes to the cooperative diversity framework and modify the extended LDPC codes to achieve decoding in three steps at the receiver. The codeword N_1 is generated by using the generator matrix obtained from $\mathbf{H_1}$. Using Eq. 4, N_1 takes the following form

$$N_1 = [i \quad p_1]_{1 \times n} \tag{6}$$

where i is the information part and p is the parity part in the codeword N_1. The second codeword N_2' is generated by the generator matrix $\mathbf{G_2}$ mentioned in Eq. 5, in the following form

$$N_2' = [i \quad p_1 \quad p_2]_{1 \times n'} \tag{7}$$

where p_1 is the same parity part as in N_1 and p_2 is the extended parity part. This N_2' is modified to generate a codeword of length n. The second codeword is transmitted in the following format

$$N_2 = [i \quad p_2]_{1\times n}. \tag{8}$$

At the receiver, in the first step N_1 is decoded using $\mathbf{H_1}$. If the codeword is not successfully recovered in the first step, then the codeword is decoded using $\mathbf{H_2}$ matrix with erasures inserted at p_1 of N_2. If the decoding fails in the first two steps, then the codeword is concatenated and jointly decoded using $\mathbf{H_2}$ to recover the codeword N.

4 PRELIMINARY SIMULATION RESULTS

We assume BPSK modulation for the simulations. We also assume very slow fading channel in which the channel fading coefficient are Rayleigh distributed and remains constant for complete codeword N. The information block size $k = 512$ and the codewords N_1 and N_2 transmitted are of length 1024 bits. The sum-product algorithm (SPA) is used for the decoding. The received packets are decoded on $H_1 = 512 \times 1024$ for the first step and $H_2 = 1024 \times 1536$ for the next two steps of decoding. The simulation results have been plotted as BER versus the channel SNR. The plots with BER versus information bit SNR will be identical with a shift of 10log$R$ dB. The bit-error rate (BER) and frame-error rate (FER) for the proposed extended LDPC codes design for cooperative diversity with varying inter user channel are shown in Fig. 2 and Fig. 3 respectively. The gain is approximately 11 dB for the perfect inter user channel as compared to worse inter user channel.

5 CONCLUSIONS AND FUTURE WORK

The proposed extension to LDPC codes successfully integrates with cooperative diversity. A very high diversity gain is achieved when the channel between the cooperating users is good. The decoding in the first step is done on a smaller parity-check matrix, hence reducing the complexity. However, the decoding in the next two steps is done on larger parity-check matrix but it gives better performance in terms of BER and FER. The proposed scheme can be further analyzed on fast fading channels. The proposed scheme can also be investigated and compared with punctured LDPC codes which will have higher decoding complexity because of larger parity-check matrices.

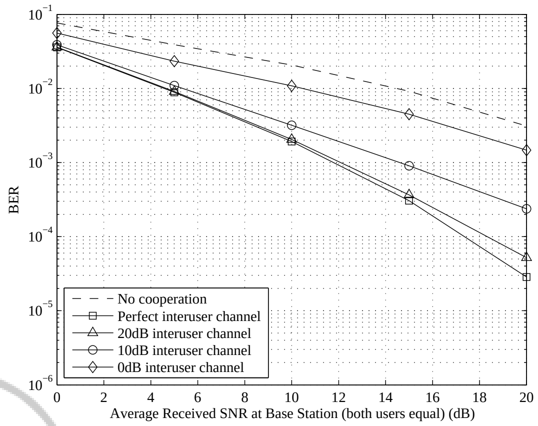

Figure 2: BER of cooperative diversity with extended LDPC codes and varying inter user channel.

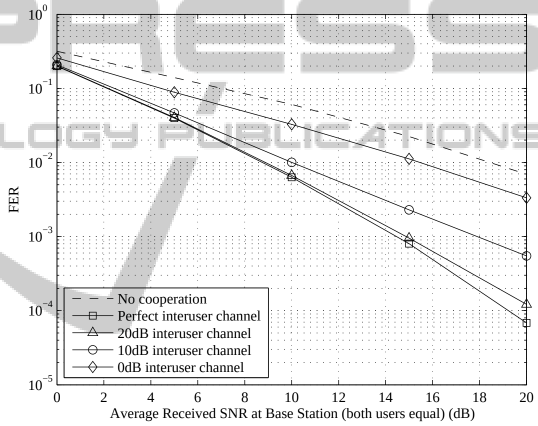

Figure 3: FER of cooperative diversity with extended LDPC codes and varying inter user channel.

REFERENCES

Bi, D. and Perez, L. C. (2006). Rate-compatible low-density parity-check codes with rate-compatible degree profiles. *Electronics Letters*, 42(1):41.

Gallager, R. (1962). Low-density parity-check codes. *IEEE Transactions on Information Theory*, 8(1):21–28.

Hunter, T. E. and Nosratinia, A. (2006). Diversity through coded cooperation. *IEEE Transactions on Wireless Communications*, 5(2):283–289.

Li, J. and Narayanan, K. (2002). Rate-compatible low density parity check codes for capacity-approaching ARQ scheme in packet data communications. In *Int. Conf. on Comm., Internet, and Info. Tech.(CIIT)*, pages 201–206.

MacKay, D. J. C. (1999). Good error-correcting codes based on very sparse matrices. *IEEE Transactions on Information Theory*, 45(2):399–431.

Sendonaris, A., Erkip, E., and Aazhang, B. (2003a). User cooperation diversity-part I: system description. *IEEE Transactions on Communications*, 51(11):1927–1938.

Sendonaris, A., Erkip, E., and Aazhang, B. (2003b). User cooperation diversity-part II: implementation aspects and performance analysis. *IEEE Transactions on Communications*, 51(11):1939–1948.

Yazdani, M. R. and Banihashemi, A. H. (2004). On construction of rate-compatible low-density parity-check codes. *Communications Letters, IEEE*, 8(3):159–161.