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Practical network-coding scheme for two-way relay channels employing a rate-compatible punctured code

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Abstract: A cooperative communication in a two-way relay channel is a bidirectional communication between two terminals with the aid of a common relay. In order to improve the performance of the cooperative communication in a two-way relay channel, a network coding can be used to exploit the broadcasting nature of wireless transmission. In [8], it was shown that each individual link can achieve its own capacity when the length of the codewords is the same. However, the length of the codewords can be different in practical systems since the two-way relay channel is naturally asymmetric. Thus, in this paper, we show a practical network coding scheme with a given modulation and coding set by employing a rate-compatible puncturing technique. Simulation results show that the proposed scheme can provide at least as good performance as that obtained in individual link without using special encoder/decoder.

Keywords: network coding, two-way relay channel, cooperation, asymmetric channel

Classification: Science and engineering for electronics

References

[1] L. Zheng, D. N. C. Tse, and G. W. Wornell, "Diversity and Multiplexing: A Fundamental Tradeoff in Multiple-Antenna Channels," *IEEE Trans. Inform. Theory*, vol. 49, pp. 1073–1096, May 2005.

[2] J. N. Laneman, D. N. C. Tse, and G. W. Wornell, "Cooperative Diversity in wireless Networks: Efficient protocols and outage behavior," *IEEE Trans. Inform. Theory*, vol. 50, pp. 3062–3080, Dec. 2004.

[3] B. Rankov and A. Wittneben, "Achievable rate regions for the two-way relay channel," *Proc. IEEE Inter. Symp. Inform. Theory (ISIT)*, pp. 1668–1672, Seattle, WA, U.S.A., July 2006.

[4] P. Larsson, N. Johansson, and K.-E. Sunell, "Coded bi-directional relaying," *5th Scandinavian workshop on Ad Hoc networks (ADBOC' 05)*, Stockholm, Sweden, May 2005.

[5] P. Popovski and H. Yomo, "Bi-directional amplification of throughput in a wireless multi-hop network," *in IEEE 63rd Vehicular Technology Conference (VTC)*, Melbourne, Australia, May 2006.

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[6] C. Hausl and J. Hagenauer, "Iterative network and channel decoding for the two-way relay channel," *IEEE International Conference on Communications, 2006, (ICC '06)*, vol. 4, pp. 1568–1573, June 2006.
[7] C. Hausl , "Improved Rate-Compatible Joint Network-Channel Code for the Two-Way Relay Channel," *JCCC*, 2006.
[8] F. Xue and S. Sandhu, "PHY-layer network coding for broadcast channel with side information," *infromation theory workshop (ITW)*, pp. 108–113, Lake Tahoe, CA, USA Sept. 2007.
[9] J. Castura and Y. Mao, "Rateless coding for wireless relay channels," *Proc. IEEE Int. Symp. Inform. Theory, (ISIT)*, pp. 810–814, Sept. 2005.
[10] H. Y. Park, K. S. Kim, D. H. Kim, and K. C. Whang, "Structured puncturing for rate-compatible LDPC codes with dual diagonal structure," *IEEE Trans. Wireless Commun.*, vol. 15, pp. 633–636, U.S.A., Oct. 2008.

1 Introduction

For reliable wireless communication, diversity techniques have been investigated to overcome the performance loss of fading channel when a transmitter does not know the channel state information [1]. Although classical transmit diversity can be achieved by using multiple antennas at a transmitter, a recent research shows that single antenna users can cooperate to provide transmit diversity [2]. Among cooperative communication schemes, a cooperative communication in a two-way relay channel, which is a bidirectional cooperative communication between two users with the aid of a common relay, has drawn much attention due to the bidirectional nature of communication [3] and it has been shown that the performance of the cooperative communication in a two-way relay channel can be improved by using network coding due to the broadcasting nature of wireless communication [4, 5]. There are two half-duplex orthogonal bidirectional cooperative communication protocols: a 4-step decode-and-forward (DF) protocol and a 3-step DF protocol using network coding. In the 4-step DF protocol, terminal A wants to transmit bit stream b_A to terminal B and terminal B wants to transmit bit stream b_B to terminal A. Relay terminal R decodes and transmits b_A and b_B to terminals B and A, respectively. On the other hand, in the 3-step DF protocol using network coding, the relay combines b_A and b_B using network coding and broadcasts the network coded bit $b_R = b_A \bigoplus b_B$ to both users. Thus, it is easily seen that the sum throughput of the two-way relay channel can be improved by a factor up to $4/3$ by using a network coding. However, in order to realize such gain in a practical system, a careful design of joint network-channel coding scheme is required.

Practical design of joint network-channel coding schemes have been investigated in [6, 7]. In [6], a joint network-channel coding scheme was proposed based on a turbo code. In [7], it was shown that a scheme applying network coding after channel encoding (NAC) is more appropriate than that applying a network coding before channel encoding (NBC) or the joint scheme in

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[6]. In [8], it was shown that each individual link can achieve its own capacity with the NAC scheme provided that both link use the same codeword length. However, in practical systems, different codeword length are typically provided by using a family of modulation and coding set (MCS). When the two-way relay channel is asymmetric (i.e., the relay is not in the center location), the two links may use different MCS options, in which the codeword length of one link is different to that in the other link. Thus, it is required to devise a network coding scheme which deals with the asymmetric data rate and performs at least as good as that obtained in individual links. In addition, it is also desired that the network coding scheme does not require a special encoder/decoder which increases the system complexity.

In this paper, we show a practical network coding scheme for matching the codeword length by a rate-compatible LDPC codes to deal with the asymmetric data rate without increasing system complexity and degrading performance. The performance of the proposed scheme is evaluated through computer simulation in terms of the bit error rate (BER) and sum throughput.

2 System model description

We consider a half-duplex orthogonal cooperative communication system in a two-way relay channel using network coding. The network coded DF (NDF) protocol, based on the selection relaying DF protocol [2], is as follows. In Step 1, terminal A transmits data to terminal B and relay terminal R. In Step 2, terminal B transmits data to terminal A and relay terminal R. In Step 3, if the relay has decoded both the packet from terminals A and B, the relay network encodes b_A and b_B and broadcasts $b_R = b_A \bigoplus b_B$ to terminals A and B. If the relay fails to decode one of the packets, network coding cannot be used at the relay and the relay transmits the successfully decoded packet only. In this case, the terminal without the aid of the relay transmits data to the destination using an additional time slot. When the relay fails to decode both the packets, the relay remains silent during step 3 and terminals A and B transmit data to each other using two additional time slots. Note that 3 time slots are used for the first case while 4 time slots are required for the other cases. The protocol for proposed network coding and traditional network coding [8] are the same, but the two individual link of the traditional network coding must use the same modulation method.

3 Proposed network coding schemes

For network coding, we adopt an NAC scheme, in which the exclusive-or operation is performed on the coded bits of the two links and the number of bits in a time slot depends only on the modulation scheme used at each link. A general NAC scheme is illustrated in Figure 1 (a). The two information streams, b_A and b_B, are respectively decoded from the received signals y_A and y_B and re-encoded using channel codes to obtain the same number of bits in a time slot (the larger one between the two links). At the decoder of terminal

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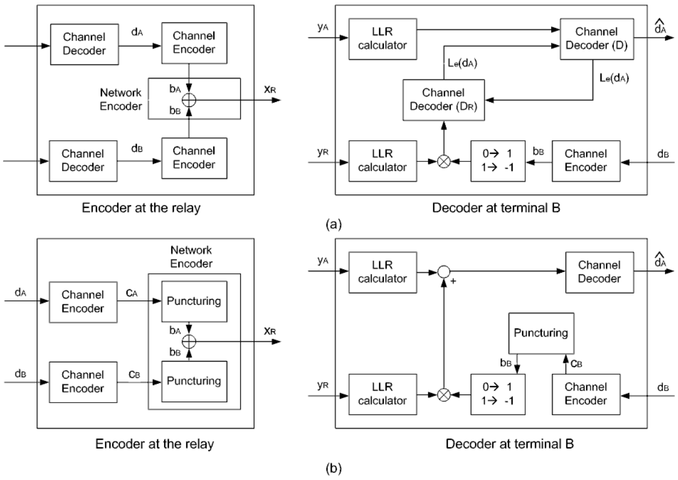

Fig. 1. Encoders and Decoders (a) re-encoded network coding scheme (b) flexible network coding scheme.

B, the sign of the LLRs obtained from the relayed signal y_R is recovered using the transmitted data b_B. Then, a turbo-like iterative decoding is performed between the two decoders, D_R and D. Thus, for a general NAC scheme, a special decoder is required at each receiver, which increases the complexity.

The proposed method, 'Flexible network coding', is illustrated in Figure 1 (b). We use a rate-compatible puncturing technique to match the codeword length. Let S be the number of symbols in a packet. Let m_A and m_B be the modulation order of symbols from terminal A and B, respectively. If $m_B > m_A$, the number of bits of the packet from terminal B (N_B) is greater than that from terminal A (N_A). At the relay, N_B-N_A parity bits of the packet from terminal A are recovered to adjust the codeword length. Then the code rate of codewords from terminal A is changed to $R_{A_R} = R_A N_A / N_B$, where R_A is the code rate of codewords from terminal A. When the required code rate R_{A_R} is smaller than the code rate of a mother code, the codeword is repeated to fill the remaining bits (priority on the systematic part). At the decoder of terminal B, the sign of the LLRs obtained from the relayed signal y_R is recovered using the transmitted data b_B and combined with the LLRs obtained from the directly received signal y_A and passed to the channel decoder. Again, the flexible network coding scheme does not require a special decoder with high complexity since an ordinary decoder with LLR combining is sufficient for this scheme.

4 Simulation results

In this section, the performance of the proposed network coding schemes are evaluated through computer simulation in terms of BER and sum throughput. The information block size, g, is set to 512 and number of symbols in a time slot, L, is set to 768 for the simulation. The MCS options used for the simulation is shown in Table I, where efficiency denotes the spectral efficiency given as $m_l r_l$. Here, r_l, m_l, and q_l respectively are the code rate, the modulation order, and the number of codeword of a packet. For the pro-

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Table I. MCS table.

MCS	r_l	m_l	Modulation	q_l	efficiency
0	No Tx.	No Tx.	No Tx.	0	0
1	1/3	2	QPSK	1	0.67
2	2/3	2	QPSK	2	1.33
3	2/3	4	16QAM	4	2.67
4	2/3	6	64QAM	6	4

posed flexible network coding scheme, a rate compatible code with mother code rate of 1/3 in [10] is adopted. The MCS selection for each direction is based on the long-term average signal to noise ratio (SNR) at the receiver after combining. Computer simulation is performed under one-dimensional linear relay network model. The distance between terminals A and B is set to 1 and d denotes the distance between terminal A and relay terminal R. We assume the average channel gain of each link to be $g_{A,B} = 1$ for the A-to-B link, $g_{A,R} = d^{-a}$ for the A-to-R link, and $g_{R,B} = (1-d)^{-a}$ for the R-to-B link, where a denotes the path-loss exponent. Here, a is set to 4 and the fading channel is assumed to be a fast fading channel, i.e., symbol-wise independent and identically distributed (i.i.d) fading channel.

Figure 2 (a) shows the BER performance of the proposed network coding scheme for various bidirectional modulation schemes when $d \ll 1$. In this figure, 'DF' denotes the BER performance of the DF protocol that using individual links without network coding. Also, 'Flexible NC' denotes the performance of the flexible network coding scheme. From the results, it is shown that the BER performance of the proposed flexible network coding is almost same to that using individual links without network coding.

The sum throughput is obtained by dividing the total number of successfully decoded bits at terminals A and B by the total transmission time. The transmission time of one time slot sets to be 1 so that the sum throughput actually denotes the sum spectral efficiency. Figure 2 (b) shows the sum throughput as a function of the relay location when SNR is 0 dB and 7 dB. The sum throughput is maximized when $d = 0.5$ and the sum throughput is symmetric with respect to the relay location d. When the SNR is 7 dB, the sum throughput gain of the NDF protocol over the DF protocol without network coding is approximately by a factor of 4/3 irrelevant to the relay location, which shows that the proposed network coding scheme can draw the full advantage of a network coding in a two-way relay channel. On the other hand, when SNR is 0 dB, the gain of the NDF scheme reduces as the relay location deviates from the middle of the two terminals A and B. This is due to the fact that the successful decoding probability in both links at the relay decreases so that the effect of network coding becomes negligible. In this figure, the 'Traditional NC' denotes the sum throughput when terminal A and B must use the same modulation order [8]. When the relay is near one terminal, the proposed scheme outperforms the traditional scheme.

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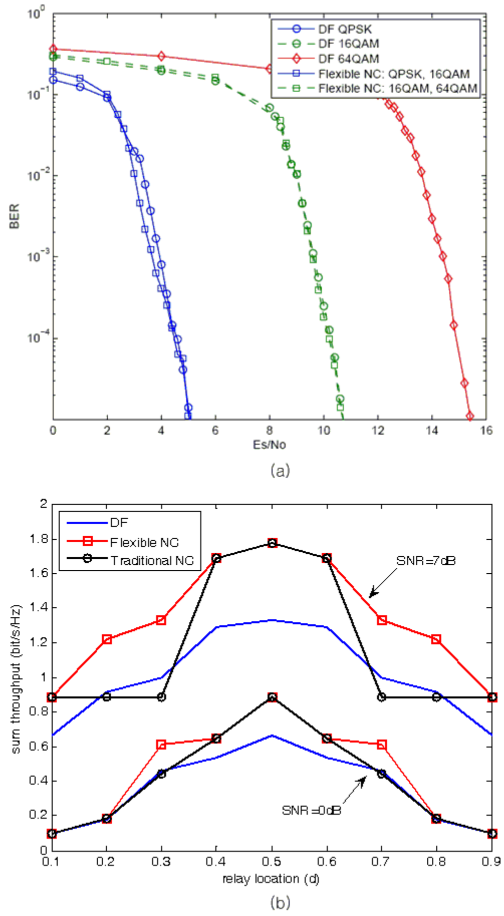

Fig. 2. Performance comparison among protocols.

5 Conclusion

In this paper, a practical network coding scheme is proposed to deal with asymmetric data rates in a two-way relay channel. The proposed network coding scheme does not increase system complexity because they do not require a special encoder and decoder for network coding. The performance of the proposed scheme is evaluated using computer simulations. The BER performance of the flexible network coding is very similar to that of individual links without network coding. Also, we can see that the proposed scheme improves the sum throughput of the selection relaying DF protocol approximately by a factor of 4/3 except when SNR is low and the relay location is far from the middle of the two terminals. Thus, the proposed network coding scheme can be adopted without increasing system complexity to improve practical systems such as a cellular system using cooperative communication or for an ad-hoc network using bidirectional transmission.

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