Network Coding for Cooperative Communications

Gordhan Das Menghwar
Christoph Mecklenbräuker (Faculty Mentor)
Institute of Communications and Radio Frequency Engineering
Vienna University of Technology
Vienna, Austria
Email: gdas@nt.tuwien.ac.at

Abstract — *In this paper, we propose network coding, as an efficient and low cost option for the implementation of block-Markov coding for cooperative communications. Cooperative communications is a strategy where users, besides transmitting their own encoded information, also relay re-encoded versions of other users' information to a common destination. Our work is motivated by the recent information-theoretic results on user cooperation. These results show that cooperating users in a multiple access channel can improve on the classical multiple access channel capacity region under the same average transmit power constraint. Additionally, cooperation provides diversity gain. The proposed implementation of the above information theoretic coding with network coding is very simple and cost effective.*

I. Introduction

Signals transmitted through radio channels are prone to wave propagation effects like scattering, reflection, refraction, and diffraction. The result of these effects is a faded signal received at the destination. This faded signal, whose receive power level varies over time, is subject to noise and interference which result in unreliable bit decisions. To counter these effects, one strategy is to increase the diversity order of the communications channel by providing several independent copies of the same transmitted signal.

For this purpose many strategies like space, frequency, and time diversity have been used. In the line of same efforts of improving the signal quality at receiver, user cooperation was introduced by Sendonaris $et\ al$ [1, 2]. Cooperative diversity is a communications strategy where users besides transmitting their encoded information also relay re-encoded version of other users' information to a common destination.

In our work, we use network coding [3] to implement block-Markov coding used by [4] to achieve diversity and capacity gain by user cooperation. The structure of the random codebooks used users u_1 and u_2 is as follows:

$$x_1 = w_1\sqrt{(\alpha_1 P_1)} + r\sqrt{(1-\alpha_1)P_1} \quad (1)$$

$$x_2 = w_2\sqrt{(\alpha_2 P_2)} + r\sqrt{(1-\alpha_2)P_2} \quad (2)$$

for some $0 \leq \alpha_i \leq 1$, where the transmission takes place in blocks. w_i represents the fresh information in the current block and r is the cooperative refinement information depending on the fresh information sent in the previous block [4].

Our results show that by using network coding in cooperative communications we can achieve diversity gain and the said strategy is easy to implement practically.

The paper is structured as follows: In section II we present our system model. In section III, we describe the network coding and receiver structure for that. Section IV presents our results and finally we conclude in section V.

II. System Model

In our cooperative communications setup, two users u_1 and u_2 wish to send information, denoted by w_i where i = 1, 2, to single destination as shown in Figure 1. We

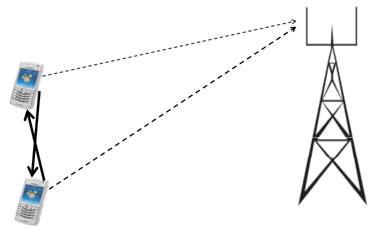

Figure 1: cooperative communications setup

assume that the channels from sources to destination and the inter-user channel are block-fading Rayleigh and receiver noise is assumed to be AWGN with zero mean and unit variance. Discrete-time baseband received signal at each receiver and at each sample time k, is

$$y_0[k] = h_{1,0}x_1[k] + h_{2,0}x_2[k] + n_0[k] \quad (3)$$

$$y_1[k] = h_{2,1}x_2[k] + n_1[k] \quad (4)$$

$$y_2[k] = h_{1,2}x_1[k] + n_2[k] \quad (5)$$

$y_0[k]$, $y_1[k]$ and $y_2[k]$ are the received signals at destination, users u_1 and u_2 respectively. x_i is the encoded message transmitted by the user u_i, where i = 1, 2. n_i represent the Gaussian noise at the receivers with variance N_o. Fading coefficients between transmitter i and receiver j are represented by $h_{i,j}$. The signal-to-noise ratio (SNR) is defined as:

$$s_{i,j} = |h_{i,j}|^2 \frac{P_i^2}{N_o} \quad (6)$$

In this model, we assume perfect echo cancellation on the basis of the fact that each user knows its own signal, therefore it can cancel out its own message's effect on their received signal.

Channel phase information availability at the transmitter side is assumed. With the help of this phase information, transmitters can adjust the phase of the signal at the transmitting side which results in coherent combination of the received signal at the destination.

Furthermore, for practical reasons we impose half duplex constraint on the channel that both of the users can not send or receive at the same time. Their channel assignment looks like as in Figure 2. An average trans-

u_1 Transmits x_1 u_2 Listens Destination Listens	u_2 Transmits x_2 u_1 Listens Destination Listens	u_1 Transmits r u_2 Transmits r Destination Listens

time

Figure 2: Proposed orthogonal cooperative communications protocol

mission power constraint of P_i is imposed on the nodes, where i = 1, 2. For simplicity, we assume that all the terminals, users u_1, u_2 and destination are at the same distance d. Furthermore, we assume perfect channel knowledge at the receivers.

III. Network Coding for Cooperative Communications

For our two user cooperative communications setup, first user u_1 broadcasts its fresh information in first time slot which is received both by another user and the destination. Same thing is done by user u_2 in the second time slot. Finally, in the third time slot both of the users send refinement information part of their message which is same for both of the users. This message is formed by taking exclusive or (XOR) operation of users' own message with the message received from other cooperating user. User power P_i is divided between their first phase of fresh information and second phase of XOR operation, appropriately.

At the receiver side, it detects and saves the messages received by both of the users during their fresh information transmission phase. In the refinement phase of transmission by users, it gets the XOR copy of both of the messages and uses this to get the second copy of the message for each user as follows:

$$\hat{x}_1 = r \oplus \hat{x}_2 \tag{7}$$

$$\hat{x}_2 = r \oplus \hat{x}_1 \tag{8}$$

IV. Outage Probability

In block fading case, channels considered follow a Rayleigh distribution, but remain constant for some specific time and than they change. As a result the achievable rates change accordingly. Therefore it is difficult to maintain constant rate, in this situation outage probability is better performance measure.

Outage probability is defined as the probability that a system rate R falls bellow a certain required rate R'. By using cooperative communications concept with network coding, we not only have capacity gain but, diversity gain is also in the list of potential gains provided by this promising scheme. For the reason of space constraint we only show the results for diversity gain as shown in Figure 3. As can be seen from the figure that with coop-

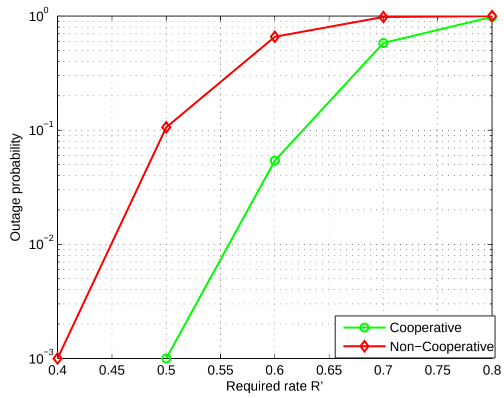

Figure 3: Outage probability comparison at 8 dB SNR

erative communications we get 25 percent reduction in outage as compared to non-cooperative communications. For these results we have taken the inter-user channels as well as user destination channel operating at the same SNR level of 8 dB.

V. Conclusion

We proposed a simple XOR-based network code for 3-phase orthogonal cooperative communications protocol. The simulation results indicate that we benefit from a 22% increase in rate for outage probability of 10^{-2}. There is 25% of reduction in outage at the rate of 0.55 bits per channel use, where inter-user and user destination channels are operating at SNR of 8 dB.

References

[1] A. Sendonaris, E. Erkip, and B. Aazhang. User cooperation diversity-Part I: System description. *IEEE Trans. Commun.*, 51(11):1927–1938, Nov 2003.

[2] A. Sendonaris, E. Erkip, and B. Aazhang. User cooperation diversity-Part II: Implementation aspects and performance analysis. *IEEE Trans. Commun.*, 51(11):1939–1948, Nov 2003.

[3] R. Ahlswede, N. Cai, S.-Y. R. Li, and R. W. Yeung. Network information flow. *IEEE Transactions on Information Theory*, 46(4):1204–1216, July 2000.

[4] J. N. Laneman. *Cooperative Diversity in Wireless Networks: Algorithms and Architectures*. PhD thesis, Massachusetts Institute of Technology, Cambridge, MA, Aug 2002.