

LDPC Convolutional Codes Coded Cooperation Based on Puncturing

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Abstract—Coded cooperation is a kind of virtual MIMO transmission technology that can achieve both coding gain and diversity gain, which is very promising in 5G communication. To design a scheme that can be used for near-capacity transmission and can be generalized for slow and fast fading channels, this paper studies the coding cooperation based on convolutional LDPC codes. Firstly, channel coding the original information by LDPC convolutional codes, then divided the coded words into two parts by puncturing algorithm; secondly, introducing space-time transmission into the second frame of coded cooperation, so the diversity gain can be obtained under different fading scenarios. Simulation results show that the system performance can be improved generally.

Keywords—coded cooperation; LDPC convolutional codes; space-time transmission; puncturing

I. INTRODUCTION

5G wireless systems are expected to realize ultra-high speed transmission, from the physical layer of technical support point of view, the use of as much as possible high-gain channel coding, and the implementation of collaborative transmission between users is an inevitable trend. An important cooperation method, known as coded cooperation^{[1]-[3]}, allows multiuser generate a virtual MIMO system by sharing their antennas to achieve the diversity gain and coding gain without increasing the transmitting power and bandwidth, has great application prospects in 5G communications.

It is known that, coded cooperation is the combination of channel coding and cooperative communication. Specific to the technology of channel coding, coding techniques that can approach the Shannon limit should be used. LDPC convolutional codes (LDPC-cc)^[4] combines the advantages of convolutional codes and LDPC block codes, can approach to the Shannon limitation as much as possible^[5]. Compared with the widely used LDPC block codes and Turbo codes, the information coding by LDPC-cc can be of any length^[6]; the parity-check matrix is periodical, makes it easier to implement; the error performance is excellent^[7]. As mentioned above, LDPC-cc is totally suite to 5G wireless systems. In recent years, a lot of scholars have studied the convolutional LDPC codes and the coding cooperation separately, but the research on the coding cooperation based on LDPC-cc is basically blank. In the context of 5G ultra-high-speed transmission requirements, it is of great theoretical and practical value to study the LDPC-cc coded

cooperation from the code word level.

Considering that the premise of coded cooperation is to separate the mother codes into several segments that can be transmitted through different paths, and the key to determine the coded cooperation performance is whether the multiplexing can achieve diversity gain. So the following research is carried out: 1) separating the mother codes created by LDPC-cc into two parts based on puncturing. Puncturing is the most direct and flexible way to realize it. In this paper, we use the puncturing algorithm of convolutional LDPC codes proposed in [8]. 2) We will introducing the technology of space-time code into the second frame transmission. As we know, traditional coded cooperation can achieve great diversity gains in slow fading, but will not bring any added benefit in fast fading^[9]. Inspired by the Alamouti space-time coding proposed by [10], space-time transmission is introduced to enhance the performance of the system in fast fading channels.

So in this paper, we studied the coded cooperation based on LDPC-cc puncturing algorithm, and introducing the space-time transmission into the cooperative transmission. Simulation results show that the system can achieve high performance gains both in slow and fast fading. The remainder of this paper is organized as follows. Section II is the system model of coded cooperation. Section III introduce the LDPC-cc coded cooperation. In section IV we support our idea with some numerical and finally make a conclusion in section V.

II. SYSTEM MODEL

The wireless network depict in figure 1 was the most simple two-user single base station coded cooperation system model. The user channel and the user to the base station of the upstream channel are fading channels and independent of each other. In this system, each channel is independent. The information transmission in the coding cooperative system is divided into two stages: the broadcasting phase and the cooperation phase.

In broadcast phase, both source messages were equipped with a CRC (cyclic redundancy check) code, there will be k bits per source block, each block was encoded into N bits, which was called the mother code. In order to transmit the message in different paths, we divided the mother code C (N bits = N_1 bits + N_2 bits) into two blocks C_1 (N_1 bits) and C_2 (N_2 bits).

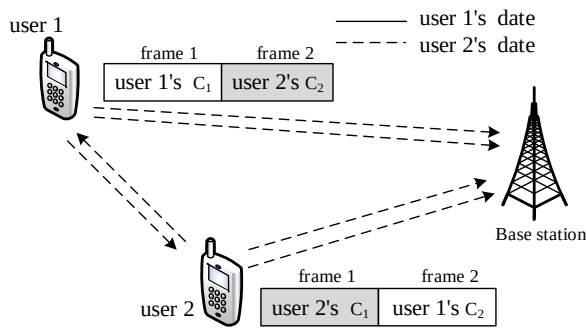


Figure 1. Cooperation system model
(C_1, C_2 are the two different parts of the mother codes)

As C_1 (N_1 bits) and C_2 (N_2 bits) was constructed, User i ($i=1,2$) broadcast C_1 to his partners and the base station, then the information received by j ($j=0,1,2; i \neq j, 0$ denotes the base station, 1 and 2 denotes user 1 and user 2 individually) is

$$y_{i,j}(n) = \sqrt{E_s} \cdot h_{i,j}(n) s_i(n) + n_j(n) \quad (1)$$

Where E_s is the transmitted energy per bit, $s_i(n)$ is the modulated information of C_1 , n_j is the white Gaussian noise with zero-mean and $N_j/2$ variance, and $h_{i,j}$ accounts for the fading coefficient magnitude between user i and j . As we know, the fading coefficients remain unchanged through all the block codes in slow fading, but in fast fading, each symbols suffered different and independent fading coefficients, so we should consider the performance of coded cooperation both in fast and slow fading.

In cooperation phase, if user j successfully decode user i 's message, then he will reconstructed the second part codes and transmit it to the base station, otherwise, he will transmit his own bits. We must consider that, base station should know the cooperation situation in order to dealing with the received signal correctly, so in the second phase, we also need to transmit the CRC checking results to the base station.

In order to improve the transmission efficiency, and solve the problem that the space-time coded cooperation have no extra performance promote in fast fading, we proposed a coded cooperation scheme based on the LDPC-cc, and bring space-time transmission into the system, enables the proposed scheme to be widely used in a variety of scenarios, combat fast and slow fading generally.

III. LDPC-CC CODED COOPERATION

In this section, we will study the coded cooperation based on time invariant LDPC-cc. LDPC-cc is an excellent channel coding technology, can achieve the Shannon capacity limitation as near as possible, and have great performance in error correcting. For time invariant LDPC-cc, his parity check matrix can be created directly from the polynomial matrix of quasi-cyclic LDPC block codes^[11,12]. The puncturing position was calculated according to the polynomial matrix^[13-15], when the memory length and the code rate remain unchanged, the polynomial matrix of time invariant LDPC-cc will be the same, it is convenient for us to

segment the mother codes into two parts for coded cooperation. On the basics of coded cooperation, we will introduce the space-time transmission in the second phase, called as space-time coded cooperation, to reducing the bit error rate effectively both in fast and slow fading.

A. Coded Cooperation

The structure diagram of ordinary coded cooperation was shown in figure 2. The cooperation was mainly have three steps: firstly, channel coding the source information which has been equipped with a CRC code, the coded words C was called as mother codes; secondly, dividing the mother code C into two blocks C_1 and C_2 by puncturing; thirdly, blocks C_1 and C_2 was collaboratively transmitted in two frames.

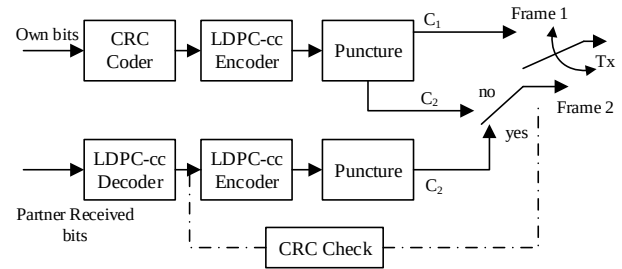


Figure 2. Coded cooperation block diagram

The first frame was also called as broadcast phase, where both user transmit their local information, user i ($i=1,2$) broadcast C_1 , both his partners and the base station can receive the information, then his partner extending the information to the length of the mother codes, filling zeros in the puncturing position, and decoding it. Checking the decoded codes by CRC code, the results determines the second frame of the cooperate situation.

In the second frame, the transmission of block C_1 and C_2 is determined by the first frame, if user j successfully decode user i 's messages, then user j will transmit user i 's data C_2 , otherwise, user j will transmit his own bits. In slow fading, if both user cooperate, Coded cooperation can achieve full diversity and obtain great performance gain, if user i cooperates but user j does not, then both user will transmit user j 's date, and user i 's date is missing, leads to a decrease in the overall performance of the system. While in fast fading, the fading coefficient between the first and second frames of a user's uplink channel is seen as independent, then using the partner's channel will not bring any added benefit, so the ordinary coded cooperation is not suitable for fast fading scenarios. Based on the above two points, the space-time transmission was considered.

B. Space-time Coded Cooperation

The main difference between these two coded cooperation schemes is the data transmission of the second frame. In the space-time coded cooperation, if users successfully decodes their partner's data, then each user will send both his as well as his partner's data to the base station. The specific process was shown as figure 3.

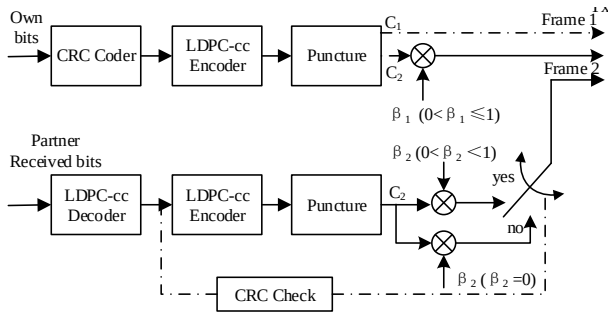


Figure 3. Space-time coded cooperation block diagram

In the space-time coded cooperation, if users successfully decode their partner's data, then each user will send both his as well as his partner's data to the base station.

Figure 3 shows that, the first frame of the space-time coded cooperation is the same as the ordinary coded cooperation, while the second frame varies. In the second frame, each user has no knowledge of whether his first frame was correctly decoded, so the transmission of the second frame will have four possible cooperative cases:

Case 1: Both user cooperate, corresponding to the full cooperation. each user use his channel transmit his code C_2 , use his partner's channel transmit his partner's code C_2' . Simulated the two input and one output MIMO system. In the second frame, the parity bits of user i transmitted by himself was denoted as c_i , transmitted by his partner was denoted as c_j' ($j \neq i$), procedure follows as figure 4.

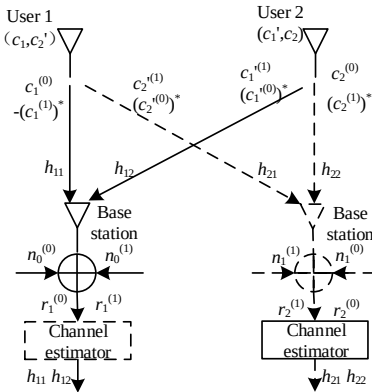


Figure 4. Full cooperation

In the second frame, user 1 transmits his own bits c_1 with energy $\beta_1 \cdot E_s$, where $0 \leq \beta_1 \leq 1$, transmits his partner's bits c_2' with energy $(1 - \beta_1) \cdot E_s$. User 2 transmits his own bits c_2 with energy $(1 - \beta_2) \cdot E_s$, where $0 \leq \beta_2 \leq 1$, transmits his partner's bits c_1' with energy $\beta_2 \cdot E_s$, E_s is the energy of the signal. Take user 1's data transfer as example, $c_1^{(0)}$ is the first symbol of c_1 , $c_1^{(1)}$ is the second symbol of c_1 , every two symbols was transmitted as a period.

Then the transmission matrix of Alamouti space-time coding was as follows:

$$C = \begin{bmatrix} c_1^{(0)} & c_1^{(1)} \\ -(c_1^{(1)})^* & (c_1^{(0)})^* \end{bmatrix} \quad (2)$$

When using user i 's channel, the fading coefficient between user j 's antenna and the base station's antenna was recorded as h_{ij} . And the fading coefficient h_{ij} remains constant over the whole transmission of the block codes in slow fading, while in fast fading h_{ij} changed quickly, so in this paper, we considered it can remain unchanged between two symbols. Then the data received in base station as follows:

$$r_1^{(0)} = h_{11} \cdot (\sqrt{\beta_1} \cdot c_1^{(0)}) + h_{12} \cdot (\sqrt{\beta_2} \cdot c_1^{(1)}) + n_0^{(0)} \quad (3)$$

$$r_1^{(1)} = -h_{11} \cdot (\sqrt{\beta_1} \cdot (c_1^{(1)})^*) + h_{12} \cdot (\sqrt{\beta_2} \cdot (c_1^{(0)})^*) + n_0^{(1)} \quad (4)$$

Where n_0 is the white Gaussian noise with zero-mean and $N_0/2$ variance. The fading coefficient h_{11} and h_{21} can be estimated by the estimator, further processing as follows:

$$\tilde{r}_1^{(0)} = \sqrt{\beta_1} \cdot h_{11}^* \cdot r_1^{(0)} + \sqrt{\beta_2} \cdot h_{12} \cdot (r_1^{(1)})^* \quad (5)$$

$$\tilde{r}_1^{(1)} = \sqrt{\beta_2} \cdot h_{12}^* \cdot r_1^{(0)} - \sqrt{\beta_1} \cdot h_{11} \cdot (r_1^{(1)})^* \quad (6)$$

When the memory length m_s and code rate R of time invariant LDPC-cc remain fixed, the parity check matrix will keep unchanging, so the same information encoded will lead to the same coded words. The two parts of the mother codes was constructed by periodical puncturing as mentioned before, so the second part of codes reconstructed by his partner c_1' is the same as c_1 , that is $c_1 = c_1'$, Substituting (3) and (4) into (5) and (6) we get

$$h = \left| \sqrt{\beta_1} \cdot h_{11} \right|^2 + \left| \sqrt{\beta_2} \cdot h_{12} \right|^2 \quad (7)$$

$$\tilde{c}_1^{(0)} = h \cdot c_1^{(0)} + \sqrt{\beta_1} \cdot h_{11}^* \cdot n_1 + \sqrt{\beta_2} \cdot h_{12} \cdot (n_2)^* \quad (8)$$

$$\tilde{c}_1^{(1)} = h \cdot c_1^{(1)} + \sqrt{\beta_2} \cdot h_{12}^* \cdot n_1 - \sqrt{\beta_1} \cdot h_{11} \cdot (n_2)^* \quad (9)$$

Sent (8) ~ (9) to the maximum likelihood detector, then calculate the bit error of this system.

Case 2: User 2 cooperates but user 1 does not, then semi-cooperation is made. User 1 transmits his own bits c_1 with energy $\beta_1 \cdot E_s$, and $\beta_1 = 1$. User 2 transmits his own bits c_2 with energy $(1 - \beta_2) \cdot E_s$, transmits his partner's bits c_1' with energy $\beta_2 \cdot E_s$. Procedure is as follows:

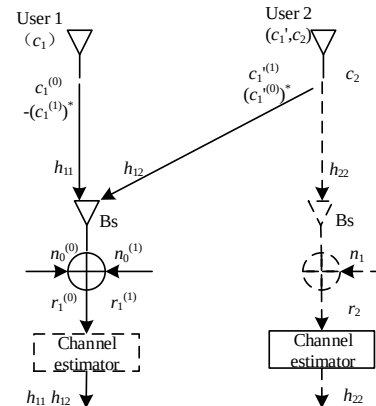


Figure 5. Semi-cooperation

As we know, user1 transmit his own bits, user2 also transmit his partner user1's bits, then the space-time coded can be used, the transmission matrix and the data processing are the same as formula (2) ~ (9).

Case 3: Adverse to Case 2, and the processing is similarly.

Case 4: Both user uncooperative, then each user will transmit his own bits c_2 with full energy.

The above analysis shows that in the second frame of space-time coded cooperation, each user use his multi-access channels transmitting data, while the ordinary coded cooperation transmit with the help of his cooperative user's multi-access channels. Simulation results of coded cooperation based on LDPC convolutional codes will be analysis in the IV section.

IV. PERFORMANCE RESULTS

To verify the validity of the proposed scheme, we give the bit error rate (BER) results of coded cooperation in both slow fading and fast fading channels based on LDPC-cc in this section. For the examples here, we consider the 2/5 rate time-invariant LDPC convolutional codes with the memory length $m_s=21$. The source block size is $k=256$ bits. The cooperation percentage is 50%, it means that we should puncturing half of the mother codes. The puncturing pattern $a=[1,0,1,0,0;1,0,1,1,0]$ with puncturing period $P=2$, where "0" represents the transmit bits, and "1" represents the puncturing bits. In the space-time transmission. In order to keep the total transmit power unchanged, all results presented in this section for space-time coded cooperation was set as $\beta_1 = \beta_2 = 0.5$. The 16 quadrature amplitude (QAM) modulation is considered. The uplink channel of each user is independent, and the interactive channel is perfect. Simulation results are based on the curves of non-cooperative to ensure fairness. We should note that all the results are for user1.

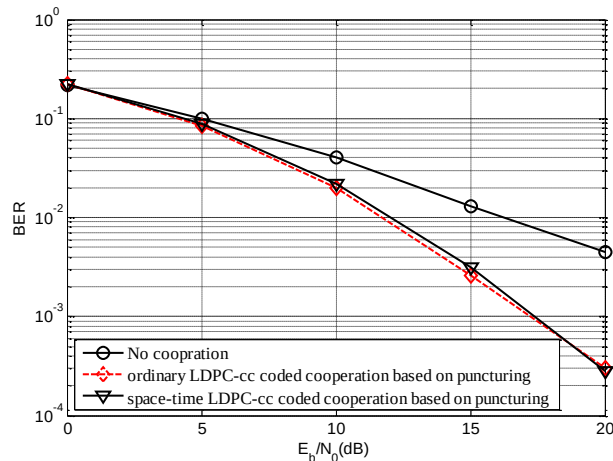


Figure 6. Slow fading, BER curves of different cooperation scheme based on LDPC-cc (user1)

As we can see from figure 6, in slow fading channels, the results shows that: under the frame of coded cooperation, the performance of LDPC-cc achieves significant gains. For

$BER=10^{-3}$, the gain is 6dB. And the performance of the space-time coded cooperation is similar to the ordinary coded cooperation. That is because in slow fading, the fading coefficient between the first and second block codes transmission is remain unchanged, so compared with ordinary coded cooperation, space-time coded cooperation will have no extra gain

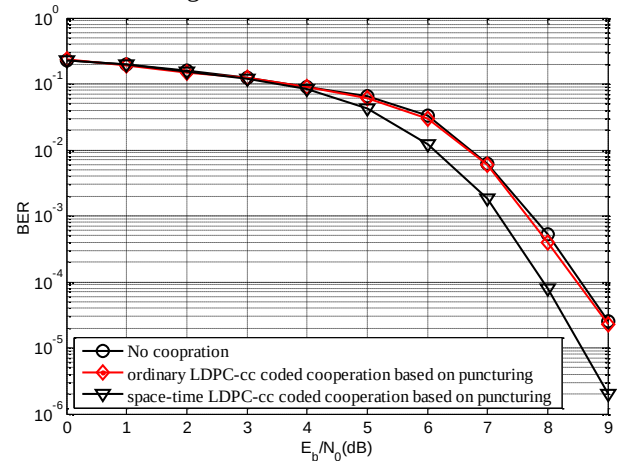


Figure 7. Fast fading, BER curves of different cooperation scheme based on LDPC-cc (user1)

As we can see from figure 7, compared with the coded cooperation, the space-time coded cooperation achieving the performance gain in fast fading. When $BER=10^{-5}$, the original coded cooperation has no performance improve, but the space-time coded cooperation has 0.7dB system gains. That is because in fast fading channels, the fading coefficient between the first and second frames of a user's uplink channel is seen as independent, then using the partner's channel will not bring any added benefit. So we bring space-time transmission into the coded cooperation in the second frame, simulated the 2 input and 1 output MIMO system, improving the system performance through multi-antenna diversity and space-time coding.

On the above analysis, LDPC-cc coded cooperation based on puncturing provides significant performance gains compared with the uncooperative LDPC-cc. In addition, when introducing the space-time transmission in the second frame, the coded cooperation scheme can be widely used both in fast and slow fading.

V. CONCLUSIONS

Coded cooperation has great application prospects in 5G communications. To propose a method that can achieve a higher coding gain, and be flexibly applied in various environments, we based on the LDPC convolutional codes which can approach to the Shannon limitation as much as possible, dividing the mother codes into two segments by puncturing algorithm to study the performance of coded cooperation in this thesis, and introducing the space-time transmission into the second frame of coded cooperation to design a scheme that can approaching the capacity limitation transfer, and generally applied to slow and fast fading.

Simulation results show that the system performance can be improved generally.

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REFERENCE

- [1] J. N. Laneman, G. W. Wornell, and D. N. C. Tse. "An efficient protocol for realizing cooperative diversity in wireless networks." *IEEE International Symposium on Information Theory*, 2001. *Proceedings* IEEE, 2001:1 - 5.
- [2] B. A. Sendonaris, E. Erkip & B. Aazhang, (2010). User Cooperation Diversity - Part I: System Description. *IEEE Trans. Commun* (Vol.51, pp.1927-1938).
- [3] A. Sendonaris, E. Erkip, and B. Aazhang. "User cooperation diversity. Part II. Implementation aspects and performance analysis." *IEEE Transactions on Communications* 51.11(2003):1939-1948.
- [4] T. E. Hunter, A. Nosratinia. Cooperation diversity through coding[C]. *IEEE International Symposium on Information Theory*, Proceedings. 2002.
- [5] T. E. Hunter, A. Nosratinia. Diversity through coded cooperation[J]. *IEEE Transactions on Wireless Communications*, 2006, 5(2):283-289.
- [6] A. Jimenez Felstrom, K. S. Zigangirov, Time-varying periodic convolutional codes with low-density parity-check matrix[J]. *IEEE Transactions on Information Theory*, 1999, 45(6):2181-2191.
- [7] A. E. Pusane, A. J. Feltstrom, A. Sridharan, et al. Implementation aspects of LDPC convolutional codes[J]. *Communications IEEE Transactions on*, 2008, 56(7):1060-1069.
- [8] C. Cardinal, D. Haccoun, F. Gagnon. Iterative threshold decoding without interleaving for convolutional self-doubly orthogonal codes[J]. *IEEE Transactions on Communications*, 2003, 51(8):1274-1282.
- [9] H. Zhou, D. G. M. Mitchell, N. Goertz, et al. Robust Rate-Compatible Punctured LDPC Convolutional Codes[J]. *IEEE Transactions on Communications*, 2013, 61(11): 4428-4439.
- [10] M. Janani, A. Hedayat, T. E. Hunter, et al. Coded cooperation in wireless communications: space-time transmission and iterative decoding [J]. *IEEE Transactions on Signal Processing*, 2004, 52(2):362-371.
- [11] S. M. Alamouti. A simple transmit diversity technique for wireless communications [J]. *IEEE Journal on Selected Areas in Communications*, 1998, 16(8):1451-1458.
- [12] R. M. Tanner, D. Sridhara, A. Sridharan, et al. LDPC block and convolutional codes based on circulant matrices[J]. *IEEE Transactions on Information Theory*, 2004, 50(12):2966-2984.
- [13] A. Sridharan, M. S. Daniel, J. Costello. Design and analysis of LDPC convolutional codes[J]. *Environmental Science & Pollution Research International*, 2009, 16(7):805-816.
- [14] J. Ha, J. Kim, D. Klinc, et al. Rate-compatible punctured low-density parity-check codes with short block lengths[J]. *IEEE Transactions on Information Theory*, 2006, 52(2):728-738.
- [15] R. Asvadi, A. H. Banihashemi. A Rate-compatible puncturing scheme for finite-length LDPC codes[J]. *IEEE Communications Letters*, 2013, 17(1):147-150.



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