Nonbinary Network Coded Cooperation With Bit-Interleaved Coded Modulation

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***Abstract*—Nonbinary network coding (NBNC) is an efficient approach to exploit the space diversity and improve the information throughput in a cooperative communication scenario. It provides substantial performance gains over those cooperative schemes without network coding (NC) or only with binary network coding (BNC). However, since the nonbinary network coded information is defined in a larger finite field, cooperative communications with NBNC will result in the loss of spectral efficiency and the increased energy consumption. This paper proposes a spectrally efficient nonbinary network coded cooperative scheme by employing the bit-interleaved coded modulation (BICM) and iterative decoding, i.e., BICM-ID, to combat spectrum and energy efficiency loss while maintaining a good communication performance. Spectral efficiency of a cooperative user is analyzed and it is utilized as a reference to compare with other existing cooperative schemes. Our simulation results demonstrate the proposed scheme achieves significant performance improvements over various benchmark schemes without further loss of spectrum efficiency and energy consumption.**

***Index Terms*—Bit-interleaved coded modulation, cooperative communications, nonbinary network coding, spectral efficiency.**

I. Introduction

As a promising spatial diversity technique, cooperative communication [1] [2] enables single antenna mobile units to share their antennas to relay each other's signal and improve their performance. In the conventional cooperative communications, the relay node simply retransmits its partner's information in the relaying time slot (TS). This would result in spectral efficiency loss and limit the information throughput when there are multiple cooperative users [3]. By allowing the relay node to process the information streams of multiple users, network coding (NC) [4] emerged as an efficient strategy to exploit the cooperative space diversity and achieve a high information throughput in user collaboration.

The applications of NC to various wireless cooperative networks have been demonstrated to be beneficial. In [5], a two-user energy saving cooperative scheme that combines binary network coding (BNC) was investigated. In the scheme, each transmitted message is generated by binary summing the local user's message and partner's message if the local user can correctly decode partner's message. It provides substantial performance improvement over the scenario without NC. Reference [6] investigated the diversity gain by implementing BNC in multiple users cooperative scenarios. It is shown that BNC yields additional diversity gain over the conventional scenario without employing NC. However, it has been realized that BNC cannot fully exploit the space diversity, especially when the channels do not remain static during the broadcasting transmission and the relaying transmission. By carefully designing nonbinary network codes, a full diversity gain can be achieved for cooperative networks. In [8], Xiao *et al.* proposed nonbinary network codes defined over finite fields in multiple users cooperative networks to achieve a full diversity gain. It is shown that the proposed scheme exhibits a better performance in terms of diversity gain and end-to-end error probability performance than those schemes with BNC or without NC. But it should be pointed out that the performance improvements of using NBNC are at the expense of spectral efficiency and energy consumption. This is due to the fact that the nonbinary network coded information is defined in a larger finite field. If the same modulation scheme is utilized in both the broadcasting and relaying transmissions, more symbols will have to be transmitted during relaying. Hence, the increased usage of channel in relaying will result in the loss of a user's multiplexing gain [9]. In a practical coded system, this would result in the loss of a cooperative user's spectral efficiency which will be defined later in the paper.

Addressing this challenge, this paper proposes a spectrally efficient NBNC cooperative scheme with an adaptive usage of the bit-interleaved coded modulation (BICM) [10] as a channel coding scheme and iterative decoding (BICM-ID) [11] as a decoding approach. In order to alleviate the retransmission burden and maintain an efficient use of each user's spectrum resource, the nonbinary network coded information will be BICM coded with the use of a higher order modulation scheme. Although transmission with a higher order modulation scheme may result in decoding performance loss, this negative effect can be compensated by BICM-ID which is utilized at the destination (D) to decode the network coded information. Different to most of the existing literature that modeled the point-to-point channels as the Quasi-static fading channels, in this paper, they are modeled as the block Rayleigh fading channels which have multiple channel realizations during the transmission of a codeword frame. Hence, channel fading diversity exists within a codeword frame. In this paper, we call it time diversity to distinguish it from the space diversity that is created by cooperative transmissions. With such a network setup, we aim to investigate the beneficiary of having both space and time diversities in a cooperative system, which is not well known so far.

The rest of the paper is organized as follows. Section II presents the system model. In Section III, a cooperative

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user's spectral efficiency is defined and analyzed to clarify the motivation of this work. A brief description of BICM-ID and its adoption in the NBNC cooperative scheme is given in Section IV. Section V presents the simulation results to show the effectiveness of the proposed scheme. Finally, Section VI concludes this paper.

II. System Model

The proposed cooperative system consists of three nodes, user 1 (U_1), user 2 (U_2) and D, as illustrated in Fig.1. Let $\mathbb{F}_q$ denotes the finite field of size q. We assume that both U_1 and U_2 aim to transmit their own message $\mathcal{M}_1$ and $\mathcal{M}_2$ to D, where $(\mathcal{M}_1, \mathcal{M}_2) \in \mathbb{F}_2^l$ and l denotes the length of the binary message vectors. U_1 and U_2 are functioning in the full-duplex mode. A complete cooperative process consists of two TSs. In TS-I, U_1 and U_2 transmit their channel coded informations $C(\mathcal{M}_1)$ and $C(\mathcal{M}_2)$ to D simultaneously in the orthogonal frequency channels, and $C(\cdot)$ is used to denote the channel coding function. In this paper, nonsystematic nonrecursive convolutional code is used as the channel code, which will be denoted in an octal form. If the code rate is r, we know that $(C(\mathcal{M}_1), C(\mathcal{M}_2)) \in \mathbb{F}_2^{l/r}$. The channel between U_1 and U_2 is called the inter-user channel. With the broadcast feature of wireless medium, $C(\mathcal{M}_1)$ and $C(\mathcal{M}_2)$ are also received by U_2 and U_1, respectively. When the M-ary signal constellation is employed as the modulation scheme in TS-I and $M = 2^{m_\mathrm{I}}$ where m_I is the order of the modulation scheme employed in TS-I, we can write the baseband signal model of transmissions in TS-I as:

$$y^{\mathrm{I}}_{\mathrm{U_1D}}(t) = \alpha^{\mathrm{I}}_{\mathrm{U_1D}}(t)x^{\mathrm{I}}_{\mathrm{U_1}}(t) + n^{\mathrm{I}}_{\mathrm{D}}(t), \tag{1}$$

$$y^{\mathrm{I}}_{\mathrm{U_2D}}(t) = \alpha^{\mathrm{I}}_{\mathrm{U_2D}}(t)x^{\mathrm{I}}_{\mathrm{U_2}}(t) + n^{\mathrm{I}}_{\mathrm{D}}(t), \tag{2}$$

$$y^{\mathrm{I}}_{\mathrm{U_1U_2}}(t) = \alpha^{\mathrm{I}}_{\mathrm{U_1U_2}}(t)x^{\mathrm{I}}_{\mathrm{U_1}}(t) + n^{\mathrm{I}}_{\mathrm{U_2}}(t), \tag{3}$$

$$y^{\mathrm{I}}_{\mathrm{U_2U_1}}(t) = \alpha^{\mathrm{I}}_{\mathrm{U_2U_1}}(t)x^{\mathrm{I}}_{\mathrm{U_2}}(t) + n^{\mathrm{I}}_{\mathrm{U_1}}(t), \tag{4}$$

where t is the symbol index and $t = 1, 2, ..., l/(rm_\mathrm{I})$. In the above equations, $x^i_A(t)$ is the modulated signal transmitted by user A, $A \in \{\mathrm{U}_1, \mathrm{U}_2\}$, i denotes the TS index as $i \in \{\mathrm{I, II}\}$. $y^i_{AB}(t)$ is the received signal at user B which is transmitted by user A, and $B \in \{\mathrm{U}_1, \mathrm{U}_2, \mathrm{D}\}$. $\alpha^i_{AB}(t)$ is the Rayleigh fading coefficient between the $A - \text{to} - B$ channel. Channel state information (CSI) is assumed to be available at the receivers. $n^i_B(t)$ is additive white Gaussian noise (AWGN) observed by receiver B.

In TS-II, if both users can correctly decode their partner's message, U_1 and U_2 will apply nonbinary network codes to reconstruct different linear combinations of the two message vectors. Specifically, U_1 will form a network coded message vector of $\mathcal{M}_1+2\mathcal{M}_2$ and U_2 will form another network coded message vector of $\mathcal{M}_1+\mathcal{M}_2$, where $(\mathcal{M}_1+2\mathcal{M}_2, \mathcal{M}_1+\mathcal{M}_2) \in \mathbb{F}_4^l$. By converting the nonbinary network coded message vectors into binary vectors as $(\mathcal{M}_1 + 2\mathcal{M}_2, \mathcal{M}_1 + \mathcal{M}_2) \in \mathbb{F}_2^{2l}$, U_1 and U_2 will apply the same channel code as in TS-I to encode their message into $C(\mathcal{M}_1 + 2\mathcal{M}_2)$ and $C(\mathcal{M}_1 + \mathcal{M}_2)$, respectively. They will be transmitted in TS-II. Note that $(C(\mathcal{M}_1 + 2\mathcal{M}_2), C(\mathcal{M}_1 + \mathcal{M}_2)) \in \mathbb{F}_2^{2l/r}$. Therefore, the baseband signal model of transmissions in TS-II can be written as:

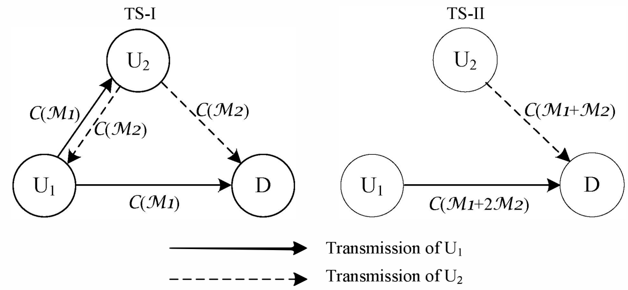


Fig. 1. System model of the proposed scheme.

$$y^{\mathrm{II}}_{\mathrm{U_1D}}(t) = \alpha^{\mathrm{II}}_{\mathrm{U_1D}}(t)x^{\mathrm{II}}_{\mathrm{U_1}}(t) + n^{\mathrm{II}}_{\mathrm{D}}(t), \tag{5}$$

$$y^{\mathrm{II}}_{\mathrm{U_2D}}(t) = \alpha^{\mathrm{II}}_{\mathrm{U_2D}}(t)x^{\mathrm{II}}_{\mathrm{U_2}}(t) + n^{\mathrm{II}}_{\mathrm{D}}(t), \tag{6}$$

where $t = 1, 2, ..., 2l/(rm_{\mathrm{II}})$ and m_{II} is the order of the modulation scheme that is employed in TS-II. If a user cannot decode its partner's message, i.e., the inter-user channel is in outage, it will retransmit the same codeword vector as in TS-I. Thus, after two TSs, D will receive different set of codeword vectors depending on the inter-user channels transmission outcome. For more general cooperative scenarios, more users will participate in the cooperation and the linear combinations of binary messages are defined in a larger finite field. Hence, higher order modulation schemes should be employed. More details of the linear combinations can be found in [8].

We first assume the inter-user channels are reciprocal, i.e., $\alpha^{\mathrm{I}}_{\mathrm{U_1U_2}}(t) = \alpha^{\mathrm{I}}_{\mathrm{U_2U_1}}(t)$. If the inter-user channels are in outage, after two TSs, D receives the codeword vectors set

$$\mathcal{A} : (C(\mathcal{M}_1), C(\mathcal{M}_2), C(\mathcal{M}_1), C(\mathcal{M}_2)).$$

While the inter-user channels are not in outage, D receives the codeword vectors set

$$\mathcal{B} : (C(\mathcal{M}_1), C(\mathcal{M}_2), C(\mathcal{M}_1 + 2\mathcal{M}_2), C(\mathcal{M}_1 + \mathcal{M}_2)).$$

If the inter-user channels are non-reciprocal, there are two more possible received codeword vectors sets that can be received by D. If the U_1-to-U_2 channel is in outage while the U_2-to-U_1 channel is not, D will receive the codeword vectors set

$$\mathcal{C} : (C(\mathcal{M}_1), C(\mathcal{M}_2), C(\mathcal{M}_1 + 2\mathcal{M}_2), C(\mathcal{M}_2)).$$

If the situation reverses, D will receive the set

$$\mathcal{D} : (C(\mathcal{M}_1), C(\mathcal{M}_2), C(\mathcal{M}_1), C(\mathcal{M}_1 + \mathcal{M}_2)).$$

Moreover, if BNC is employed in TS-II and both users can cooperate, D will receive codeword vectors set

$$\mathcal{E} : (C(\mathcal{M}_1), C(\mathcal{M}_2), C(\mathcal{M}_1 \bigoplus \mathcal{M}_2), C(\mathcal{M}_1 \bigoplus \mathcal{M}_2)),$$

where $\bigoplus$ denotes the binary sum (XOR) operation. By comparing set $\mathcal{B}$ to set $\mathcal{E}$, it can be seen that NBNC enables D to recover both two users' messages from a minimum subset of received codeword vectors. That says if any two codeword vectors of set $\mathcal{B}$ can be correctly decoded, messages of U_1

and U_2 can be recovered. Apparently, the BNC cooperative scheme does not have this advantage.

III. Spectral Efficiency Analysis

In a cooperative network, each user has a benevolent feature since they will utilize their own transmission resources to relay other users' informations. Therefore, it is always desirable to limit a cooperative user's relaying burden and allow it to spend more transmission resources for its own information. In order to demonstrate the relaying burden of using NBNC and clarify our motivation of employing an adaptive usage of BICM, we first define a cooperative user's spectral efficiency as the follows.

Definition: In a cooperative network, a user's spectral efficiency (η) is defined as the number of its own information bits carried by each of its transmitted symbol [3], i.e.,

$$\eta \triangleq \frac{\text{number of own info. bits}}{\text{number of transmitted symbols}} \text{ bits/symbol.} \quad (7)$$

For the proposed NBCN cooperative system, the rate half convolutional code is employed in the two TSs. In TS-I, if QPSK with $m_{\mathrm{I}} = 2$ is employed to modulate the codeword vectors $C(\mathcal{M}_{\mathrm{I}})$ and $C(\mathcal{M}_2)$, a spectral efficiency of

$$\eta_{\mathrm{I}} = \frac{1}{2} \cdot m_{\mathrm{I}} = 1 \text{ bits/symbol}$$

can be achieved for each user. However, in TS-II, since $(C(\mathcal{M}_1 + 2\mathcal{M}_2),\ C(\mathcal{M}_1 + \mathcal{M}_2)) \in \mathbb{F}_2^{2l/r}$, if we still use QPSK, i.e., $m_{\mathrm{II}} = 2$, each user will transmit twice as many symbols as in TS-I. More importantly, since each nonbinary network coded information symbol of $\mathbb{F}_4$ contains one user's own information bit and one partner's information bit, the user spectral efficiency becomes

$$\eta_{\mathrm{II}} = \frac{1}{2} \cdot \frac{1}{2} \cdot m_{\mathrm{II}} = 0.5 \text{ bits/symbol.}$$

Up to this end, the spectral efficiency loss due to the use of NBNC becomes clear. In order to alleviate the retransmission burden and maintain the same spectral efficiency as in TS-I, in TS-II, each user will apply 16QAM to transmit the network coded message to compensate the cost of applying NBNC. Consequently, in TS-II, $m_{\mathrm{II}} = 4$ and

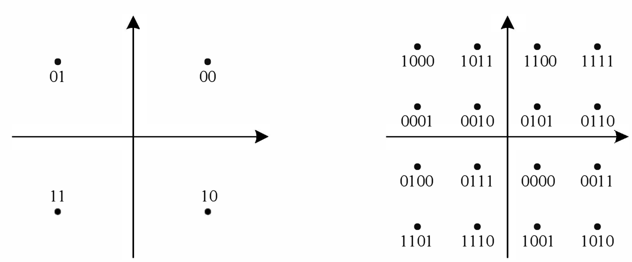
$$\eta_{\mathrm{II}} = \frac{1}{2} \cdot \frac{1}{2} \cdot m_{\mathrm{II}} = 1 \text{ bits/symbol.}$$

After TS-II, D will employ iterative decoding to retrieve the network coded message of $\mathcal{M}_1 + 2\mathcal{M}_2$ and $\mathcal{M}_1 + \mathcal{M}_2$ to compensate the error performance loss of using 16QAM.

Therefore, with the above mentioned spectral efficiency analysis and the baseband signal model of Section II, we can further complement the NBNC cooperative scheme as the follows. In TS-I, $x^{\mathrm{I}}_{\mathrm{U}_1}$ and $x^{\mathrm{I}}_{\mathrm{U}_2}$ are QPSK symbols, U_1 and U_2 receive $y^{\mathrm{I}}_{\mathrm{U}_2\mathrm{U}_1}$ and $y^{\mathrm{I}}_{\mathrm{U}_1\mathrm{U}_2}$, respectively. While D receives $y^{\mathrm{I}}_{\mathrm{U}_1\mathrm{D}}$ and $y^{\mathrm{I}}_{\mathrm{U}_2\mathrm{D}}$, with which it tries to decode $\mathcal{M}_1$ and $\mathcal{M}_2$, respectively. In TS-II, if both users apply NBNC, $x^{\mathrm{II}}_{\mathrm{U}_1}$ and $x^{\mathrm{II}}_{\mathrm{U}_2}$ are 16QAM symbols. D receives $y^{\mathrm{II}}_{\mathrm{U}_1\mathrm{D}}$ and $y^{\mathrm{II}}_{\mathrm{U}_2\mathrm{D}}$, with which it tries to decode $\mathcal{M}_1 + 2\mathcal{M}_2$ and $\mathcal{M}_1 + \mathcal{M}_2$, respectively. Note that if a user does not decode its partner's message after TS-I, it will retransmit its information using QPSK. Therefore, if both users can fully cooperate, D can recover $\mathcal{M}_1$ and $\mathcal{M}_2$ if it can successfully decode any two of the four codeword vectors of set $\mathcal{B}$.

IV. BICM-ID

BICM [10] was proposed to capture the time diversity of the block fading channels and has been regarded as a spectrally efficient coded transmission scheme. It consists of a channel encoder, a serial-to-parallel converter, random bit interleavers and a signal mapper. With a careful design of the constellation diagram, a BICM coded system can achieve a high performance and maintain a high spectral efficiency. Hence, BICM as a channel coding scheme is particularly suitable for our proposed scheme and is applied throughout this paper to compensate the loss of using nonbinary network codes. Specifically, in TS-I of our cooperative networks, the Gray labeling QPSK modulation is utilized to transmit codeword vectors $C(\mathcal{M}_1)$ and $C(\mathcal{M}_2)$. In TS-II, if NBNC is utilized, the modified set partitioning (MSP) labeling [13] 16QAM modulation is utilized to transmitted codeword vectors $C(\mathcal{M}_1 + 2\mathcal{M}_2)$ and $C(\mathcal{M}_1 + \mathcal{M}_2)$. Otherwise, the Gray labeling QPSK modulation will again be utilized. The Gray labeling QPSK and MSP labeling 16QAM are shown in Fig.2. The main reason of employing MSP labeling 16QAM in using NBNC is that BICM-ID can provide pronounced iterative decoding gains. Such a decoding effect can compensate the inherited performance loss of using a higher order modulation scheme. Note that if QPSK is used in TS-II, D will not perform iterative decoding as for QPSK, iterative decoding does not enhance the error correction performance. Therefore, in our proposed scheme, D is able to adapt its decoding approaches according to whether NBNC has been utilized. This is recognized as an extra implementation complexity for achieving spectrally efficient transmission in TS-II.



(a) Gray Labeling QPSK (b) MSP Labeling 16QAM

Fig. 2. Constellation diagrams used in the proposed scheme.

Iterative decoding [11] achieves a good performance by iteratively exchanging soft information between the soft-in-soft-out (SISO) demodulator and the SISO decoder [12]. As depicted in Fig.3, at the demodulator of the iterative decoding system, the corresponding bit metrics are calculated through the channel observations, i.e., $y^{\mathrm{II}}_{\mathrm{U}_1\mathrm{D}}$ and $y^{\mathrm{II}}_{\mathrm{U}_2\mathrm{D}}$, and the *a priori* probabilities $P_a(v_\tau)$ of the interleaved coded bits v_τ

where τ denotes the coded bit index. It provides the extrinsic probabilities $P_e(v_\tau)$ which are then deinterleaved and mapped to the *a priori* probabilities $P_a(c_\tau)$ for the coded bits c_τ for the SISO decoder. With the probabilities $P_a(c_\tau)$, SISO decoder further determines the extrinsic probabilities $P_e(c_\tau)$ of coded bits. They are then interleaved and fed back as the *a priori* probabilities $P_a(v_\tau)$ to update the demodulator for the next iteration. Note that at the beginning of the iterative decoding, the *a priori* probabilities $P_a(v_\tau)$ are unavailable and are assumed with equal likelihood for the bit being 0 and 1. At the end of the iterations, the decoded output is determined base on the *a posteriori* probabilities $P_p(u_\tau)$ of information bits u_τ.

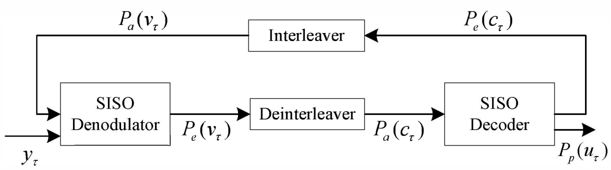


Fig. 3. Iterative decoding diagram.

V. Performance Analysis

We further present the simulation results of the practical BICM coded systems to evaluate the frame error rate (FER) performance of our proposed NBNC scheme. It is compared with direct transmission, cooperation without NC and cooperation with BNC. Cooperation without NC is equivalent to the conventional decode-and-forward scheme in which D performs decoding after each TS. All channels are assumed to have the same SNR that is characterized by E_b/N_0 where E_b is the transmitted energy per information bit and N_0 is the noise power. The network channels are parameterized by the number of channel realizations within the transmission of a codeword frame and the average square channel gain $\mathbb{E}[|\alpha|^2]$. If NBNC is utilized in TS-II, D performs iterative decoding with 10 iterations. The rate half $(5,7)_8$ convolutional code is employed as a channel code and each message frame contains 500 information bits as $l = 500$. QPSK signals are used in direct transmission, cooperation without NC and cooperation with BNC. Therefore, all the cooperative schemes except cooperation without NC exhibit the same spectral efficiency of $\eta = 1$ bit/symbol for both TSs. For cooperation without NC, $\eta = 1$ bit/symbol can only be achieved if a user does not relay its partner's information in TS-II.

Fig.4 presents the FER performance of the BICM coded NBNC cooperative scheme and its comparison with the benchmark schemes. There are 10 channel realizations during the transmission of each codeword frame and hence every 50 symbols experience a channel realization. It shows that the coded NBNC scheme achieves significant performance improvement over the benchmark schemes. For example, the coded NBNC scheme outperforms the coded BNC scheme with 2dB gain at the FER of 10^{-4}. More importantly, the error decay rate of the coded NBNC scheme demonstrates it achieves a higher space diversity gain over the benchmarks. On the other hand, it can also be observed that reciprocal and non-reciprocal inter-user channels setups exhibit a similar performance. This is due to the statistical characteristics of all channels are the same in both of the setups.

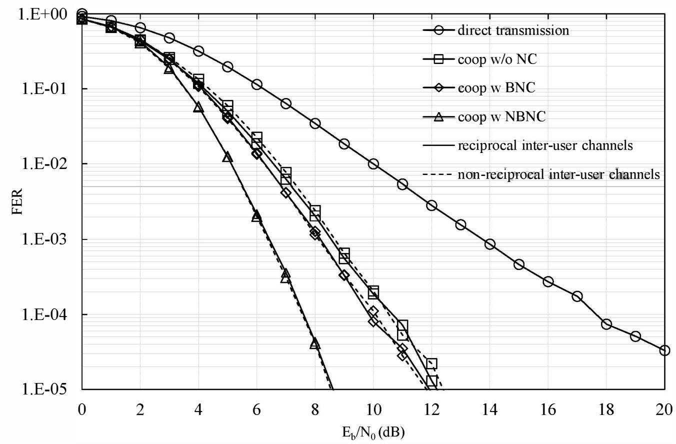


Fig. 4. FER performance of the BICM coded NBNC scheme with 10 channel realizations and $\mathbb{E}[|\alpha|^2] = 2$.

Fig.5 shows the proposed scheme's performance over faster point-to-point fading channels in which there are 25 channel realizations during the transmission of a codeword frame. The inter-user channels are reciprocal. We can see the enhanced FER performance of each scheme by comparing with Fig.4. This is due to higher time diversity exists in each point-to-point channel. The above mentioned results show that the proposed scheme does not only maintain a spectrally efficient relaying transmission, but also achieve a higher space diversity gain which ensures a more reliable communication.

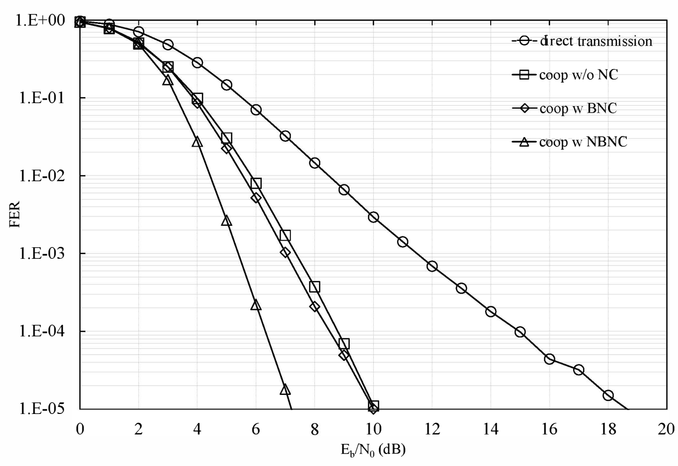


Fig. 5. FER performance the BICM coded NBNC scheme with 25 channel realizations and $\mathbb{E}[|\alpha|^2] = 2$.

Fig.6 shows the performance of a nonsystematic setup, in which we consider the average square channel gain for inter-user channels is 8 while for other channels it is 2. Again, the inter-user channels are reciprocal. By strengthening the fading gain of the inter-user channels, the probability of employing NBNC in TS-II is increased. Consequently, it enlarges the proposed scheme's performance gain over the other schemes. On the other hand, it is also observed that the performance of cooperation with BNC converges to that of cooperation without NC. It implies when the inter-user channels are satisfactory good, the conventional decode-and-forward cooperation can already well capture the space diversity gain and it is not necessary to use BNC.

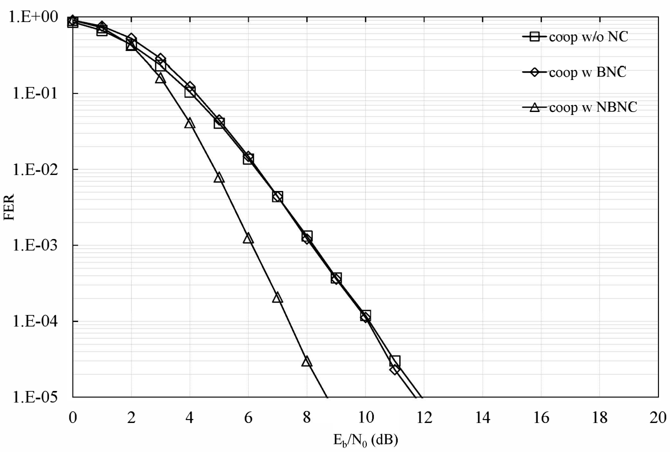


Fig. 6. FER performance of the BICM coded NBNC scheme with 10 channel realizations and $\mathbb{E}[|\alpha|^2] = 8$ for the inter-user channels and $\mathbb{E}[|\alpha|^2] = 2$ for other channels.

Fig.7 shows the simulation results of the system FER performance. The system FER implies a frame error is counted if D cannot successfully decode both messages of U_1 and U_2. Again, the NBNC scheme exhibits a similar performance improving margin over the benchmark schemes as shown in Fig.4. But it is also noticed that cooperation with BNC achieves a more significant performance gain over cooperation without NC, which explains NC's capability of enlarging a network information throughput.

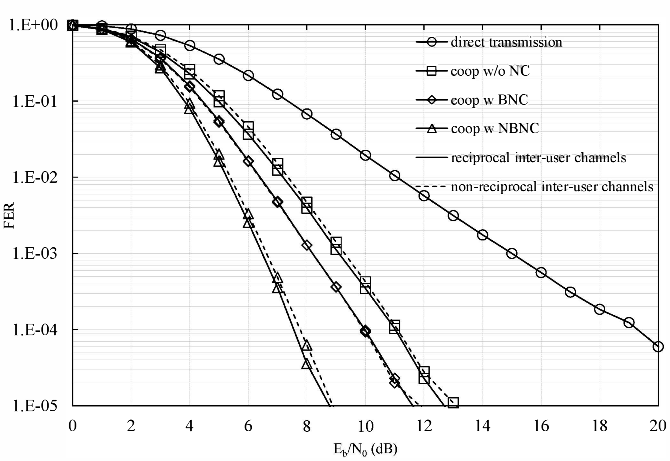


Fig. 7. System FER performance of the BICM coded NBNC scheme with 10 channel realizations and $\mathbb{E}[|\alpha|^2] = 2$.

The presented results show cooperation with NBNC is capable to achieve a better space diversity gain over the existing cooperative scheme, including cooperation without NC and cooperation with BNC. By employing an adaptive use of BICM, such a performance gain can be obtained without further sacrificing the user spectral efficiency.

VI. Conclusion

In this paper, we have proposed a spectrally efficient NBNC scheme with an adaptive use of the BICM coding scheme. It is shown that significant FER performance improvement can be achieved without sacrificing the spectral efficiency and energy consumption, both of which appear to be the negative impacts of using NBNC. Therefore, the proposed cooperative scheme can well exploit the time diversity of block fading channel and the space diversity that is introduced by user cooperation. The effectiveness of our proposed scheme is confirmed by the simulation results. It is important to point out that our proposed scheme can be further extended the cooperative networks that have multiple users by utilizing higher modulation schemes, e.g., 64QAM, 256QAM, which will be our future work.

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