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A Dynamic Queue Management for Network Coding in Mobile Ad-hoc Network

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Abstract

Network Coding (NC) is a new paradigm for network communication. In network coding, intermediate nodes create new packets by algebraically combining ingress packets and send it to its neighbor node by broadcast manner. NC has rapidly emerged as a major research area in information theory due to its wide applicability to communication through real networks. Network coding is expected to improve throughput and channel efficiency in the wireless multi-hop network. Many researches have been carried out to employ network coding to wireless ad-hoc network. In this paper, we proposed a dynamic queue management to improve coding opportunistic to enhance efficiency of NC. In our design, intermediate nodes are buffering incoming packets to encode queue. We expect that the proposed algorithm shall improve encoding rate of network coded packet and also reduce end to end latency. From the simulation, the proposed algorithm achieved better performance in terms of coding gain and packet delivery rate than static queue management scheme.

Keywords: *Multi-hop wireless network, network coding, MAC, Queue management*

1. Introduction

In today practical communication networks information delivery is accomplished through routing: network nodes simply store and forward packets and processing is only accomplished at the end nodes. Network Coding (NC) is a recent field in information theory that breaks with this assumption: instead of simply forwarding data, the intermediate nodes may combine several input packets into one or several output packets. This way, NC allows the intermediate nodes to generate new packets by combining those received on their incoming NIC. The potential advantages of NC over routing include resource (*e.g.,* bandwidth and power) efficiency, computational robustness to network dynamics [1].

After the initial theoretical studies in wired networks, the applicability and advantages of network coding in wireless networks were soon identified and investigated extensively [2 - 7]. Though the noiseless assumption no longer holds for wireless communications, the wireless medium does provide a unique characteristic conducive for network coding operations | the inherent broadcasting capability.

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Again this can be best understood by another classic example of the “Alice and Bob" topology as in Figure 1. Assume that Alice (node S1) and Bob (node S2) want to exchange their information represented by message ‘a’ and ‘b’, respectively, and each link has a static capacity of 1 bps. It can be readily seen that under the traditional routing paradigm, four time slots are needed to exchange the bits through relay R, which sequentially forwards one bit at a time. On the contrary, with network coding, R can XOR the two bits together and transmit the coded bit. Because of the broadcast nature of wireless medium, this transmission can be heard by both Alice and Bob. Alice then receives a + b, and recovers Bob's bit b as b = a + (a + b).

Similarly Bob can recover a. Therefore only three time slots are needed in this case, which represents a 25% throughput improvement for both parties

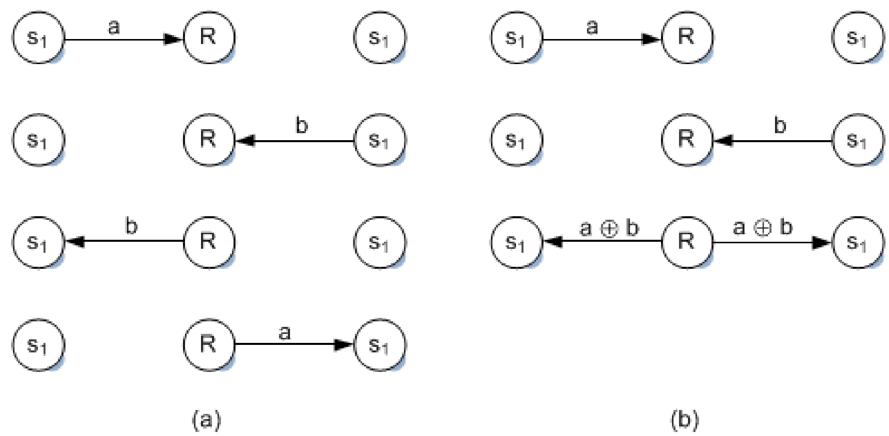


Figure 1. The benefits of network coding in wireless ad-hoc networks

(a) Four time transmissions are needed for S1 and S2 to exchange messages through relay node R by plain routing. (b) With network coding, R can XOR the bits and broadcast the coded messages to both parties simultaneously, reducing it to three time slots.

Recently, many researches are carried out to employ network coding to wireless networks to enhance the capacity for both multicasting and broadcasting [6-10]. But there are several research issues that should be considered to implement network coding in the wireless multi-hop networks. The wireless network characteristics and required factors for network coding process would be research issues. Because wireless network are highly likely to experience packet loss due to high bit error rate, collision and cross-channel interference, those characteristics make it more likely fail to decode coded packets arriving at a the receiver. Additionally, there is a low likelihood of receiving multiple packets, and thus there is a small low coding opportunity can be performed in low traffic load conditions. For high traffic loads, on the other hand, there is a high likelihood of receiving multiple packets simultaneously, and thus there is a high probability that network coding can be performed, which would improve network performance. There would be, however, increased packet loss probability from the broadcast of coded packets. All of NC scheme use queue for further network coding. In this paper, we proposed dynamic queue management scheme to improve coding opportunity and reduce end-to-end delay of packets.

Also we evaluated the efficiency of network coding in terms of variables such as the traffic load and the number of connections.

2. Dynamic Queue Management for Network Coding in Wireless Ad-hoc Network

2.1. Conventional network coding scheme

The concept of network coding is introduced in [6], which basically allows the intermediate nodes to combine the received packets for generating encoded packets on the outgoing link.

Network coding scheme utilizes characteristics of wireless medium and packet encoding techniques as follows.

(a) **Opportunistic Hearing**: Wireless is a broadcast medium, creating many opportunities for nodes to overhear packets when they are equipped with omni-directional antenna. Network coding scheme sets the nodes in promiscuous mode makes them snoop on all communications over the wireless medium and store the overheard packets for a limited period T.

(b) **Opportunistic Coding**: The key question is what packets to code together to maximize throughput. A node may have multiple options, but it should aim to maximize the number of native packets delivered in a single transmission, while ensuring that each intended next-hop has enough information to decode its native packet. Simple opportunistic coding is that mixes packets to single NC packet which next-hop node address are different. But the relay node has little knowledge of its neighbor whether it has enough packets to decoding or not. Thus receiver node would fail to decode NC packet to native packets. It also results increasing loss of packet and waste of network resources.

To transmit n packet, $p_1, \ldots p_n$ to next hop nodes $r_1, \ldots r_n$,

A relay node can XOR the n packet together only if each $r_1, \ldots r_n$ are different.

2.2. Dynamic queue management scheme

In conventional NC scheme, it has two type of queue: one for encoding (Q1), the other is for decoding (Q2). When a packet received, relay node puts the received packet to Q1 and Q2. When NC packet arrived, relay node decode it with packets in Q2. Packets in Q1, after waiting certain period (time T), are transmitted to outgoing link, if they could not be mixed coding packet.

Conventional queue management scheme is effective when traffic load is high, but traffic load is low, packets in Q1 waiting more time for encoding to single coded packet. This cause long end-to-end delay time.

To enhance delay time, we proposed dynamic encoding queue management in NC scheme.

Basic concept of the proposed scheme is that manage number of waiting packet in Q1 according to incoming traffic load. This will increase coding opportunity and reduce average packet waiting time in Q1.

The proposed algorithm has 3 variables: Nmax, Tmax, state for Q1 management. Where Nmax is the maximum number of packets in Q1, and Tmax is the maximum waiting time of packet. Every time T which is smaller than Tmax, encoding timer handler is called. In encoding timer handler, a packet in the head of S1 is de-queued.

If de-queued packets enable to encode to NC packet, they are combined to NC packet and then transmit to outgoing link. In this case, relay node set state to “UP” because it assumed coding opportunity is high.

If de-queued packets are not encodable and state is "DOWN", relay node send it to outgoing link.

When state is "UP" and packet number of Q1 is less than Nmax and waiting time of packet in the head of Q1 is less than Tmax, relay node do nothing and maintains current state.

Figure 2 show the procedure of the proposed queue management scheme.

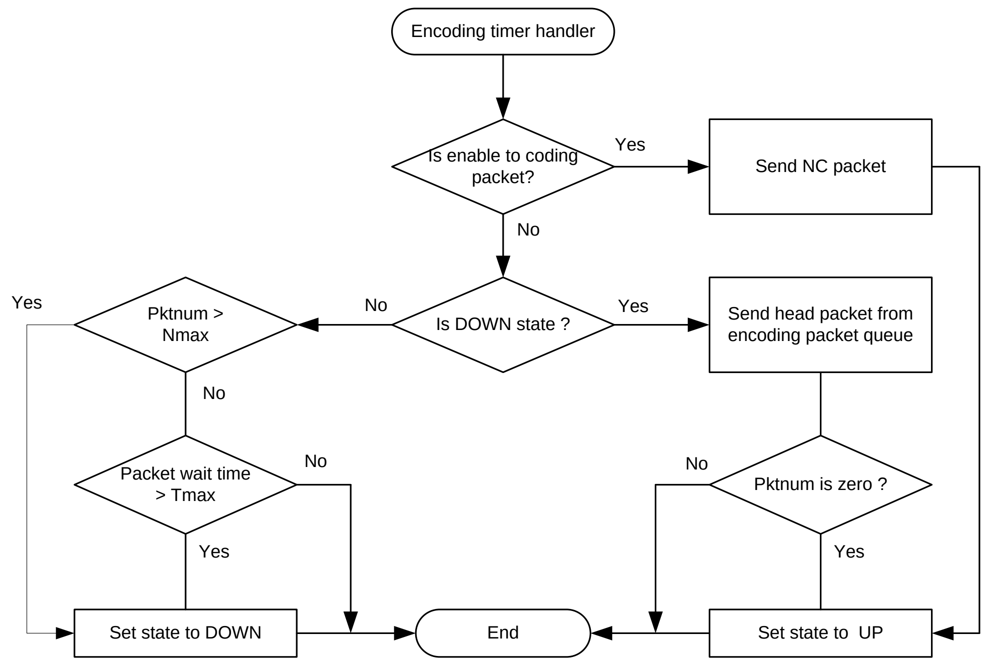


Figure 2. The flow chart of encoding Queue management

3. Network Coding Implementation for Wireless Ad-hoc Network

3.1. Network simulation environment

Network simulation is performed to investigate validity of dynamic queue management in a multi-hop ad-hoc network by. NS2 [11] was used for network simulation and network coding scheme was modeled and implemented in the routing layer and MAC layer. The network model consists of 50 wireless nodes in the form of a random topology in an area of 2.6km× 2.6km in order to examine the effects of node density. CBR/UDP (Constant Bit Rate/User Datagram Protocol) is used for traffic generation. The packet size was 1024 bytes, and the packet inter-arrival time was in the range of 0.25-0.05 sec. Therefore, the traffic load was in the range of 4- 20KBps (Kbytes per second). The wireless channel bandwidth was set to 2Mbps. The IEEE 802.11 protocol [12] was used for MAC protocol, and the wireless channel/wireless physical transmission model was used for the channel model. The two ray ground model was used for the radio transmission model. The transmission range and the interference range of wireless nodes were set to 250m and 500m respectively. Table 1 shows the simulation parameters. The performance metrics used for the performance assessment is as follows:

Packet delivery ratio, m/n : m is the number of packets successfully received at the receive node, and n is the number of packets transmitted by the source node.

Network coding gain, G_{NC} : the formula for G_{NC} is as follows.

$$G_{NC} = \frac{F_{classical}}{F_{classical} - F_{NC}}$$

F_{NC} and $F_{classical}$ are the number of packet transmissions, with network coding and without network coding respectively.

Decoding success rate, m_d/m_e : me is the number of received encoded NC packets, m_d is the number of successfully decoded NC packets.

Table 1. Parameters for wireless network simulation

Parameter	Value
Traffic source	CBR / UDP
Routing protocol	AODV
MAC protocol	IEEE 802.11
Channel bandwidth	2M bps
Radio channel model	Two-way ground
Packet size	1024 bytes
Number of nodes	50

3.2. Numerical result

To investigate the effects of the number of connections on network coding, the number of connections was varied from 5 to 40 while traffic load of connection is 4Kbps. Figure 3 shows the packet delivery ratio of with NC, without NC and with proposed NC scheme. The packet delivery ratio steadily decreases when number of connections is 15. This is due to the fact that the channel load became full when number of connections is 15, causing packet loss during transmission. From the simulation result, the dynamic queue management scheme gives 10 - 20% improvements in performance compared to with NC.

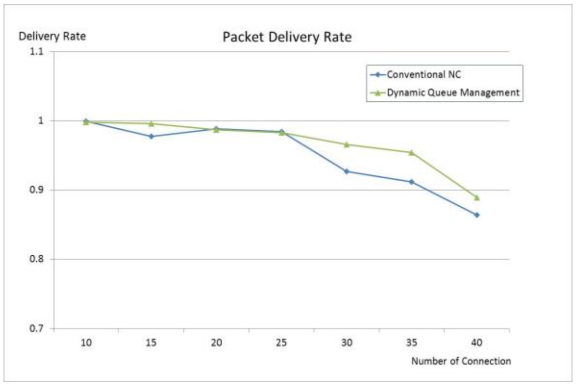


Figure 3. Numerical result (Packet delivery ratio)

Figure 4 shows average end-to-end delay of three schemes. It can be seen that dynamic queue management, the delay is lower than conventional NC scheme in entire simulations. This is because intermediate nodes, upon receiving a packet, don't forward it right away but performs buffering in order for network coding.

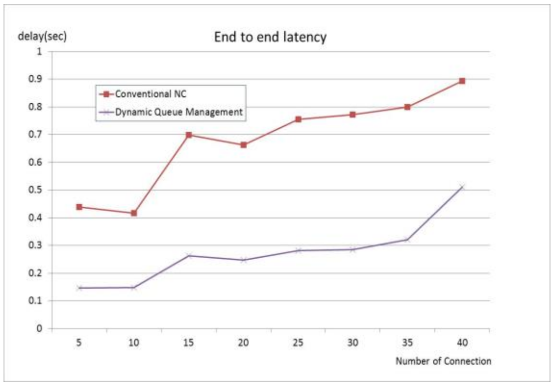


Figure 4. Numerical result (Average end-to end latency) (Tmax = 300ms, Nmax = 5, Traffic load of one connection = 4Kbps, number of nodes: 50)

Figure 5 shows coding gain of conventional NC scheme and that of the proposed queue management scheme and figure 6 shows decoding NC packet success rate of coded packet of the conventional scheme and the proposed scheme.

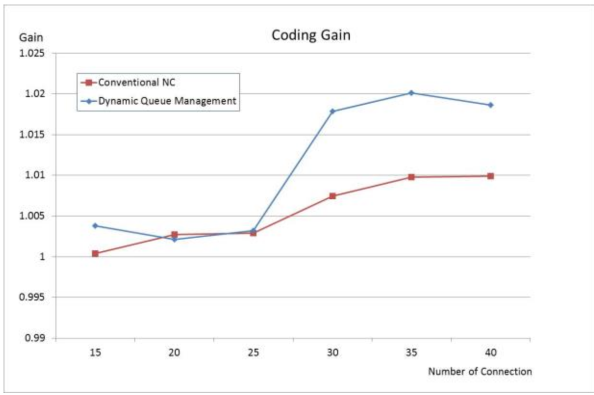


Figure 5. Numerical result (Coding Gain - Tmax = 300ms, Nmax = 5)

In the dynamic queue management scheme, The value of Nmax would impact performance of NC. To investigate effect of Nmax, we performed simulation with various values of Nmax: 5, 10, 15. Figure 7 (a), (b) depict packet delivery ratio and average end-to-end latency. From the simulation result, higher value than 5 will degrade performance of dynamic queue management scheme. This is because that high Nmax value lead packet to wait in Q1 too long time. Thus end-to-end latency was increased dramatically. 5 of Nmax show the best performance in terms of packet delivery ratio and latency.

The simulation results showed that, the proposed scheme, the higher the traffic load, achieves the more efficient the use of the wireless channel, compared with conventional NC scheme.

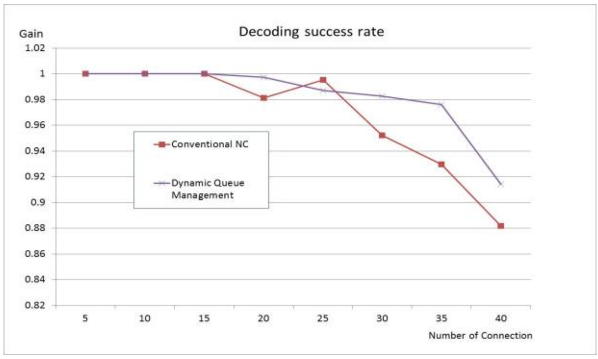
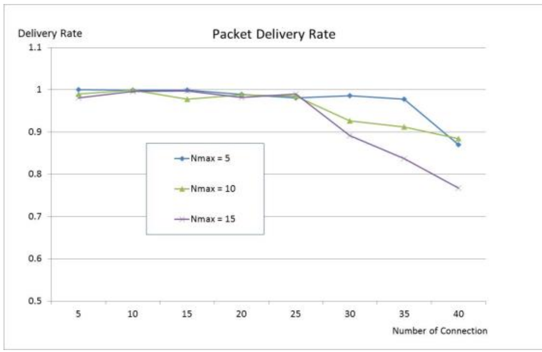
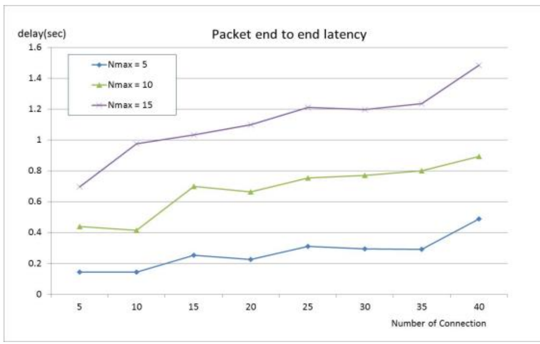


Figure 6. Numerical result (Tmax = 300ms, Nmax = 5)

(Decoding coded packet success rate - number of nodes: 50, traffic load of all connections is 4Kbps)



(a)



(b)

Figure 7. Experimental result (Tmax = 300ms, Nmax = 5, 10, 15)
(a) Packet delivery ratio, (b) End to end latency (number of nodes: 50, traffic load of all connections is 4Kbps)

4. Conclusion

Multi-hop wireless ad-hic networks have been widely considered as promising approaches to provide more convenient Internet access due to their easy deployment, extended coverage, and low deployment cost. However, providing high-speed and reliable services in these networks is still challenging due to the unreliable wireless links, broadcast nature of wireless transmissions, and frequent topology changes.

Network coding (NC) is a new technique that improves network capacity and power consumption by allowing mobile node to compresses multiple packets into a single packet for transmission. Therefore, many relevant studies are currently actively underway. Queue management plays an important role in NC to encoding multiple packets. In this paper, we proposed new queue management scheme that manage encoding queue dynamically based on ingress traffic load. The proposed queue management scheme was implemented in the network layer and the routing layer in a multi-hop ad-hoc network for performing network coding. Its suitability was analyzed using a simulation model. The experimental results showed that there were little coding gains from the use of the proposed network coding compared to conventional network coding, and there was also a drawback that the delays increased. However, end-to-end latency is dramatically reduced than conventional network coding scheme and achieve more throughput and packet delivery ratio.

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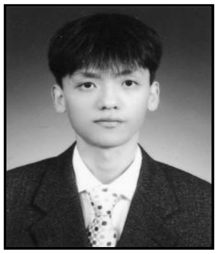

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