2012 International Conference on Advanced Computer Science Applications and Technologies

Performance Measurement of Evolutionary Routing protocol in Network Coding

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***Abstract*— Wireless networks are suffer from throughput limitation, one of the effective method to solve limitation of wireless throughput are network coding which is combine several packets from difference input to a single packet size length and forwards the packet in a single transmission time slot. Furthermore, network coding also reduce energy usage in wireless devices. However, while network coding improve throughput of network it also introduce side effect such as increasing on buffer capacity and delay. In this paper, an evolutionary approach is proposed to optimize the advantages and disadvantages of network coding in a network. The simulation result shows that evolutionary algorithm is able to search multipath with minimal usage of coding nodes to balance the overhead and throughputs of network.**

Keywords- network coding; optimization; wireless networks

I. INTRODUCTION

Wireless technology is capable of helping humans increase their productivity and simplify complexities of daily work. A lot of applications benefit from wireless technology. One of such examples is a number of sensors placed around an environment to form a wireless sensing network [1] or using satellite for data transfer to all around the world and etc. Some applications are slowly evolving their communications channel from wired to wireless due to the added advantage in mobility, robustness, and simplification of networks distribution. Implementation of wireless technology into new applications is much cheaper and time saving compared to wired network. Furthermore wireless networks are easier to maintain compare to wired networks. In wireless network however, the throughput are restricted by many factors. Wireless technology need high quality links to reduce packet error rate [2], thus avoid packet retransmissions. Improvements on throughput for wireless network are essential to increase the overall performance. For that reason, network coding has been proposed to increase network throughput in wireless networks especially [3].

Network coding is a method that combines or encodes several packets from different flow that wish to hop to different destinations. In short, network coding transfer encoded packets to different destinations in single packet time slot and length. Network coding method boosts the throughput by increasing the opportunities of the coding [4, 5]. An increase in coding opportunities also increase the throughput of the network, but these may also cause the delay on the packet to reach the destination [6].

Fig. 1 shows how network coding increases the network throughput by comparing with the conventional transfer method. Consider node *1* and node *3* wants to communicate with each other, but their communication cannot extend to each other's range, so they use intermediate node, node *2* at the center as their relay. In Fig. 1, node *1* will send packet *a* to node *2* and then forward to node *3*, this require *2* time slot in store and forward method, another packet *b* will send from node *3* to node *2* then forward to node *1*. In total, in order to transfer packet *a* and packet *b* to their respective destinations, store and forward method used a total of 4 transmission time slots to complete the task. Meanwhile, for network coding, node *1* will send packet *a* to node *2*, and node *3* will send packet *b* to node *2*. Instead of transmitting packet *a* and packet *b* separately, node *2* will XOR both packet to a single coded packet with single packet size length, and then broadcast it to node *1* and node *3*. Node *1* has packet *a,* it send earlier so it use packet *a* to extract packet *b* from coded packet it receive, node *3* will do the same like node *1*. In total, network coding approach only require 3 transmission time slot to transfer packet *a* to node *3* and packet *b* to node *1*.

Fig. 2 shows another scenario to illustrate how network coding works in cross topology. In scenario of cross topology in Fig. 2, node *4* want to send packet to node *7*, and node *5* wants to send packet to node *8*, the scenario is similar to that in Fig. 1, whereby node *4* cannot direct communicate with node *7* and node *5* cannot direct communicate with node *8* since they are out of each other's wireless coverage range. In this case, they can only use node *6* as their relay to transfer the packet.

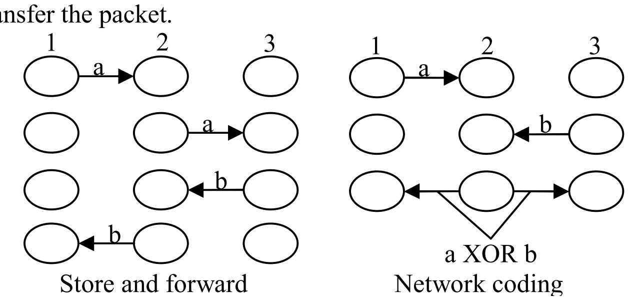

Figure 1. Store and forward and network coding approach

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DOI 10.1109/ACSAT.2012.21

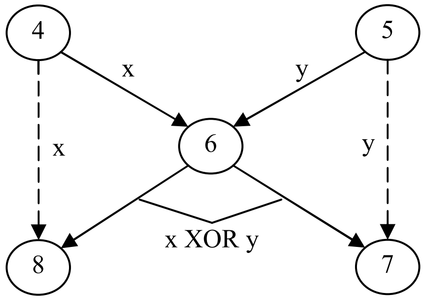

Figure 2. Cross topology

In scenario shown in Fig. 2, node *4* wants to send a packet *x* to node *7*, and node *5* want to send packet *y* to node *8*, both will use node *6* to forward their packet. When node *4* send packet *x* to node *6*, node *8* will sense these packet due to the broadcast nature of wireless network. In conventional wireless network, node *8* will ignore this packet since these packets are not for node *8*, however in network coding node *8* will keep these packet for a short amount of time. When node *5* transmit packet *y* to node *6*, it will also transmit to node *7* due to broadcast nature. After node *6* receive packet *x* and packet *y* in buffer, node *6* will make forward queue according to buffer list. Most of the protocol on wireless network use first in first out (FIFO) principle, but in network coding it is more than that. The first packet come in will send out first, additional the node will search for more packet to transmit. The node will search which packet is suitable to encode with first packet, the packet which can be decoded at neighboring destination nodes will be chosen to perform XOR. In Fig. 2 packet *x* and packet *y* will be encoded together and broadcasted to node *7* and node *8*, node *7* and node *8* has another native packet they received earlier so they can decode the packet they want from the packet they receive.

II. PROTOCOL OF NETWORK CODING IN WIRELESS NETWORK

In this section, few important issues that need to be taken care of in order to make network coding work in wireless network are discussed in detail. Network coding protocol used in the paper is modified from wireless LAN standard IEEE 802.11 [7, 8]. A practical network coding in wireless network called COPE [9, 10] has been proposed by Sachin. Few changes are made on COPE. First the waiting time on the intermediate node and the route is selected base on genetic algorithm [11]. The waiting time on the intermediate node is used to increase coding opportunities. An increase on coding opportunities also leads to increase of throughput. Besides, route of the source to destination are also searched by genetic algorithm to meet optimality on throughput and delay of packet.

A. Queue Management on Intermediate Node

The mechanism of queue management used in this paper works by appending buffer storage for every packet received of the node as shown in Fig. 3. Besides, every first received packet will have priority to forward first, which is first in first out (FIFO) principle. In store and forward network, when wireless channel is available, the node will send the head of the buffer to next hop, but for network coding mechanism the node will search the entire buffer to look for suitable packet that can encode with the head packet of the queue. All selected packets will be XOR together, and then these types of packets will be broadcasted to the next hop.

The intermediate node will wait for the next packet based on the past experience of received packet. The node will recognize the packet type and predict what type of packet will come next. The waiting delay will be allocated accordingly. Intelligently waiting for the next receive packet can increase coding opportunities. In result, throughput is increased due to the extra coding opportunities.

During the selection of suitable packet to be coded, packet size lengths are taken into consideration. Packet sizes that have similar packet size length will be coded together because smaller packet encoded with larger packets will reduce bandwidth efficiency. Therefore, every node has the ability to overhear packets with right size to react accordingly.

While network coding transfer or exchange data has two scenarios which has been discussed at previous section, bidirectional and cross exchange. Intermediate nodes can check each packet route to know or guess what packet does its neighbors has. In bidirectional data exchange scenario, every packet that passes by a node before reaching the destination will keep a copy of the packet on every stepping node. In bidirectional exchange scenario, packet can be coded without checking the buffer on next hop, because the next hop sure has a reserved packet to decode them. Fig. 4 and Fig. 5 show the scenario of that decision of XOR packet in buffer. In Fig. 4, node *1* will send to intermediate node *2* before the packet reach node *3*. At node *2*, the node will either encode both packet into a single coded packet or transmit it separately. However in this case, encoded packet cannot be decoded because next hop does not have the required packet to decode it, in this case node *2* will forward packet *a* and packet *b* separately to node *3*.

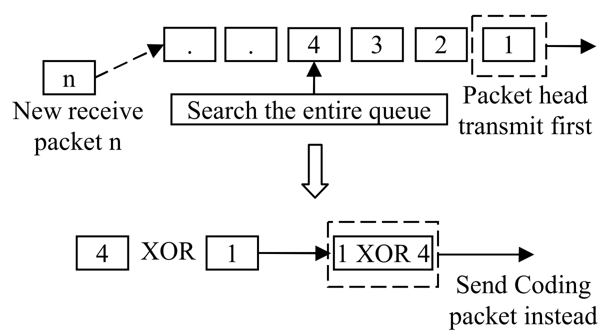

Figure 3. Queue flow in buffer.

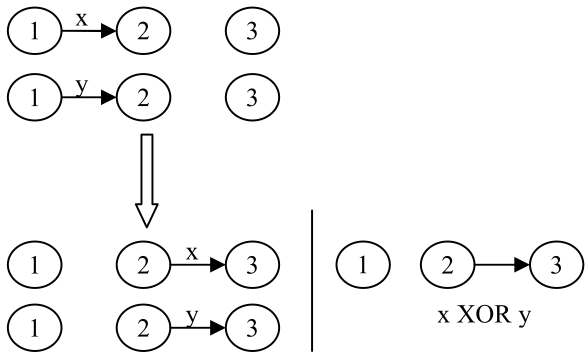

Figure 4. Packet to same next hop.

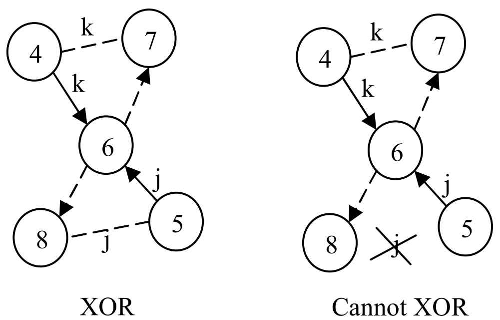

Figure 5. XOR decision.

Fig. 5 shows a scenario of packet exchange in cross topology. Node 4 wants to send packet k to node 8 and packet j will be sent through node 5 to node 7. In the process of sending packet k and packet j to node 6, node 7 and node 8 may overhear packet k and packet j, this packet will be stored for a short amount of time. If node 7 hears packet k and store it, but node 8 did not hear packet j because when node 5 transfer packet j to node 6, wireless channel for node 8 is not available. In this case, node 6 cannot XOR packet j and packet k and broadcast to both because node 8 cannot decode the packet. The buffer stored by neighbor node can be known from receiving hello packets that is used to check the connectivity between two nodes, the selected packet id will be sent alongside with the hello packet. Intermediate node will also request the packet type their neighbors' buffer to analyze the packets they can overhear. Based on these packets, the intermediate node is able to guess what packets their neighbor have and react to the situation.

The packet chosen to be encoded with the head of queue are extracted out from queue list, which means this incoming packet has the chance to combine with the queue head rather than considering the other packets that came in earlier. In such scenario, this strategy however will not add extra waiting time to the other packets, because in network coding theory the chosen packets are combined and share a single time slot.

B. Packet Buffer

In network coding scheme, buffer types can be categorized into two types. First one, the buffer used to store the queue as shown in Fig. 3, where every node will store the packet in the buffer that it receives and will forward to next hop when wireless channel is available. The details of how network coding uses this type of buffer had been discussed in the previous section. The second buffer type is the buffer that is used to store any unintentional overheard packet, this happens due to the broadcast nature of wireless transmission, every node that in the wireless range of transmitter is able hear the packet information. Fig. 6 shows the scenario of node *1* transmitting packet *a* to node *2*. So, every node in the range will hear the packet and store in buffer for coding purpose.

III. Genetic Algorithm in Network Coding

Genetic algorithm is a method that addresses optimization problems. Genetic algorithm has been used in a lot of applications and research for searching the best solution in possibly large groups in a given scenario.

The mechanism of Genetic algorithm comes from Darwin's biological evolution process. Genetic algorithm works well in solving discrete and continuous problems, theoretical research of Genetic algorithm is mature enough to solve many optimization problems such as batch process control.

Fig. 7 shows the flow chart of genetic algorithm, it consists of mutation, selection, and crossover. Genetic algorithm is a method that can search for a global optimization solution. The process of genetic algorithm starts with converting the problem into a set of chromosomes and placing this population in a desired environment. The best solution or best individual that can fit into the environment will survive longer and finally only the strongest chromosome remains. Traditionally, genetic algorithm is formulated in binary as string of 0's and 1's, this encoded method offers simple and fast calculation for the processing unit.

Since genetic algorithm has been developed, a lot of researchers also used genetic algorithm to solve different complex problems. After so many years, genetic algorithm also utilizes other encoding such as real number beside binary encoding method. Real number representation also uses the same flow shown in Fig. 7, it is just that real number representative searches a more precise solution.

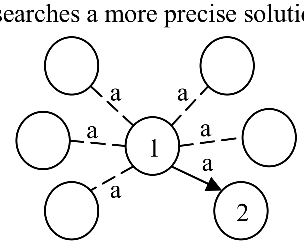

Figure 6. Packet overhearing.

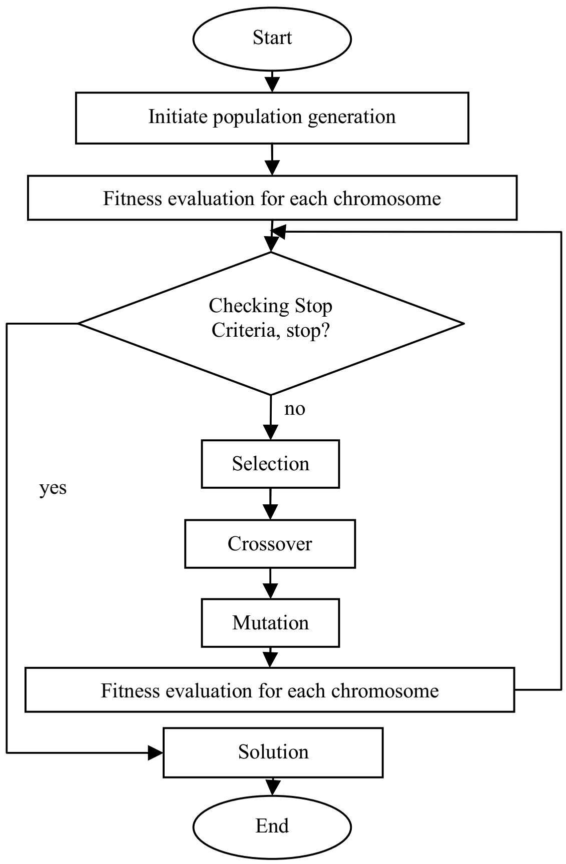

Figure 7. Flow chart of genetic algorithm

A. Chromosome Definition

Binary coded genetic algorithm is simple and fast in computational because it is straightforward and can be done by human calculation standards. Binary encoding also simplifies the calculation process for crossover and mutation operations. In binary encoding, each binary bit represents the individual's existence. On the other hand, individual's bit representation of network coding is equivalent to link existence of point to point connection [12, 13, 14]. In a given topology, every node with more than two input links has the possibility to become a coding intermediate node.

Consider a given topology in a network, the quantity of nodes that has potential to become coding node is *j*, so it will represent total number of segments in a chromosome. Let say in *j* number of total potential node, node v_i, i=1, 2, 3 …j is referring different potential nodes in *j*. Let v_i^{th} node has *m* incoming flow and *n* outgoing flow, so total bit g_i of each segment of chromosome are shown as in (1).

$$g_i = m \times n \tag{1}$$

Fig. 8 illustrates a node v_2 has 3 incoming links and 2 outgoing links, in total g_2 will have 6 bits to represent x_1, x_2, x_3 to link y_1 and x_1, x_2, x_3 to link y_2. If a packet is transmitted

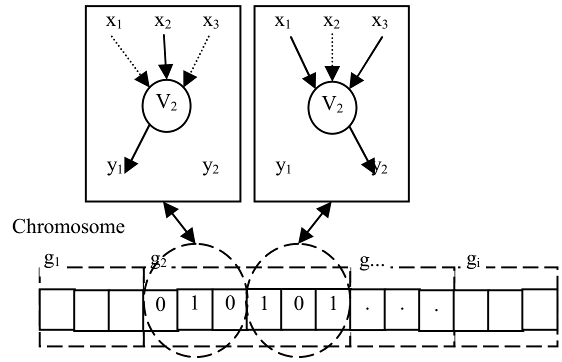

Figure 8. Chromosome representative for node *V* with 3 incoming flow and 2 outgoing flow.

into the node, binary bit 1 will represent the existence of packet in that link, else it is bit 0. In scenario Fig. 8, knowing that incoming packet from link x_1=0, x_2=1, x_3=0 will flow to outgoing link y_1. In this case, this mean that only 1 packet flow in from x_2 of the link x_1, x_2, x_3, therefore 010 is used to represent input for output link y_1, but since only 1 packet will come in so this node will not doing any encoding. However for link y_2, there will be 2 incoming flow from link x_1 and x_3, so this node will use 101 to represent the input for outgoing link y_2.

Every node in a given topology who has more than two input has chance to become encoding node, each node which has more than 2 incoming flow will potentially perform encoding. Like shown in Fig. 8 link y_2 has 2 incoming packet 101, so this node will perform encoding, that is combine both packet into single packet and send out through link y_2. Other nodes at the topology with single incoming flow will just forward the packet normally through the output link

B. Fitness Function

Fitness function is important functions in genetic algorithm, without a proper fitness function the solution will get into wrong direction, thus, unable to obtain optimize solution. Fitness function used in this paper is shown in (2).

$$F(R) = \begin{cases} n_{node}, reachable = 1 \\ n_{\max} + 1, reachable = 0 \end{cases} \tag{2}$$

Where in (2), n_{max} represent the quantity of all possible coding nodes in a given topology, n_{node} is the quantity of selected nodes to become coding nodes in the topology. The solution obtained will be tested to make sure the solution provided is valid or not. The solution is tested with using a reachable test. This means the solution is said to be valid if the packet can flow from source to destination. If the chromosome indicates the packet can flow from source to destination, that means it is reachable = 1, then n_{node} value will be fitness value for that combination of chromosome. However, if the reachable test fails, then n_{max}+1 will be the fitness value. In short, reachable test is a test to make sure if the solution found is valid or not. This solution can route the packet from source to destination. The chromosome which fails the test will be eliminated. It is easy to see that if all chromosomes are 1 then it implies a solution of the maximum possible coding node in the network. It also means all coding nodes are chosen, therefore n_{max} will never bigger than n_{node}.

C. Performance Equation

Performance measure in network is importance in order to test the performance of difference method toward network. Network coding is a method that will increase network throughput and increase the information flow in network. Throughput of the network can be focus to only measure throughput for a node or throughput for overall networks. This paper focus on measure the throughput of overall networks, the throughput equation is shown as (3).

$$Throughput = \frac{\sum p_n}{time} \quad (3)$$

P_n is total bit that success sent by every node in network at n time, n=1, 2, 3…, until all the packets in network are delivered to destination. In this paper, throughput of the overall network is importance then throughput in of a node. Another importance performance measure in this paper is end to end delay of packets. End to end delay shown in equation (4).

$$delay = \begin{cases} t_d, reach \\ 0, lost \end{cases} \quad (4)$$

T_d is the total time of a packet to travel from source to its destination, if a packet lost at the middle of the journey, the delay is counted as zero. Zero delay is more suitable to indicate the packet lost instead of using infinity to show the packet lost since infinity unable to show in graph.

IV. SIMULATION AND RESULT

Simulation setup for wireless network in this paper will be discussed in detail. The comparison of different performance measure in wireless network with network coding and without network coding will be compared. The route for packet flow from source to destination will searched by genetic algorithm. The route obtained from genetic algorithm will tested using simulations.

A. Simulation Setup

The mechanism of simulation will be modeled according to the structure discussed in the previous section. Wireless network with network coding capability will be constructed in MATLAB m-file. The protocol in the simulation will follow IEEE 802.11 standards. In conventional wireless network, the protocol used is IEEE 802.11. So in this type of network, nodes will store and forward the packet in buffer, modification on MAC layer and network layer of OSI model is made according to the network coding protocol that was discussed in previous section.

In MAC layer, the modification of how packets queue in the buffer is made to allow every node that can encode packet ready to send. Nodes can decide which packets are needed to combine together so that next hop of the packet can decode to get the original packet. While network layer on the next hop will examine the packet received, whether the packet is required to be decoded or not. The nodes also know what packet should be used to decode the received packet by reading the packet header on the packet.

As shown in Fig. 9, the topology will be used in this paper. The simulation will generate 16 nodes and arranged base on Fig. 9 topology. In scenario Fig. 9, node *s* will send a total of 30 packets to each node t_1, t_2, t_3, and t_4, in total node s will prepare 120 packets. Performance measure of throughput for overall network and end to end delay for each packet will be evaluated. The simulation will stop after the last packet has delivered node t_1, t_2, t_3, and t_4. Packets that drop at the middle of the transaction will not be retransmitted from source in order to evaluate the packet lost rate. The performance of network coding with minimized coding node using genetic algorithm will be compare with the normal network coding.

In the given scenario shown in Fig. 9, node 3, node 4, node 5, node 10, and node 11 will become potential network coding node because all of these nodes has several incoming packets flow. Using equation (1), it can be calculated that genetic algorithm needs 20 bit on each chromosome. Crossover rate of genetic algorithm is fixed at 0.7, population size is 20 chromosomes, and the stopping criterion is either the solution converges to 80% of total population or 100 generation has passed. The mutation rates are constant value of 0.01.

B. Simulation Result

In scenario Fig. 9, within 5 potential network coding node, only 3 nodes are chosen to be encoding node, the result are searched base on genetic algorithm. Dynamic mutation rate is used to prevent the solution from trapping in the local optima.

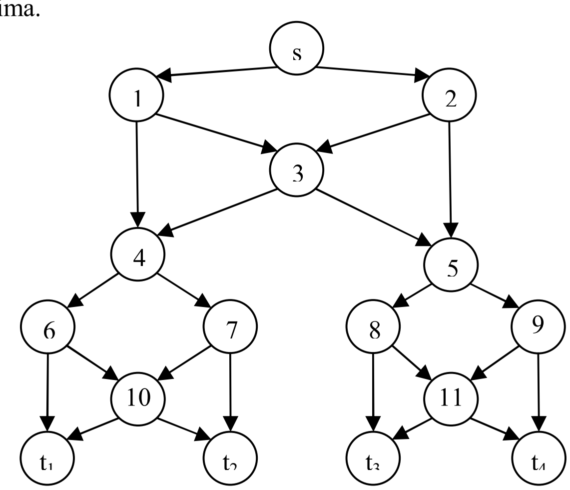

Figure 9. Simulation topology

Fig. 10 shows the average throughput of entire network. Store and forward method has lower throughput compare to network coding method. Network coding method goes through longer paths compare with store and forward method because network coding can only happen when cross section communication occurs. Route using by store and forward are heading to same next hop for all packets, so it is impossible to do network coding with that route.

Fig. 11 shows end to end delay of each packet. End to end delay for network coding is lesser, but network coding has packet lost due to UDP protocol.

V. CONCLUSION

Network coding is a method that will increase network throughput by the concept of transmitting more than one packet in a single transmission time. However, this method also introduces side effects such as delay and network overhead. Therefore, a method that can determine which node can be a coding node in a network is of main importance. In this paper, genetic algorithm is used to search optimal coding nodes in a network in order to optimize the throughput of the network and at the same time minimize the side effects brought by network coding. Simulation results show that end to end delay of network coding is reduced but still have packet lost in the middle of transmission. For future work, network coding protocol with RTS-CTS will be used to obtain more successful delivery rate and genetic algorithm that is able to search routes of multiple sources to single destination will be considered.

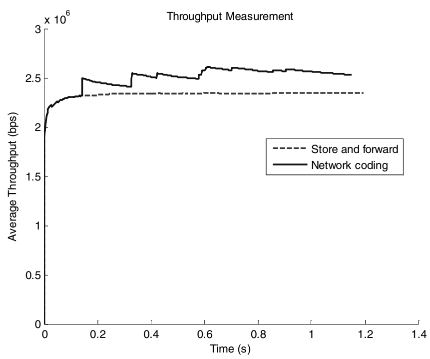

Figure 10. Average throughput.

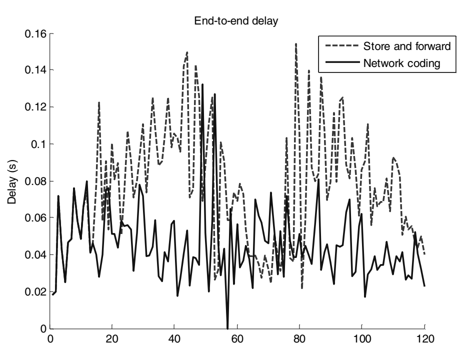

Figure 11. End to end delay

ACKNOWLEDGMENT

The authors would like to acknowledge the financial assistance of the Universiti Malaysia Sabah Research Grant Schemes, grant no. SLB0014-TK-1/2011, and Ministry of Higher Education of Malaysia (MoHE) under Fundamental Research Grant Schemes (FRGS), grant no. FRG0309-TK-1/2012 and scholarship support under MyMaster program.

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