Simple Relay Selection for Wireless Network Coding System

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Abstract

Broadcasting nature of wireless communications makes it possible to apply opportunistic network coding (OPNC) by overhearing transmitted packets from a source to sink nodes. However, it is difficult to apply network coding to the topology of multiple relay and sink nodes. We propose to use relay node selection, which finds a proper node for network coding since the OPNC alone in the topology of multiple relays and sink nodes cannot guarantee network coding gain. The proposed system is a novel combination of wireless network coding and relay selection, which is a key contribution of this paper. In this paper, with the consideration of channel state and potential network coding gain, we propose relay node selection techniques, and show performance gain over the conventional OPNC and a channel-based selection algorithm in terms of average system throughput.

I. Introduction

Channel coding concept is used to mitigate the influence of noise and interferences in the physical layer. In [1], it was also shown that we can get coding gain in higher layers. Compared to the routing and scheduling technique which are devised to prevent bottlenecks of packets from different senders, Alswede et al [2] showed a way of making use of this disadvantage, and showed that the achievable rate can be increased by applying certain in-network processing at an intermediate node when packets are received at the node simultaneously. This type of in-network processing is called network coding. Routing can be treated as a special case of network coding which is a simple permutation. Network coding has received attention since it can enhance system throughput and reliability. For throughput, network coding technique can take advantages of bottleneck effect of data at the intermediate node in wireless communication to improve the system throughput [3]. And Ghaderi et al. [7] has shown that there are reliability benefits by applying network coding technique in their system. Li et. al. [4] show that the maximum achievable rate can be achieved by linearly combining input packets at an intermediate node. Random linear network coding [5] (RLNC) and opportunistic network coding [6] (OPNC) have been known as one of prcatical implementations. RLNC randomly chooses elements from a finite field as the coefficients for a linear combination of packets.

As a practical implementation of OPNC, Katti et al. [6] introduced a scheme, COPE, that takes advantage of broadcasting nature of wireless communications. COPE employs practical network coding techinique for unicasts in wireless mesh networks to improve total throughput. They showed through experiments that with OPNC in the system, there exist significantly improvements in throughput of wireless networks with UDP traffic.

In this paper, we consider the following two factors. One factor is the channel state information which can affect the performance of a system. The other factor is how to deal with multiple intermediate nodes which can perform network coding simultaneously. This kind of networks, without certain decision methods at the intermediate nodes, we cannot guarantee the throughput gain by using network coding in the system as in [6]. In the area of cooperative communications, Bletsas [8] introduced a distributed network path selection algorithm which involves opportunistic relaying to transmit information by using an objective function of channel state at the relay nodes. Contrast to [8] that deals with a cooperative communication system consisting of single source, single sink and multiple relays, we consider a system with multiple relays and multiple sink nodes. With this system model, we combine the opportunistic relaying with network coding and propose a relay selection measure which considers the channel state between the relays and the destination nodes. We compare the performance of proposed algorithms with conventional OPNC and opportunistic relaying in terms of throughput.

The rest of this paper is organized as follows. The system model is described in section II. In section III, we propose several relay selection schemes for network coded transmission. The performance of these schemes are compared with the conventional relay selection schemes. The results are verified by simulations in section IV. We draw our conclusions in section V.

II. System model and scenario

A. Transmission from source to neighbor nodes

We have a source node S, a set of relay nodes R, and a set of sink nodes D. Assume that S has n packets to transmit to corresponding sink nodes (i.e. $S_a = \{a_1 \cdots a_n\}$), R includes l nodes ($R = \{r_1 \cdots r_l\}$), and D includes m elements ($D = \{d_1 \cdots d_m\}$). Each packet $\alpha_i \in S_\alpha$ has its own destination address to be delivered. We assume all nodes in R and D are within communication range from S. At first, the source node S broadcasts n packets to all the nodes in its range. Every neighbor node is assumed to be able to overhear data traffic of other nodes as in OPNC, and stores all the overheard packets in its buffer. A relay node r_j receives a set of packets, α_j , and a sink node d_i gets a set of packets, β_i. Both α_j 's and β_i's are subsets of the original n packets. ($n \geq |\alpha_j|, |\beta_i|, \forall d_i \in D$ and $\forall r_j \in R$).

After the source transmission is over, there may be packet loss at sink nodes due to a poor channel between source and those nodes. Hence we need retransmissions for those missing packets. If the source retransmits data, the packet loss may occur again. If there exists a relay node (r_j) with better channel response than the source node S, it may be better for r_j to retransmit the packet to the destination. It is assumed that the relay set R receives all the packets that the source sent. We then have

$$\bigcup \{\alpha_j \mid \forall r_j \in R\} = S_\alpha. \qquad (1)$$

This means that the union of packets of all relay nodes is identical to the set of all the packets from from the source S. The number of packets from the source should be less than the buffer size to prevent overflow.

B. Retransmission procedures

1) Reception report from the destinations to the relays: Each of relay and destination nodes operates in opportunistic listening mode which stores every received packets for a given period regardless of the destination. After the source transmission, each destination d_i in D creates a report packet, and sequentially broadcast it to all the relays. Since there are multiple sink nodes in D, each sink node uses a random access method to avoid collision. The report packet is sent to the source and the relay nodes. The information in the report packet consist of the source node ID, the current node ID, multiple original sink node IDs of received packets, and pilot signal.

The report packets which are transmitted from sink nodes are overheard by nodes in R. Based on the information in these report packets, each relay r_j in R estimates the channel state to each destination, and calculate the objective function which will be used for selecting the re-transmitting node.

2) Retransmission procedure from a relay node: After the packet report, each r_j has the knowledge of the packet set β_i of the destination d_i, and estimates the corresponding channel response h_{ji} between r_j and d_i ($1 \leq i \leq m$; $1 \leq j \leq l$). Using that knowledge, each relay r_j checks its buffer for possible network coding. If there are

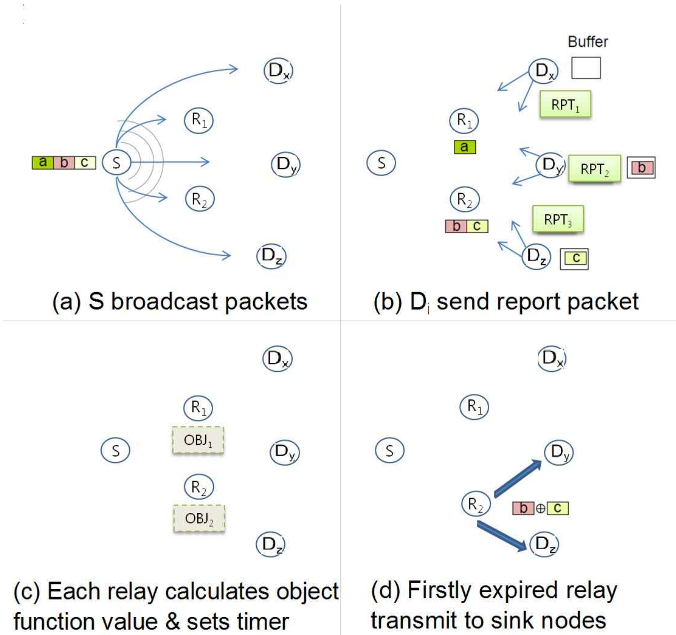

Fig. 1. Simple example: There is one source node, two relay nodes and three sink nodes. Source has three packets, a; b; c, each has its own sink node address. Packet a is heading to Dx and both b and c are to Dy and, Dz respectively. Intermediate relay nodes are able to perform opportunistic network coding

more than two packets, it checks whether the packets can be network coded or not. If positive, the relay node r_j creates a coded packet using the OPNC algorithm. In the OPNC algorithm, the optimal network coding can be constructed based on how many packets r_j can mix to create a network coded packet (i.e., how many destinations would receive packets).

However, since the operation does not consider channel response between the relay node rj and its destination node in D, the decoding failure may occur with high probability when the channel quality is poor. This failure will cause a retransmission and degrade system performance such as throughput. To improve the throughput, we need to modify the selection rule by considering the channel state. We will define an objective function which depends on the number of packets that can be network coded as well as the channel state, and the retransmission node will be chosen by this function. Opportunistic relaying was introduced in [8], which proposed a distributed relay selection algorithm for a system which has multiple relays and single sink node. The basic idea is that each relay node sets up an internal timer which triggers transmission. This timer is a function of the channel responses of source-relay and relay-sink pairs, and it is given by

$$T_i = \frac{c}{h_i} \qquad (2)$$

where T_i is the timer function of the relay R_i, and c is a constant. There is possibility of hidden node problem, which can be mitigated by adjusting the constant c in (2). Another method to reduce the hidden node effect is that we use the minimum channel response instead of harmonic mean value [8]. Hence h_i is defined as a minimum of the channel responses of S ~ R_i and R_i ~ D, which is given by

$$h_i = \min(\|h_{SR_i}\|^2, \|h_{R_iD}\|^2). \quad (3)$$

When the timer has expired, the relay node is expected to broadcast a channel reservation message to neighboring relays to prevent other relays from transmission. The relay whose timer expired first broadcast a channel reservation message to the neighbors. Contrast to [8], in our model, we do not need to consider the channel between the source and the relay node since only the relay performs retransmission. This will reduce processing delay in relay node selection. Based on this idea, we propose a new distributed relay node selection algorithm combined with OPNC for the topology of multiple relays and multiple sink nodes. If we only use channel state information to choose the proper relay node, which is the case of opportunistic relaying algorithm, we would not achive enough throughput.

Fig. 1 shows an example of overall system scenario. There are single source S, two relays, and three sink nodes. Three packets a, b, and c should be delivered to Dx, Dy, and Dz, respectively.

First, S broadcasts these three packets sequentially. The relays R1, R2 and the sink nodes Dx, Dy, Dz overhear packets and store them in their buffer. What each sink node overheard and stored in their buffers are depicted in the righ-side box of the figure. After first phase, using OPNC algorithm, we can find the amount of innovative information that each relay node can deliver to sink nodes: R1 is able to sends 1 packet to Dx, and R2 can deliver 2 innovative packets to Dy and Dz in one time frame using network coding.

Suppose $h_1 = h_{1x}$ and $h_2 = \min(h_{2y}; h_{2z})$. Then we can then calculate theoretical throughputs κ_1 and κ_2 for R_1 and R_2 respectively,

$$\kappa_1 = \log_2(1 + \|h_1\|^2 \cdot \rho) \quad (4)$$
$$\kappa_2 = 2 \cdot \log_2(1 + \|h_2\|^2 \cdot \rho)$$

where is the transmit signal to noise ratio. The multiplication factor of 2 in (4) is due to the network coding at R_2. If $\|h_1\|^2 > \|h_2\|^2$, then opportunistic relaying algorithm will choose R_1 to transmit packet 'a' to Dx. However, if $\kappa_2 > \kappa_1$, it may be better to choose R_2 for retransmission.

III. PROPOSED RELAY SELECTION TECHNIQUES

In this section, we propose relay selection techniques for network-coded transmission, which is based on a timer function.

Let us denote the minimum channel response at the j-th relay node from itself to sink nodes by h_j, and the set of packets that can be network-coded by K_j. K_j is obtained from OPNC algorithm at each retransmission phase. To improve throughput, we consider channel state information, h_j, as well as the number of packets, $\|K_j\|$, that each r_j can deliver simultaneously by network coding. We assume that the objective function at the relay node r_j is a function of h_j and $\|K_j\|$, which is denoted by $f(h_j, \|K_j\|)$. The objective function 'f' is a increasing function of each variable. The minimum channel response, h_j, from relay r_j to a sink node is a modified version of (3) since only the relay nodes can retransmit. We then have

$$h_j = \min_{d_i \in D} \|h_{ji}\| \quad (5)$$

$\|K_j\|$ is the number of packets that r_j uses to create a network coded packet. Both variables, h_j and $\|K_j\|$, may vary from one frame to another. Since the objective function is proportional to h_j and $\|K_j\|$, a relay r_j which has either larger channel response or larger number of packets that can be network coded will have high probability of using the channel. We can then define the internal timer value at the relay node rj as

$$T_j = \frac{c}{f(h_j, \|K_j\|)} \quad (6)$$

We will use the timer value in (6) in choosing a proper relay node for retransmission. This means that a node with smaller internal timer value will transmit earlier than other relays, which is a kind of decentralized selection scheme. We compare three relay selection algorithms using different internal timer functions. First, set the objective function f as a modified version of opportunistic relaying algorithm of [8]. In this case, the function 'f' at a certain relay node r_j depends only on the channel states between the relay and its corresponding sink nodes (5). Those sink nodes are the destinations of the packets that can be network coded among all overheard packets in r_j . As mentioned before, we use only the channel between a relay node and a destination node unlike the original opportunistic relaying scheme of (3). Thus the 1st kind of timer function for the modified opportunistic relaying algorithm is given by

$$T_j^A = \frac{c}{\min_{d_i \in D} \|h_{ji}\|} \quad (7)$$

As in the method of OPNC in choosing the best network coding option to increase system throughput, we use only $\|K_j\|$ as a variable of the objective function. In this case, we can create the the 2nd timer function as inversely proportional to $\|K_j\|$, which is given by

$$T_j^B = \frac{c}{\|K_j\|} \quad (8)$$

This means that the relay whose $\|K_j\|$ is the largest would occupy the channel. Moreover, logically thinking, the 3rd proposal of timer function is given by

$$T_j^C = \frac{c}{h_j \cdot \|K_j\|} \quad (9)$$

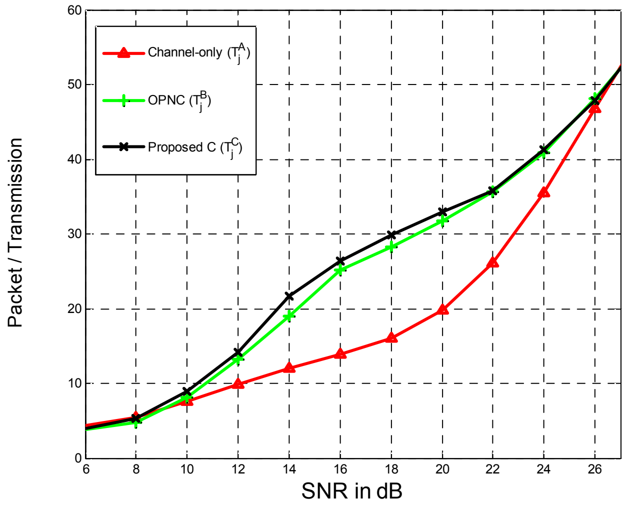

Fig. 2. Average system throughput comparisons

As we mentioned, c is an empirical constant to control the collision among the relay nodes. Typically c has a value of a few micro seconds [8]. Each relay node r_j uses T_j's as its internal timer value. A relay node whose internal timer expires first broadcasts a signal to neighbor relays to stop their transmission to reserve the channel, which is a first-come-first serve policy. The sink nodes that successfully overhear the network-coded packets decode the packets using theirs own stored data, and update their decoding results. Until there are no more packets to be delivered from the relay nodes to the sink nodes, the procedure is repeated.

IV. SIMULATION RESULTS

We perform the simulation in the following enviroment: independent Rayleigh fading channel model, packet size of 1KB/packet, 16QAM modulation, 50 relay nodes, 100 sink nodes those which are randomly distributed around the source node. All nodes are assumed to be in the communication range from the source node.

The system throughput is defined as the total number of successfully delivered packets to sink nodes per transmission for a given system. Fig. 2. shows the system throughput comparison of each algorithms. As mentioned before, algorithm C (T_j^C) selects a relay node, based on $||K_j||$ and the h_j value simultaneously, so it can be thought of as a combination of Algorithm A and B. In Fig. 2, it is observed that the performance of Algorithm C is better than previous two algorithms.

V. CONCLUSION

In this paper, we proposed a new relay selection scheme which is combined with wireless network coding. By taking advantage of broadcasting and opportunistic listening capability of wireless networks, feedback based retransmission schemes are devised and tested. From the simulation results, it was shown that the algorithm based on the minimum channel gain and the OPNC coding gain shows the best performance in terms of average system throughput. It was also observed that the proposed relay selection scheme performs better than the conventional schemes especially in the medium SNR regime. It appears that the proposed approach is promising in that it is a practical wireless network coding scheme with high throughput.

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REFERENCES

[1] D. Tuninetti and C. Fragouli, "Processing along the way: forwarding vs. coding," ISITA Conference, Parma 2004
[2] R. Ahlswede, N. Cai, S.-Y. R. Li, and R. W. Yeung, "Network information flow," IEEE Trans. on Information Theory, vol. 46, pp. 1204-1216, 2000.
[3] M. Charikar and A. Argawal "On the Advantage of Network Coding for Improving Network Throughput," IEEE Information Theory Workshop, Oct. 2004
[4] S.-Y. R. Li, R. W. Yeung, and N. Cai "Linear network coding", IEEE Transactions on Information Theory, Feb. 2003
[5] T. Ho, M. Medard, J. Shi, M. Effros, and D. R. Karger "On randomized network coding," Proceedings of the Annual Allerton Conference, 2003
[6] S. Katti, H. Rahul, W. Hu, D. Katabi, M. Medard, and J. Crowcroft, "XORs in the air: practical wireless network coding," IEEE/ACM Transactions on Networking, June. 2008.
[7] M. Ghaderi and D. Towsley, J. Kurose, Reliability Gain of Network Coding in Lossy Wireless Networks, INFOCOM 2008, The 27th Conference on Computer Communications.
[8] A Bletsas, A Khisti, DP Reed, and A Lippman "A simple cooperative diversity method based on network path selection," IEEE Journal on Selected Areas in Communications, 2006