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A channel estimation based opportunistic scheduling scheme in wireless bidirectional networks

Zhaolong Ning, Qingyang Song*, Yang Huang, Lei Guo

College of Information Science and Engineering, Northeastern University, Shenyang 110819, PR China

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ABSTRACT

Generally speaking, there are two assumptions in the previous bidirectional networks. The first one is assuming that no direct transmission paths exist between the source and destination nodes due to high shadow fading or large separation. The second one is assuming that either channel parameters are pre-established or perfect global channel state information (CSI) can be obtained by the relay nodes. In this paper, we get rid of these limitations and estimate channel gains for both analog network coding (ANC) and time division broadcasting (TDBC) schemes based on outage probability. As the channel gain of each link varies from time to time in wireless networks, we first estimate the channel gain according to outage probability, then propose an opportunistic scheduling scheme to optimize the sum rate values by maximizing the minimum link transmission rate. Simulation results are presented to demonstrate the effectiveness of our channel estimation scheme, and the performance of our proposed opportunistic scheduling scheme is compared with the round robin scheduling (RRS) scheme for both ANC and TDBC schemes.

1. Introduction

The shared wireless medium is the chief factor that limits the capacity of wireless multi-hop networks. Overlapped signals in wireless communication systems have always been considered to be harmful (Ning et al., 2012a; Zhang et al., 2005a, 2005b), and much work focused on improving the performance of communication networks through investigating appropriate routing strategies (Guo, 2007; Huang et al., 2011, 2012; Jiang and Hu, 2009). However, the wireless broadcast medium enables enhanced interactions among wireless transceivers, and the emergence of network coding has shifted the paradigm under which network communications are designed. In recent years, numerous transmission schemes were studied in the context of bidirectional network, including conventional network coding (CNC) scheme, physical-layer network coding (PNC) and time division broadcast (TDBC).

An example is shown in Fig. 1, where node S_1 intends to send one packet to node D_1, and node S_2 intends to send one packet to node D_2. x_1 and x_2 are the signals transmitted by S_1 and S_2, respectively. For this topology, three time slots are required in the CNC scheme, where the relay node encodes packets after receiving them in a separate communication phase, since the relay can forward an encoded packet. Only two time slots are required for the PNC scheme. In the first time slot, nodes S_1 and S_2 transmit signals to relay node R simultaneously, and the relay node performs PNC operation and broadcasts the overlapped signals to destinations D_1 and D_2 in the second time slot. It is a simple fact in physics that when multiple electromagnetic waves come together within the same physical space, they can add. The mixed wave is a form of network coding performed by nature. The greatest difference between CNC and PNC is the coding pattern. In CNC, the relay node performs the XOR operation on bit streams within the network layer (or other higher layers). In contrast, the encoding is processed within the physical layer in PNC. Besides, CNC can encode more than two packets during one time slot, however, it has been proved in Wang et al. (2011) that at most two packets can be decoded in PNC unless adopting sophisticated self-interference cancellation techniques. There are two benefits from the utilization of PNC. First, the overall system throughput increases because it takes less time to convey the same amount of data. Second, the network system saves energy because there are fewer transmissions due to simultaneous transmission in the multiple access step. For the TDBC scheme, node S_1 transmits signal x_1 to nodes R and D_1 in the first time slot, and node S_2 transmits signal x_2 to nodes R and D_2 in the second time slot. In the third time slot, the relay node combines the received signals and broadcasts the overlapped signal to destinations. Since the destination node has received two copies of the information from the source node, the transmission reliability in the TDBC scheme is higher than that in the PNC at the cost of one additional time slot used.

* Corresponding author. Tel.: +86 13804008890.
E-mail address: songqingyang@ise.neu.edu.cn (Q. Song).

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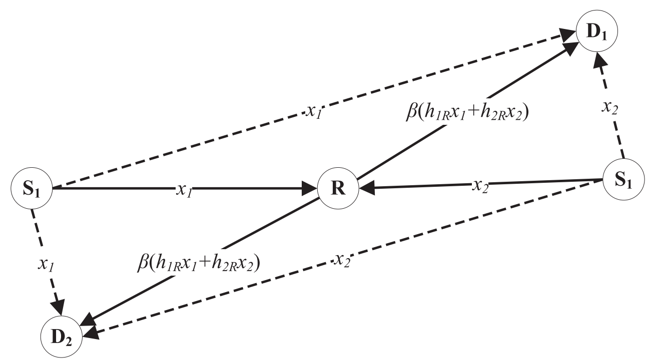

Fig. 1. Amplify-and-forward based bidirectional network scheme, where β is an amplification factor.

Two general methods of PNC and TDBC have been investigated, namely the denoise-and-forward (DF) method (Jeon et al., 2011; Gong et al., 2009; Wang et al., 2013) and the amplify-and-forward (AF) method (Upadhyay and Prakriya, 2011; Yi et al., 2010; Wang et al., 2011; Su and Zhang, 2009). The former decodes the superposed signal at the relay node before forwarding. Although this scheme avoids noise amplification and signal attenuation, it requires strict synchronization among source nodes which is difficult to realize in practice. The latter simply amplifies the superposed signal at the relay node without any decoding operation. The AF method of PNC is often referred as analog network coding (ANC), which is easy for implementation since it only requires coarse synchronization. Therefore, we focus on the AF-based bidirectional network in our work.

It has been demonstrated in Su and Zhang (2009) that the network coding performance is largely dependent on the joint decision between the physical layer and the medium access control (MAC) layer. Because greedy network coding reduces spatial reuse, which limits throughput improvement, a trade-off has to be made between the network coding gain and the spatial reuse. To optimize network performance, the network should adopt scheduling schemes in the MAC layer. However, the existing scheduling schemes used in CNC are not suitable for PNC and TDBC. This is because PNC and TDBC are performed in the physical layer, while CNC is handled by the XOR in the network layer. Therefore, we propose a ANC based sum-rate optimization opportunistic scheduling scheme in this paper.

The remainder of this paper is organized as follows. Section 2 introduces the related works, and Section 3 presents the system model for both ANC and TDBC schemes. Section 4 describes the outage probability estimation scheme. Section 5 states the opportunistic scheduling strategy. Section 6 gives simulation results and Section 7 concludes this paper.

2. Related works

Opportunistic scheduling schemes have been studied in recent years due to the network channel gains varying from time to time among different links (Ning et al., 2012b). In Jeon et al. (2011), the authors proposed an opportunistic user selection scheme in a three-way wireless communication system for PNC, which is based on the minimum distance between the signal points for the superposed signals. However, with high-order modulation, this method could be rather complex and difficult to implement. In Gong et al. (2009), the authors studied a joint scheduling problem for MAC layer and physical layer, and considered a more realistic model than that of Jeon et al. (2011) with practical modulation schemes such as MPSK and MQAM. However, to maximize the throughput during one transmission, all available packets are selected, regardless of the channel conditions between the source and destination nodes, which is actually a greedy coding method. In Upadhyay and Prakriya (2011), the authors investigated the performance of an AF-based two-way relay network by employing opportunistic scheduling with fairness among users, and formulated the scheduling policy to minimize the outage probability. Expressions for the upper and lower bounds on the outage probability, together with the average sum rate, were derived for a flat Rayleigh fading scenario. However, it was assumed that the signal to interference plus noise ratio (SINR) value was at an unrealistically high level. In Su and Zhang (2009), the authors maximized network throughput subject to the fairness requirements based on both CNC and ANC schemes, and quantitatively analyzed the network throughput gains brought by these two types of wireless network coding schemes for a variety of ad hoc network topologies with different routing strategies. After that, a heuristic joint link scheduling, channel assignment, and routing algorithm that aims at approaching the optimal solution was proposed. However, the efficiency of the greedy algorithm proposed in that paper was low, and spatial reuse was not considered.

Since the network performance improved by opportunistic scheduling algorithm largely depends on the instantaneous SINR values, which reflect channel state information (CSI) directly, it would be beneficial if the scheduling methods can be adopted according to the CSI. However, there are mainly two assumptions in the previous researches. The first one is assuming that no direct channels exist between the source and destination nodes due to high shadow fading or large separation (Jeon et al., 2011; Gong et al., 2009; Upadhyay and Prakriya, 2011; Yi et al., 2010; Wang et al., 2013). The second one is assuming that either channel parameters are pre-established or perfect global CSI can be obtained by the relay nodes. Some other channel estimation schemes are based on low layer measurements, such as received signal strength (RSS) (Torkestani and Meybodi, 2011; Kharraz et al., 2012); however, collecting and analyzing low layer data are generally more complex than considering the link connectivity, which can be estimated within the MAC layer (Bamis et al., 2008).

Meanwhile, some literatures have provided methods to estimate CSI and analyze the impact of CSI estimation errors in bidirectional network. In Gacanin et al. (2012), the authors presented a closed form bit error rate (BER) expression with imperfect knowledge of CSI based on the channel estimation error, and demonstrated that the imperfect channel estimation due to additive white Gaussian noise (AWGN) has less impact on self-information removal than the imperfect channel tracking. In Zhang et al. (2012), the authors proposed an iterative channel estimation scheme based on parallel interference cancellation (PIC) at the receiver. They demonstrated that semi-blind channel estimation together with PIC detection is very promising for large signal constellations. In Wang et al. (2012), the authors proposed a method to study the impact of CSI estimation error by considering imperfect self-interference cancellation at the source nodes, which is based on soft and hard estimation of the transmitted data symbols with a low computational complexity. However, the network model in these literatures is different from us, and they did not consider scheduling schemes.

In this paper, we get rid of the two assumptions stated above and propose channel gain estimation schemes for both ANC and TDBC based on probability of outage (PoO), then we present a sum-rate optimization opportunistic scheduling scheme according to the channel gain estimation results.

3. System model

We consider a multi-user bidirectional network consisting of $2K+1$ single-antenna nodes (K pairs of users and one relay), as depicted in Fig. 2. This network topology can be regarded as a