Network Coding Based Packets Queue Operation for Wireless Ad Hoc Networks

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***Abstract*— Wireless communication is a technology that simplify the daily life and to narrow the distance between people. Unfortunately throughput limitation of wireless networks is limiting the performance of wireless networks. In order to increase the throughput of the wireless network, network coding has been proposed to increase the throughput of network. Unlike conventional store-and-forward method, network coding is a method that intelligently combines packet from difference flow to reduce the transmissions while transfer the packets instead of just relay packets without doing any additional processing. Ad hoc on-demand distance vector routing protocol (AODV) will be used to discover route for packets from source to destination in wireless ad hoc networks. The simulation of wireless ad hoc network with and without network coding will be conducted in MATLAB. This paper introduces the development of simulation to illustrate the performance of network coding in wireless ad hoc network. The simulation will calculate the transmit packet time according to the size of the packet. Lastly, average network throughput performance between network coding and store-and-forward is shown and compared.**

Keywords - Network Coding, AODV, Wireless Ad Hoc Network, Performance, Queue menagement.

I. INTRODUCTION

Wireless network is widely used in common industries such as sensor network, vehicular network, and mobile ad hoc network due to the mobility, wide coverage, robustness, reliable connectivity, and other features that simplify the network distribution [1]. However, wireless communication has limitation on link quality and throughput. Adaptive modulation is proposed to overcome the link quality, while network coding is proposed to increase the throughput of the networks [2, 3]. In traditional wireless ad hoc networks, two nodes which are distanced from each other will communicate through intermediate relay nodes, the intermediate nodes only stores and forwards the packet to the next node and it cannot conduct further processing on the packet. The more hops each travel route has, the probability of packet collision increases. Thus, it is imperative that researchers invent methods and protocols to increase network throughput. Network coding is one of the efficient methods which aim to achieve that.

Network coding is a technique that effectively combines several packets received from different data packet flows and to forward the packets in fewer transmissions [4]. Network coding allows the intermediate nodes to make additional process toward incoming packets to minimize the number of transmissions and improve network throughput [5]. The broadcast nature of the wireless medium has been noted as a fertile ground for developing network coding solutions since when a node transmitting data, the nearby wireless node overhears the packet can get the packet too [6, 7, 8].

Fig. 1 and Fig. 2 show the scenarios of two nodes exchanging information through a common intermediate node without network coding and with network coding. Consider the case shown in Fig. 1, where node A and node C want to communicate with each other through intermediate node B. Assume that the channel is ideal so the packet 'd'elivery is guaranteed. In other words, there is no disconnection and collision that causes the packet 'd'rop. Intermediate Node B in Fig. 1 uses the conventional method, which is store-and-forward the data packet without doing any additional process on the packet. This method requires 4 transmissions to deliver their respective packets to the destination, that is packet 'd' flow from node A to node B and node B forward to node C, and packet 'e' flow from node C to node B, then node B to node A.

Now consider how node B delivers the packets if network coding is employed. First, node A will send packet 'd' to node B as shown in Fig. 2, but note that node A will retain packet 'd' temporarily. When node B receives packet 'd' from node A, it does not forward the packet 'd' to the next hop node C immediately. Node B will instead save the packet 'd' to the buffer and wait for packet 'e' transmit from node C. Node C will send packet 'e' to node B and it will also store packet 'e' temporarily. After node B receive packet 'e', node B combines 'd' and 'e' by XOR between both packet, and the packet then broadcasts 'd' XOR 'e' to both node A and node C. Note that the packet remain same packet size length after XOR, for example packet 'e' and packet 'd' have 10 bits respectively, after XOR both packet will give the result of 10 bits for the packets size length. Recall that node A still has packet 'd' saved, so it extracts packet 'e' from what it just received from node B.

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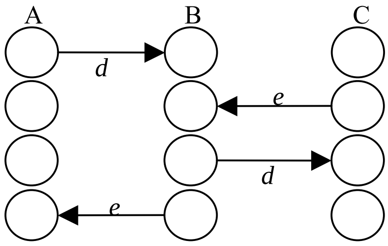

Figure 1. Conversation bi-directional forwarding.

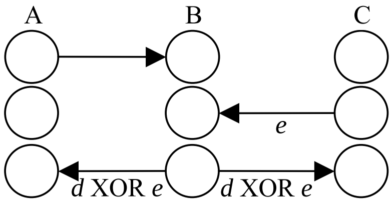

Figure 2. Network coding bi-directional Conversation.

Node C also does the same thing as node A, it extracts packet 'd' from the received reduce XOR packet. Network coding based forwarding requires only 3 transmissions to transfer 'd' and 'e'. Network coding is reducing 1 transmission time slot if compare with the conventional store-and-forward method, therefore the throughput is improved approximately 33.33% when compared to conventional method.

II. Benefits of Network Coding

Network coding is a method that will effectively improve the throughput of network significantly. For the case when 2 nodes want to exchange packets through intermediate node, network coding is able to reduce the number of transmission to delivered all packet to the destination compared with conventional method. Throughput is an important performance measure for network coding in this situation. The reduced transmissions can save the resource for other transmission as power is a limited resource in ad hoc networks. Besides, reducing the number of transmissions will decrease the chance of collision, packet drop, and retransmission. Network coding offers throughput increment not only for unicast flows, but also for other traffic patterns, such as multicast. Unicast flow is a data packet traffic patterns that is a source having a packet send to a single destination, whereas multicast data traffic flow is a source having a packet sends to multiple destinations.

Throughput is an all round important performance measure for network coding networks. A typical method of performing throughput measure is to transfer a big file in network and measure the time taken to complete the task. Throughput of the network will be calculated by dividing the total number of byte received with the total transfer time.

Coding gain is the ratio of the number of transmission require for non-network coding to the minimum number of transmission require used by network coding node. Coding gain for Bi-directional exchange packet for case in Fig. 2 is 4/3, the coding gain for this case is 1.33, and this value is used to determine which route has more coding opportunities.

III. Background and Related Work

In Wireless ad hoc networks communication, the function of a node is to send, receive, and forward data packets, but this method provide very limited network throughput. Therefore, this inspires researchers to study on how to increase the network throughput.

Network coding is one of the available methods to increase throughput of the networks, and another advantage is network coding does not need to change wireless hardware because it only makes changes on protocol. Network coding research began for more than 10 years ago and is proposed by R. Ahlswede *et al.* There are many researches on network coding until now. Most of the research on network coding was focused on theoretical throughput analysis.

The practical of network coding in wireless network has been introduced and it works in wireless mesh network environment [9].

There are studies for analog network coding which consume less transmission number compare to digital network coding, the intermediate node will still receive signal from other nodes while the nodes are communicating with another node, but analog network coding require more complex computational algorithm to work on, and analog network coding is not mature yet to work in practical environment. Besides, the topics on coding-aware routing protocol are widely discovered by many researchers. Coding-aware is an area of network coding that aims to create more coding opportunities according to the topology and environment of the networks. Therefore actively react to increase network coding chance is importance to improve the network coding method [10, 11, 12, 13].

A. Overview on AODV

AODV is an On-Demand routing protocol for ad hoc Network [14]. Route from source to destination is established by AODV while sources want to send packets to destination. When a node is in idle mode, it will periodically broadcast HELLO message to obtain information of neighboring nodes. When the node wants to send a data, it will broadcast route request (RREQ) to its neighbors and will continue to broadcast until it reaches the destination. While doing RREQ a routing table is generated for all nodes. Once RREQ reaches the destination, the destination node will backtrack along the route back to the source. The destination node chooses the route based on the sequence number and metric of the RREQ received on the destination. The value of sequence number will determine whether the route is the latest route, and the metric shows the hop count from source to destination.

Fig. 3 and Fig. 4 show the process of route discovery and route reply process. AODV will discover the fastest path for the source to send packet to destination. Fig. 5 and Fig. 6 show the flow chart of the wireless node request route to destination. At Fig. 5, when a node wants to send data to a

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destination, it will look up for the route table for the hop to destination. If it cannot find the routing path in route table, the first thing to do is to search for the routing path.

The RREQ packet will be readied at the network layer, and then MAC layer will tell physical layer to send the RREQ packet. Before the physical layer sends the RREQ to the neighbor, it will count down to make sure the node is ready to send the RREQ packet, if the node is ready then it will broadcast the RREQ packet. In Fig. 6, when a node receives a packet, it will determine what is the packet type, after that the node will reply with an ACK packet to inform the delivery success. The node will then check the packet whether it is RREQ or RREP, because the packet received might be a route reply from destination instead. The packet contains not only the type of the packet, but it also contains the destination or source ID.

At the node's network layer, the node decides whether the packet should be sent as RREQ or RREP to the next hop or it will stop forwarding whereby the node itself is the source or destination. This summarizes the procedure of AODV routing protocol. AODV routing protocol is widely used for the wireless networks due to the stability of the method as it can discover a new route for packet when an old route is disconnected in the middle of transmission. The performance of how fast the network can recover from route disconnection is vastly evaluated by researchers.

However, network coding toward RREQ and RREP packet is not considered because it is very hard to decide whether the packets can be XOR or not, and the increase of transmission is not significant to cover the overhead increase due to the additional complexity in computation.

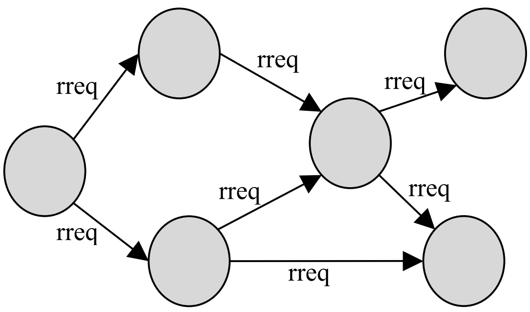

Figure 3. Request for route process.

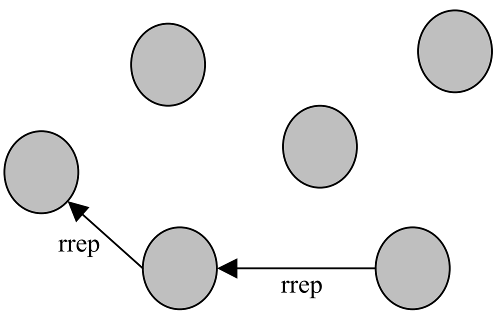

Figure 4. Reply route process.

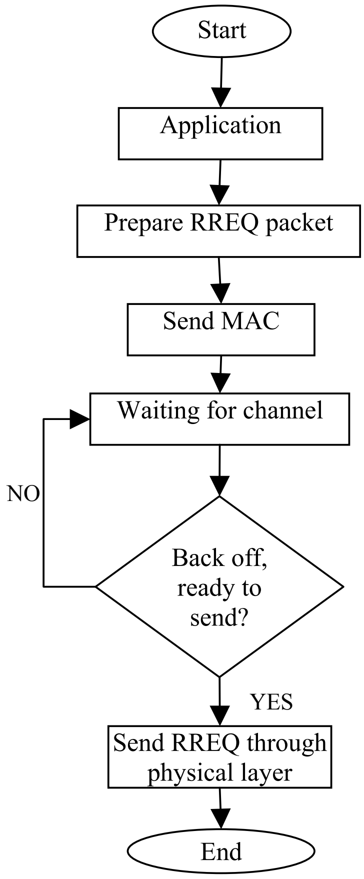

Figure 5. Broadcast RREQ.

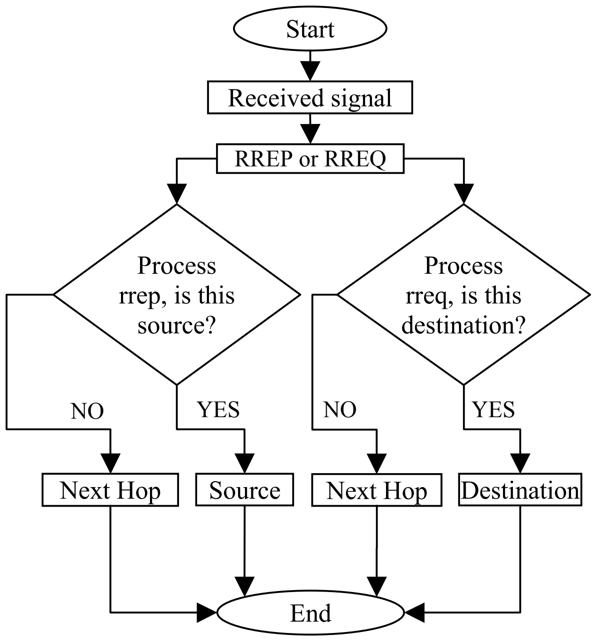

Figure 6. Received RREP and RREQ.

B. Network Coding in AODV

Although network coding is implemented in AODV routing protocol, the control messages on AODV such as HELLO, RREQ and RREP will not fully utilize the network coding. The reason is that this packet cannot gain benefit from network coding. Although there is scenario when 2 nodes will send the RREQ or RREP in bi-directional, but because the node does not know the destination of the packet and the next hop for the packet, network coding fails to establish when the flow is unclear. This is because the intermediate node doesn't know the correct packet to be combined. Also, the situation may become worse if a lot of RREQ and RREQ packet will distort due to the wrong combination of packet.

IV. NETWORK CODING IMPLEMENTATION

In this section, the development of network coding with queue management is shown in detailed. For traditional store-and-forward network, the intermediate node will forward the packet immediately once the node receives the packet [15, 16]. In this paper, the proposed method delays for a while so the other packet that can be coded into a single packet instead of directly forwarding the packet [17].

A. Queue Management and Packet Management at Intermediate Nodes

The queue management of this paper uses the first in first out (FIFO) method. Fig. 7 shows the flow chart of a node when sending packet. Before the next packet in waiting list transmits, the node will search the packet pool to find for a suitable packet that can be merged with another packet to perform network coding. The packets at the back of the waiting list can only gain benefit by merging with the first packet in the waiting list. FIFO can prevent a packet from being stuck in the waiting list for too long as it would be unfair.

The node will then send a request to send (RTS) packet to the next hop to check whether the node is free, if the next hop replies clear to send (CTS), it means the next hop is ready to receive data. Before that, if the packet is the only packet in the waiting list, it will wait for another 0.01 second. This delay may lower the throughput but if there is an incoming packet that can perform network coding, the throughput gain from the reduced transmission will compensate the throughput losses in the waiting time.

When the node receive CTS packet from next hop, the node will prepare the first packet in the packet pool for the transmission, but if the node fails to receive CTS, it means the next hop is busy communicating with another node, as such the node will try to send RTS again to the next hop until it reaches the maximum tries of RTS. The packet will drop if the maximum tries of RTS is met. The criteria of having network coding chances are decided by evaluating the route for the packet.

Fig. 8 shows the receiving procedure of every node. When a packet is received by a node, it will check the packet type, whether it is a single data packet or network code data packet. Next, the node will check the route on the packet, if the node cannot be found in the packet route, it will drop the packet because the packet is not meant for this node, and it received the packet due to broadcast nature.

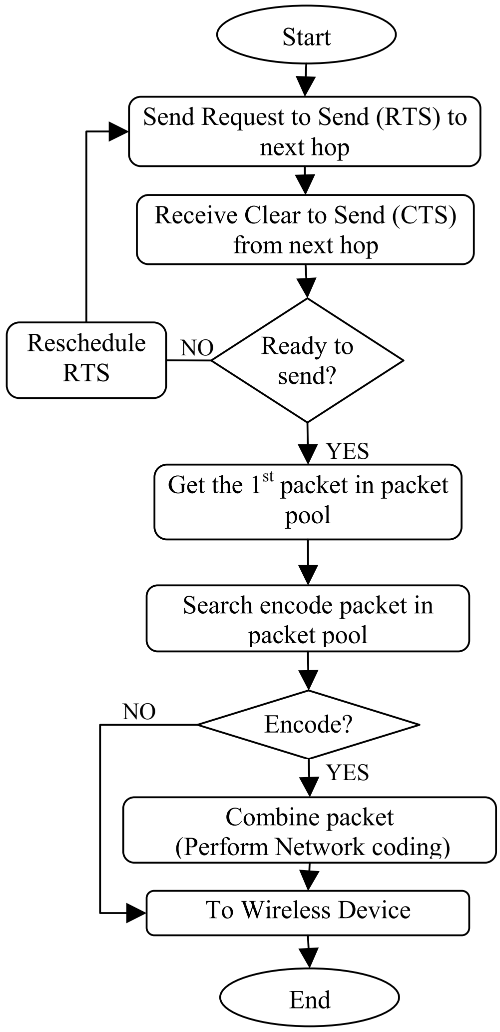

Figure 7. Flow chart of sender.

The receive packet will be decoded into desired data packet if the packet received is a network coded packet. Lastly, if the packet is not at the destination node yet, it will be added into MAC waiting list to forward to next hop.

Algorithm 1 shows the queue process for packet at the intermediate nodes, the node will search for the packets and send out together.

Algorithm 1 Network Coding output queue at node i

```
1: for m = 1 do
2:    for n > 1 do
3:        if packet(m) XOR packet(n) qualify then
4:            packet(m)=packet(m) XOR packet(n)
5:        end if
6:    end for
7:    update queue list(i)
8:end for
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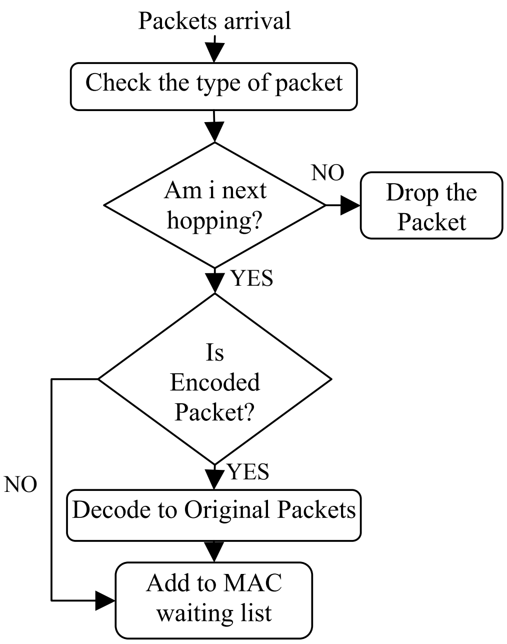

Figure 8. Flow chart of receiver.

B. *Packet Sending from Source*

At the beginning of the simulation, packets are generated for the source to be sent to the destination. The packet will be sent out when the next hop is free or idle. The sending timing of the packet from source nodes can be set accordingly. Packet that has already known the route to the destination will send out from source. Otherwise, the route towards the destination will be discovered by AODV routing protocol.

The packet sending from source will divide into smaller piece of data, for example a 50kb file will separate into 10 pieces of 5k data packets. The data packets send from source will directly be transmitted to the next hop if knowing the data route. This is due to the packets send from a source does not have a chance to be coded. A packet from a source, it is clear that no other node have this packet beside source node, therefore other nodes do not have the packet to extract another packet from coded data.

In wireless ad hoc networks node, if the source node has lots of difference packets wish to be sent to different destinations, these packets will break into many pieces of smaller packets, and queue by using round-robin method. Round-robin method used to make sure every type of packets has equal sending rate, so a source node are not always sending a same type of packet for a period of time.

C. *Search Suitable Encode Packet on Buffer*

The packets received in wireless nodes will be stored in buffer, and queue management is based on FIFO method. FIFO is the method that the transmission will give the priority to the packet that arrived to the nodes first. However, a change is made on FIFO in order to implement NC. While a top priority packet, which is the first packet received prepare for transmitting, the node will search for other suitable packets in buffer to combine with, as illustrated in Fig. 9. Fig. 9 shows a node choosing a encode packet from buffer based on route of the packet. In Fig. 9, A packet '*a'* is traveled from a source node to destination, and at the middle of the route the packet will flow through node 5, node 34, and node 12. Another packet '*b'* is flow from a source node to a destination through node 12, 34, and 5. Knowing that both packet will flow through node 34, when both packets arrive, these packets will stack on the buffer of node 34 and queue by FIFO method. A node will search the entire buffer to look for suitable coding packet as shown in Fig. 7. Coding decision can be based on the route of the packet, like packet 'a' and packet 'b' at intermediate node 34, both packets can process and know that node 5 has packet 'a' and node 12 has packet 'b', therefore packet 'a' and packet 'b' will XOR to combine into single coded packet and broadcast to node 5 and node 12.

Buffer can be categorized into two types, buffer that store queue list, and buffer that store packets information of neighbor wireless nodes.

Network coding is taking advantages of broadcast nature of wireless node to gather information of neighbor node. When a node is transmitting a packet to the next hop, the wireless node around the sending node will overhear the packet as well. Conventional method will straight away drop the packets which are not for the node. However for network coding method, the packet is important information in order to create more coding opportunities. When a node is having more packet information of neighbor node received, it will lead to more network coding occur in networks.

Wireless node can inform what the packets they have received by sending packet identity together with HELLO packet, RREQ packet, and RREP packet to neighbor wireless nodes. The node can make better coding decision if the node has more packets information of neighbor nodes. Overhearing packet is a characteristic on wireless communication, and this characteristic has been fully utilized by network coding method to collect, the packet information of neighbor node.

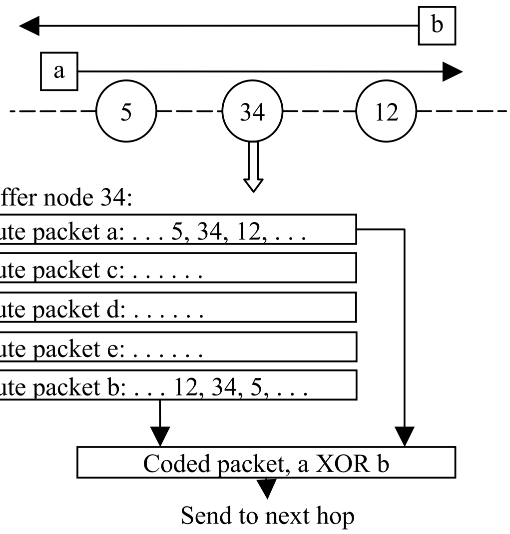

Figure 9. Selecting encoding packet.

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V. Simulation and Performance Evaluation

In this section, the details of simulation environment setup will be discussed and average throughput performance will be shown in detail.

A. Topologies

The topologies used in simulation are bi-directional forwarding in cross topology environment. Fig. 10 shows 9 nodes organized in cross topology structure. Node 1, node 5, node 6, and node 9 will be source and destination. Node 1 will transmit packets to node 5 and node 5 will transmit packets to node 1 to produce bi-directional forwarding environment, node 6 and node 9 are transmitting in bi-directional like node 1 and node 5.Four source nodes will transmit packets to four destination nodes. Four sources nodes and four destinations nodes communicating with each other via multiple intermediate nodes, the node will continuously communicate with intermediate node to simulate busy traffic.

B. Simulation Setup

The environment of wireless ad hoc network is simulated in MATLAB M-file according to the wireless ad hoc network and AODV routing protocol discussed in previous sections.

Comparison between performances of different methods in topologies of cross topology communication will be the focus of the simulation. The simulation will generate 9 nodes and the placement of these nodes is according to the Fig. 10. These nodes are assumed in static form. Center nodes 2, 3, 4, 7, and 8 acts as relay nodes for the other four source and destination nodes. In MAC layer, the simulation use IEEE 802.11 RTS/CTS to ensure the packet ‘delivery for packet transmission. Shadowing model will be used as radio propagation model. It will be used to calculate the probability for a packet ‘delivery rate.

25 packets will be generated at each source node to let all source and destination nodes communicate each other through the center node. Every node will send the packets once the center node is free or idle. The simulation will stop when all the packets are received at receiver.

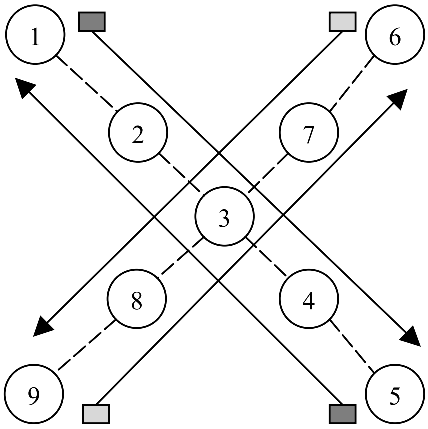

Figure 10. Bi-directional forwarding.

C. Simulation Resultand Discussion

In this section, simulation result for the cross topologies will be presented. The packet from sources will send the packet to the intermediate node, and intermediate node will handle the packet in 3 different methods. These 3 methods are traditional store-and-forward, network coding with waiting delay time (NCD) and network coding without waiting delay time (NCWD).

The simulation result shown on Fig. 11 illustrates the average throughput for whole topology. The simulation stops when all packets from source are reaching corresponding destination. Time taken to deliver all packets for NCWD is slightly higher than the NCD, but store-and-forward are far higher than NCWD and NCD.

The average throughput of NCD after 0.0029 second are higher than other methods, this is due to the chance of performing network coding at the intermediate node for NCD are higher than NCWD. Average throughput of NCWD is higher than store-and-forward method after 0.0029 second, the reason is the node had performed network coding to increase throughput.

Total number of times of packet combination for coding-aware method is 132 times, and without coding-aware is 117 time. This shows that delaying the forward packet will increase the occurrence of network coding. The average throughputs for these 3 methods are shown in Table I.

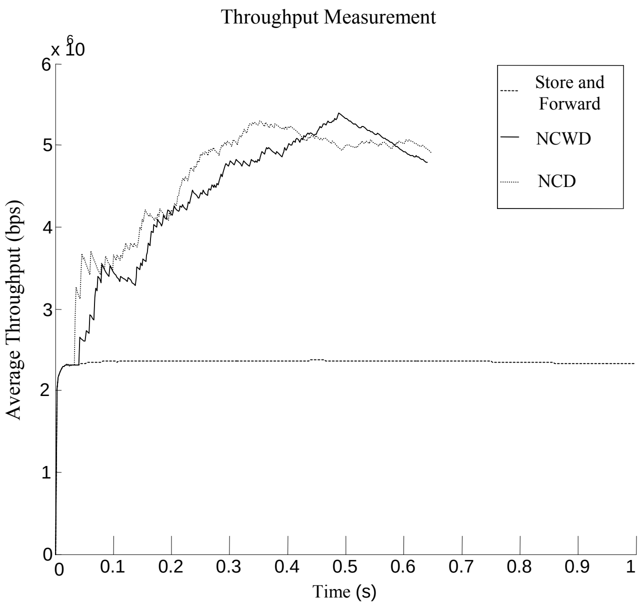

Figure 11. Average throughput.

TABLE I. Average Throughput for Simulation

	Average throughput (Mbps)
Store-and-forward	2.3251
Network coded with waiting time	4.9093
Network coded without waiting time	4.7898

VI. Conclusions

The importance of network coding to be implemented in communication network is to increase the throughput while delivering information packet to the destination. In wireless communication, the packets are transmitted through the air medium, thus the packets need to be transmitted through intermediate nodes if the source and the destination are not direct connected with each other. In this paper, the queue management at the intermediate node improves the chance of network coding at the intermediate node. An optimum wait time can increase chances of coding opportunity. The average throughput and queue management of all 3 methods are evaluated and their overall performances are compared.

For future work, route for the packet will be considered since routes of the packets affect the chance of coding. The route of packets from the source to the destination with the consideration of coding opportunities is worth to be exploring since the throughput of the networks will increased if more network coding occurs in the intermediate nodes.

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