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Development of 6LoWPAN Adaptation Layer with Fragmentation and Reassembly Mechanisms by Using Qualnet Simulator

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Abstract. This paper presents the development of 6LoWPAN adaptation layer with fragmentation and reassembly mechanisms by using Qualnet simulator. The developed adaptation layer is based on 6LoWPAN working group specifications and is added into the current existing Qualnet libraries. The IPv6 protocol stacks, however, are not currently supported and provided by Qualnet simulator. Thus, a modified version of IPv4 based addressing scheme to emulate the IPv6 protocol stacks for developing the 6LoWPAN adaptation layer has been successfully implemented and validated in Qualnet simulator. This developed adaptation layer has also been examined over the IEEE 802.15.4 standard WSN environment. The performance of the developed 6LoWPAN is evaluated and compared to WSN in terms of packet delivery ratio, throughput, average end-to-end delay and total average energy consumption.

Keywords: 6LoWPAN, WSN, adaptation layer, IEEE 802.15.4, fragmentation, reassembly, Qualnet.

1 Introduction

Wireless sensor network (WSN) IEEE 802.15.4 standard consists of many sensor nodes which are able to perceive changes in environment and perform certain actions. These sensor nodes are the tiny devices equipped with radio, microcontroller, sensors and battery. WSN is envisioned to be the future pervasive computing in different types of fields including environmental monitoring, military surveillance, and inventory tracking. Normally, the sensed information in WSN is passed to Internet and the control message returns to sensor nodes through a connection with an external network. Thus, the integrated sensor nodes with Internet will allow WSN to be widely deployed in many other fields later [1].

WSN becomes increasingly important especially in embedded applications. These applications require low cost, low power and low data nodes that communicating over

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multiple hops to cover a large geographical area. In conjunction with the emergence of large scale sensor network, it requires survivability, stability, and mobility in sensor networks. Challenges will be present especially when large scale of sensor network is deployed in future. The small and low power sensor device in WSN is not suitable to be loaded with high resource Internet protocol (IP) capabilities. Since the IP version 4 (IPv4) 32-bit address space is unable to address problems associated with the rapid consumption of network address, the introduction of the IP version 6 (IPv6) 64-bit address space gives solution to rapid growth of Internet. Besides providing huge address spaces, IPv6 is also able to support the address's auto-configuration and mobility. Hence, the IPv6 over low power wireless personal area network (6LoWPAN) is proposed to standardize the end-to-end communication between sensor nodes and external IP networks [2], [3].

One of the challenges in 6LoWPAN is how to adapt IPv6 packet over IEEE 802.15.4 standard WSN. The minimum size of IPv6 maximum transmission unit (MTU) is 1280 bytes. Since the IEEE 802.15.4 MAC layer can only support the maximum 127 bytes of data units, it fails to accommodate the 1280 bytes of IPv6 MTU. Hence, in order to provide a smooth evolution from WSN to 6LoWPAN, an adaptation layer is introduced between MAC and Network layers to provide a seamless connection between IPv6 layer and IEEE 802.15.4 MAC layer [4], [5].

In this paper, the 6LoWPAN adaptation layer is designed and developed with fragmentation and reassembly functionalities using Qualnet in order to support the packet transition across the layer protocol stacks. The fragmentation mechanism is performed whenever the received packet at the end of adaptation layer is larger than IEEE 802.15.4 MAC frame size. The packet is fragmented into smaller size with new header appended such that the payload of bottom layer is able to carry the received data. The reassembly mechanism always emerges as a pair with fragmentation mechanism. The adaptation layer will reassemble the fragmented packets whenever the received packets at the other end are identified as 6LoWPAN fragments. The Qualnet simulator, however, does not currently provide the IPv6 protocol stacks. In order to overcome this issue, the IPv6 protocol stacks for developing the 6LoWPAN adaptation layer has been successfully emulated by modifying IPv4 based addressing scheme.

The performance of the developed 6LoWPAN has been evaluated and compared to WSN in terms of packet delivery ratio, throughput, average end-to-end delay and total average energy consumption. Both 6LoWPAN and WSN developed in Qualnet simulator are based on the IEEE 802.15.4 standard. It is shown that the developed adaptation layer with its fragmentation and reassembly mechanisms in 6LoWPAN has greatly improved the throughput and packet delivery ratio as expected by 201.34% and 14% respectively compared to WSN. This enhancement is caused by the adapted datagram size that indicates the original packet size for reassembly purpose helps in the process of reassemble packet. Hence, this reduces the chances of packet lost at intermediate node when the synthesized reassembly buffer is full compared to IP fragmentation. As a tradeoff from these results, the total average energy consumption in 6LoWPAN is higher than WSN by 274.4%, since big amount of energy is consumed for sending higher amount of fragmented packet. Also, the average end-to-end delay in 6LoWPAN is higher by 33.66% which caused by experiencing two time processes of fragmentation and reassembly compared to only one time process in WSN.

The rest of this paper is organized as follows. Section 2 presents the overview of 6LoWPAN. Section 3 presents the important elements in 6LoWPAN adaptation layer. The fragmentation and reassembly mechanisms in the adaptation layer are described in Section 4. The performance evaluations for 6LoWPAN and WSN are discussed in Section 5. Finally, this paper is concluded in Section 6.

2 6LoWPAN Overview

The 6LoWPAN is defined based on the low power personal area network (PAN) with the integration of IPv6 over IEEE 802.15.4 standard. It enables IPv6 to be applied to WSN sensor nodes to provide end to end communication. There are some basic specifications distinguished in 6LoWPAN such as it supports large address space of IPv6, both short 16-bit or IEEE 64-bit extended MAC address, and operates as ad-hoc with star and mesh network topologies, besides operated in low power, low bandwidth, low data rates, low cost, and small packet size [6], [7].

Since 6LoWPAN utilized IPv6 as upper network layer for low rate wireless PAN (WPAN) its technology has attracted extensive attention with offering several technical advantages associated to IPv6. Due to the integration of IPv6, the next generation IP, with low rate WPAN, the deployment of 6LoWPAN will be easy and widely accepted in the future which is suitable to WSN. 6LoWPAN is able to support the increased number of sensor devices with the new addressing scheme. This exactly meets the need of disposing large-scale and high density of low rate WPAN. It also supports the stateless address auto-configuration since the MAC address is read automatically once sensor nodes are operated for reducing overhead configuration on the hosts comparing to stateful addressing scheme. Hence, the implementation of low rate WPAN using IPv6 technology will make the network access becomes easier compared to others [5].

2.1 Network Architecture

The sensor nodes in 6LoWPAN are defined into three types: reduced functional device (RFD), full functional device (FFD) and PAN coordinator. RFD is considered as an end device with limited function, which can only communicate to FFD. FFD can communicate with both RFD and FFD by sending its MAC layer beacon frames. PAN coordinator is considered as a coordinator to coordinate the bilateral communication by synchronizing the services through the MAC layer beacons transmission [6]. The communication between the sensor nodes in 6LoWPAN and other end of IP network nodes are shown in Fig. 1. Note that in each 6LoWPAN topology there is only one PAN coordinator.

The end device of RFD first sends packet to FFD in order to route the packet to 6LoWPAN gateway which is defined by PAN coordinator. The data of sensor nodes is then forwarded to IP network nodes the 6LoWPAN gateway [5], [8]. Normally, the 6LoWPAN network topology is designed as either star or mesh topology. In the star network topology, the role of PAN coordinator acts as a single central controller to establish communication link between sensor devices. Thus, each device has one hop left from the PAN coordinator. However, in the mesh network topology, the sensor devices can communicate with each other when their provided radio range allows them to do so. The multi hops to another hop is possible to route the message from one sensor node to the others [4].

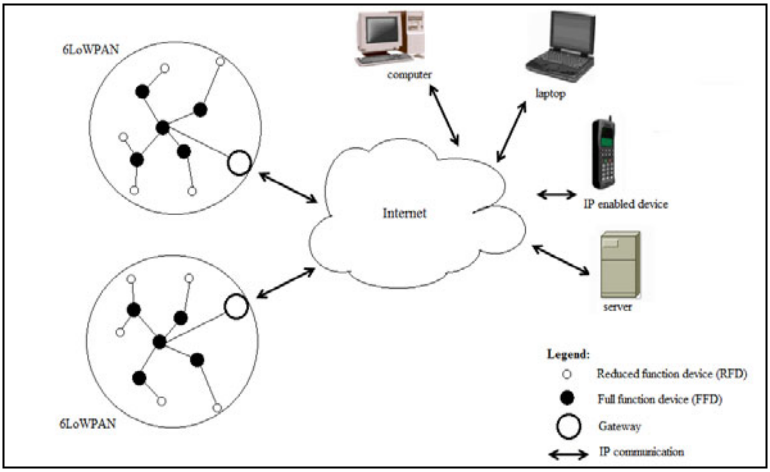

Fig. 1. 6LoWPAN network architecture

2.2 Network Protocol Stack

Internet Task Working Force (IETF) has defined 6LoWPAN adaptation layer to provide interoperability of IPv6 to sensor networks [2]. 6LoWPAN employs IEEE 802.15.4 protocol as its bottom layer standard, where layer one and layer two of 6LoWPAN protocol are adopting the IEEE 802.15.4 standard physical (PHY) and MAC layers respectively as shown in Fig. 2 [4].

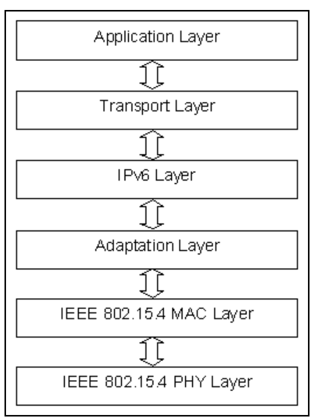

Fig. 2. The reference model of 6LoWPAN protocol stack

The intention of 6LoWPAN adaptation layer is to enable efficient communication between network layer and IEEE 802.15.4 standard layer. The maximum MAC frame size of 127 bytes is unable to accommodate 1280 bytes MTU of IPv6. The other 25 bytes of MAC frame overhead and 21 bytes of link-layer security overhead are imposed, and it leaves only 81 bytes MAC frame payload size. In upper network layer the 40 bytes of overhead is allocated for IPv6 header which reduces the 81 bytes MAC frame payload size to 41 bytes. It will be further reduced to only 33 or 21 bytes when user datagram protocol (UDP) or transmission control protocol (TCP) is taken into consideration. The general packet format of subsequent layers in 6LoWPAN protocol stack is shown in Fig. 3 [8].

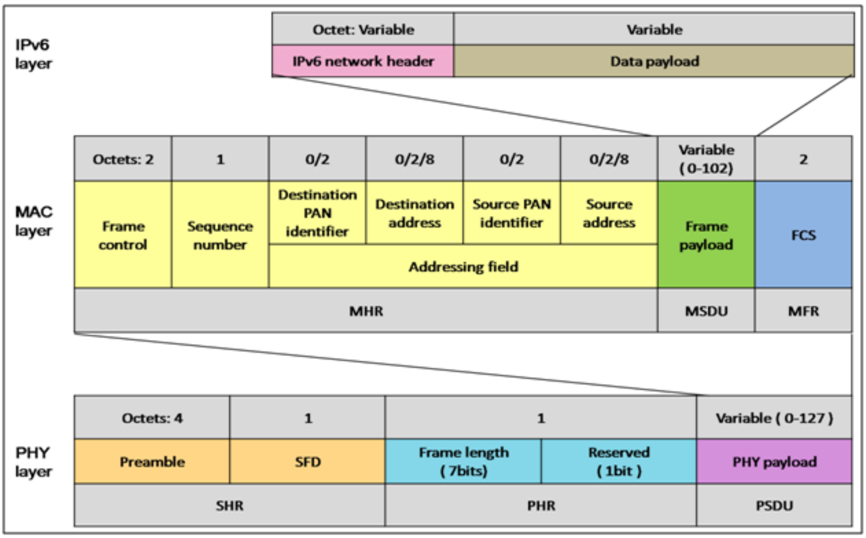

Fig. 3. The general packet format of subsequent layers in 6LoWPAN protocol stack

3 6LoWPAN Adaptation Layer

In order to implement the seamless communication between IEEE 802.15.4 standard MAC layer and IPv6 network layer, an adaptation layer between them has been proposed by 6LoWPAN working group to perform header compression, fragmentation and layer-two forwarding [2]. In the header compression mechanism, the 6LoWPAN defines HC1 encoding as an optimized compression scheme for the link-local IPv6 communication. Some IPv6 header fields such as IPv6 length fields and IPv6 addresses are eliminated from its packet as long as the adaptation layer can derive them from the headers in the link-layer frame. Furthermore, the header fields that come from adaptation, network and transport layers usually carry the common value. Hence, in order to reduce transmission overhead, header compression mechanism is used to compress those header fields into a few bits while reserving an escape value for the less appeared bits.

In the fragmentation mechanism, when the IPv6 packets cannot fit into the IEEE 802.15.4 MAC frame payload size (81 bytes), these packets are fragmented into multiple link-layer frames such that the IPv6 minimum MTU can be accommodated and as a requirement for reassembling them at the other end. The first fragmentation header (4 bytes) and the subsequent fragmentation header (5 bytes) which includes an extra byte for offset field in the 6LoWPAN fragmentation mechanism are shown in Fig. 4. The datagram size header field is used to specify the entire IP packet size before the adaptation layer fragmentation. This field value shall be the same for all link-layer fragments of an IP packet. The datagram tag header field is used to identify all fragments of a single original packet. Basically, all fragments of a single packet have the same value in this field. Another header field, the datagram offset field presents only in the second and subsequent fragments, and shall specify the offset of a fragment (increments of 8 octets) from the beginning of payload datagram. Usually the implicit value of the datagram offset field in the first fragment is zero [2].

1	1	0	0	0	Datagram size (11 bits)	Datagram tag (16 bits)

(a)

1	1	1	0	0	Datagram size (11 bits)	Datagram tag (16 bits)
Datagram offset (8 bits)						

(b)

Fig. 4. The (a) first and (b) subsequent fragmentation headers

In the layer-two forwarding of IPv6 datagram mechanism, the adaptation layer can forward the link-layer level addresses at the end of each IP hop. Alternatively, the IPv6 network layer can accomplish intra-PAN routing via layer-three (adaptation layer) forwarding, where each 802.15.4 radio hop is an IP hop [10]. To accomplish the multi hops packet forwarding, the 6LoWPAN has defined the mesh header (4 or 5 bytes) as shown in Fig. 5. Basically, the mesh header is used to standardize the way to encode the hop limit and the link layer's source and destination of the packets.

1	0	O	F	Hops left (4 bits)	Originator address (16-64 bits)	Final address (16-64 bits)

1	0	O	F	0xF	Hops left (8 bits)	Originator address (16-64 bits)	Final address (16-64 bits)

Fig. 5. Mesh header

The different mechanisms in adaptation layer require different types of header, the first two bits of the header is used to identify this header type. As shown in Figs. 4 and 5, the bit pattern 11 is used for the fragmentation header while bit pattern 10 is

0	1	Dispatch (6 bits)

0	1	0x3F	Dispatch (8 bits)

Fig. 6. Dispatch header

used for the mesh header. The bit pattern 00 is reserved to identify the coexistence of non-6LoWPAN frames. The bit pattern 01 is used for the dispatch header (1 or 2 bytes) as shown in Fig. 6.

4 Fragmentation and Reassembly Mechanisms

The developed adaptation layer between IPv6 network layer and IEEE 802.15.4 MAC layer will perform the fragmentation and reassembly mechanisms. The basic fragmentation and reassembly mechanisms are shown in Fig. 7. Since the Qualnet simulator does not currently provide the IPv6 protocol stacks, an IPv6 packet is emulated by modifying the IPv4 based addressing scheme. This emulated IPv6 packet can be developed by enlarging the 576 bytes of IPv4 MTU to the minimum 1280 bytes of IPv6 MTU. The emulated IPv6 packet needs to be fragmented before sent to IEEE 802.15.4 MAC layer. The fragmented packets will be reassembled to the original emulated IPv6 packet before sent to network layer at the other network end.

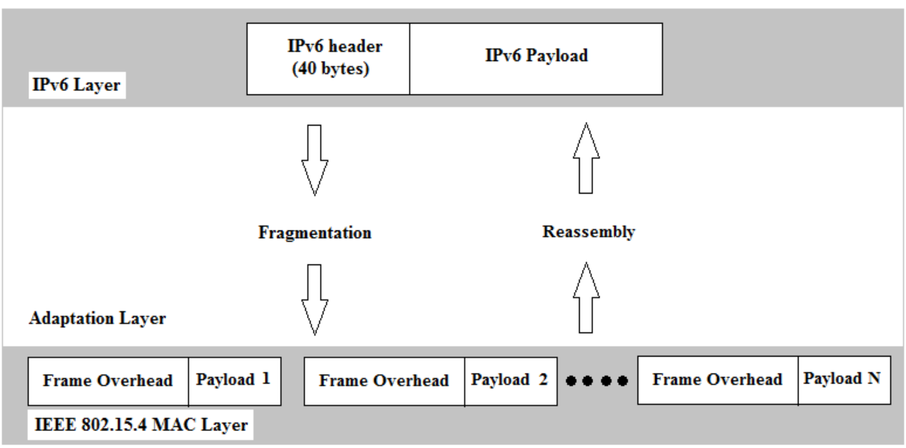

Fig. 7. The overview of fragmentation and reassembly mechanisms

4.1 Fragmentation Mechanism

Fragmentation is a process of breaking down IPv6 packet into multiple link-layer fragments. The maximum available MAC frame size is reduced to 81 bytes where 25 bytes is reserved for MAC frame overhead and 21 bytes is reserved for security overhead. Thus, a packet will only be fragmented when the adaptation layer receives an IPv6 packet with the minimum size of 81 bytes. 6LoWPAN fragments are formed

6LoWPAN Fragmentation Header	IPv6 Header	Payload
Header length		Packet length

Fig. 8. 6LoWPAN packet

by appending IPv6 header and 6LoWPAN fragmentation header on the fragmented payload as shown in Fig. 8.

Algorithm of fragmentation is summarized in Fig. 9. Recall that the process of fragmenting packet will only take place when the IPv6 size is at least 81 bytes. Once this condition is fulfilled, the measurement of IPv6 header length of the received IPv6 packet is recorded as unfragmented length. This is because the IPv6 header will be removed first at the beginning of fragmenting process. Then, the measurement of a fragmented packet length will be computed based on the received packet payload size. During the fragmenting process, each fragment will be appended with the previously eliminated IPv6 header, followed by the 6LoWPAN fragmentation header. All of these successful fragments from a same IPv6 packet will be queued to ensure a complete fragmentation process is done for a particular IPv6 packet before sending to IEEE 802.15.4 MAC layer.

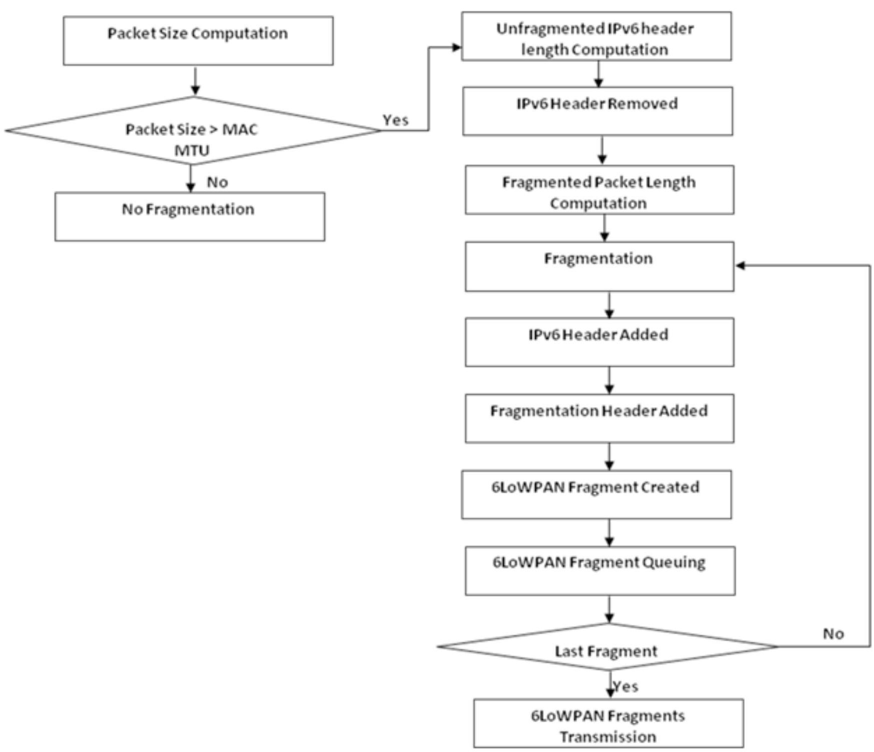

Fig. 9. The flow of fragmentation mechanism

4.2 Reassembly Mechanism

Reassembly is a process to combine fragmented packets into original IPv6 packet upon the reception at the other end of adaptation layer. Before performing reassembly mechanism, each received packet at the end of adaptation layer is examined. The algorithm of reassembly is summarized in Fig. 10.

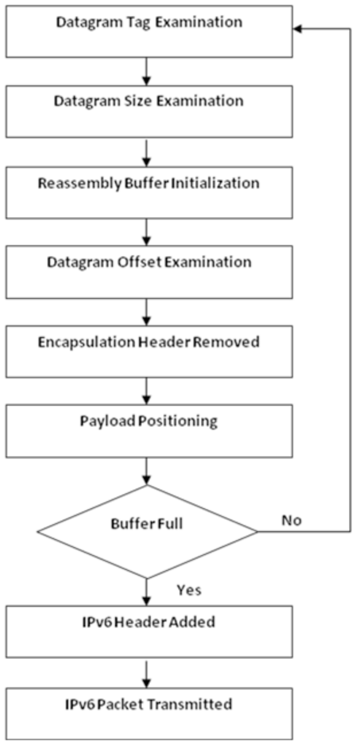

Fig. 10. The flow of reassembly mechanism

5 Performance Evaluation between 6LoWPAN and WSN

In this section, the performance of the developed 6LoWPAN is evaluated and compared with WSN in terms of packet delivery ratio, throughput, average end-to-end delay and total average energy consumption using Qualnet simulator. Table 1 shows the list of simulation parameters for the simulation setup. These simulation parameters are including radio type, MAC and Network protocols, IP fragmentation unit, routing protocol, number of nodes, area size, simulation time, and packet size. The configuration parameter of IP fragmentation unit for 6LoWPAN is given as 1280 bytes instead of 70 bytes which is for WSN as shown in Table 1. The packet size for 6LoWPAN is fixed to 1280 bytes instead of 512 bytes which is for WSN.

Table 1. List of simulation parameters

Parameter	**Measurements**
Radio Type	802.15.4 Radio
MAC Protocol	802.15.4
Network Protocol	IPv4
IP fragmentation unit	1280, 70 bytes
Routing protocol	AODV
Number of nodes	5, 10, 15, 20, 25, 30 nodes
Area size	500 meters x 500 meters
Simulation time	30 minutes
Packet size	1280, 512 bytes

In each simulation, the number of sensor nodes in the simulation scenario is increased by five nodes. Due to the processed computing limitation, the maximum number of sensor nodes that can be simulated is up to 30 which can be shown in Fig. 11. In each scenario only one PAN coordinator is used which is responsible to route and forward data from sending node to receiving node. Two nodes which have large enough distance between each other will use constant bit rate (CBR) application. The node placement in each scenario is done by setting node placement model as random in Qualnet. This is mainly because each sensor node in a network may have unpredicted movement or condition (turn on and off) which is caused by the environment, functionality, and so on. Therefore, the random node placement in Qualnet will eventually cause some fluctuation in the performance graphs of this section.

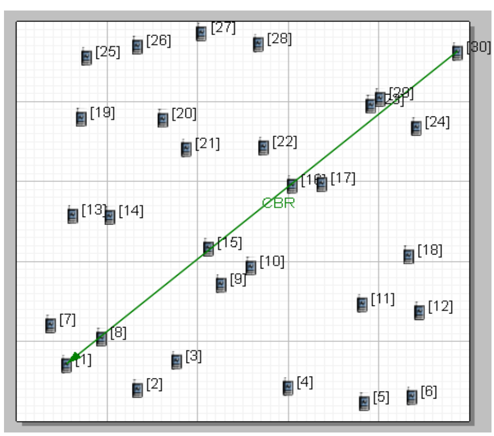

Fig. 11. The simulation scenario of 30 sensor nodes

5.1 Packet Delivery Ratio

Packet delivery ratio is calculated as the total packet received with respect to total packet sent. As depicted in Fig. 12, the packet delivery ratio for 6LoWPAN is 14% higher than WSN. This is because the datagram size in 6LoWPAN fragment header is used to indicate the original size of a packet before fragmentation. The receiving end will create a buffer for reassembling process upon the reception of first fragment. Also, the arrival of fragments does not necessary in order. Since WSN employs more fragment flag header field without indicating the original size of a packet as what the 6LoWPAN fragment header done, the created buffer might not be sufficient to accommodate all fragments. Therefore, 6LoWPAN experiences less packet lost in the intermediate node compared to WSN.

5.2 Throughput

The throughput is calculated as ratio of the total bits received with respect to the difference of time between the last received packets and the first received packet. Fig. 13 illustrates that 6LoWPAN has 201.34% higher throughput than WSN. Since WSN has lower packet delivery ratio and experienced more delay which is induced by the packet lost, therefore WSN may experience a lower throughput compared to 6LoWPAN.

5.3 Average End-to-End Delay

The average end-to-end delay is calculated as the sum of delays from each packet received with respect to the number of received packet. Fig. 14 describes that the average end-to-end delay of 6LoWPAN is 33.66% higher than WSN. This is because 6LoWPAN uses route-over mechanism to route packet. The route-over mechanism requires each fragment that received at intermediate node to be reassembled first before the packet is re-fragmented and forwarding out to the next hop toward the destination node. Thus, each sensor node in 6LoWPAN is suffered for two times of delay which is induced from the network and adaptation layers for the repeating fragmentation and reassembling mechanism in the intermediate node. The number of required hops is increased with the number of nodes, since the data is transmitted between two nodes with a large distance.

5.4 Total Average Energy Consumption

The maximum number of bits sent by a node is defined by total battery energy divided by the required energy per bit. The used radio energy is Mica Motes. This model reads the power consumption in three different modes: transmit, receive and idle modes. The energy consumption for each sensor node is the sum of all energy used in these three modes. Thus, the total average energy consumption is calculated by summing energy consumption for each node with respect to total number of nodes.

The total number of bits sent by 6LoWPAN is higher than WSN due to introduction of 6LoWPAN fragmentation header and 40 bytes of IPv6 header appended in the packet. From the results shown in Fig. 15, the total average energy consumption in 6LoWPAN is higher than WSN by 274.4%. This is due to the huge amount of energy is consumed for sending higher amount of fragmented packet. Nevertheless, the consumed energy is almost same independent of number of nodes. This is due to all present nodes in the network may not be participated in the communication.

Fig. 12. Performances of packet delivery ratio for 6LoWPAN and WSN

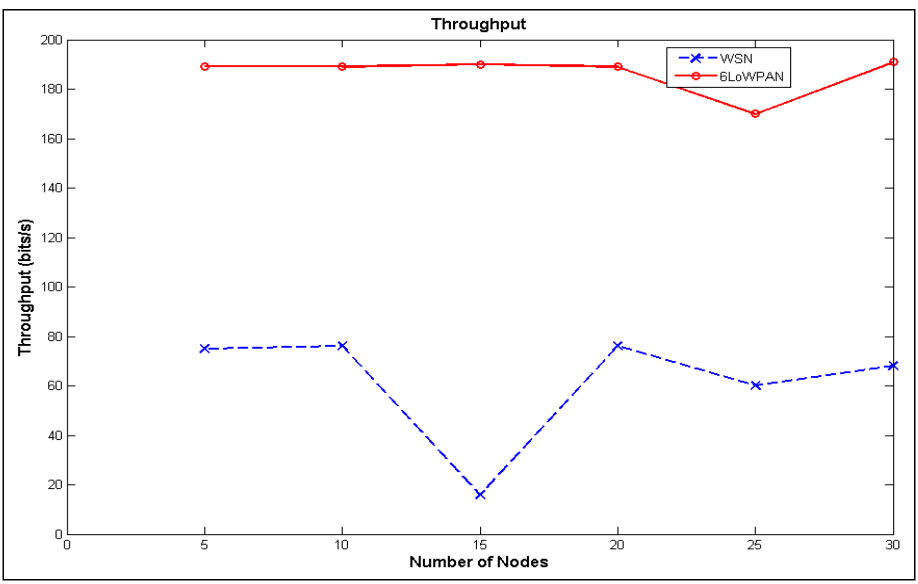

Fig. 13. Performances of Throughput for 6LoWPAN and WSN

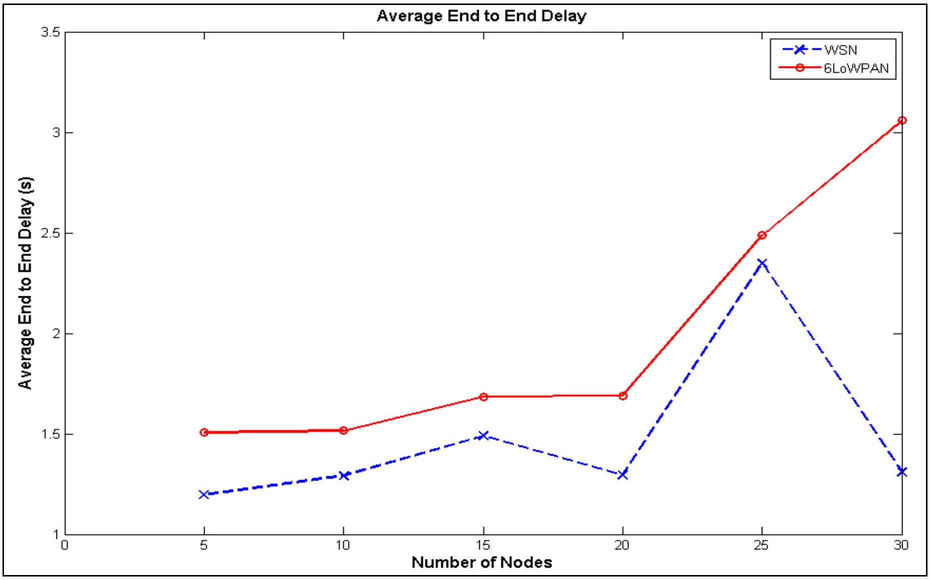

Fig. 14. Performances of average end-to-end delay for 6LoWPAN and WSN

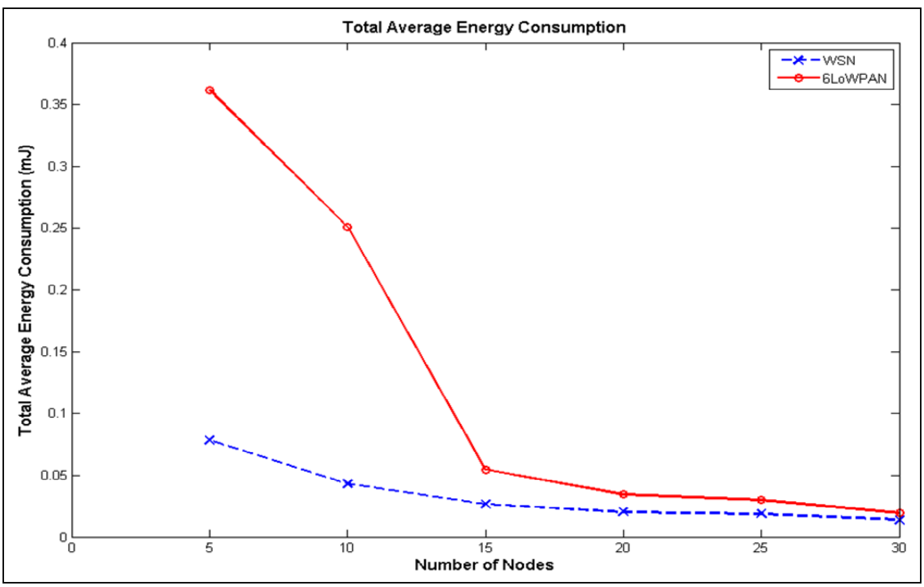

Fig. 15. Performances of total average energy consumption for 6LoWPAN and WSN

6 Conclusions

The 6LoWPAN adaptation layer with fragmentation and reassembly mechanisms has been developed and simulated by using Qualnet simulator. Since the IPv6 protocol stacks are not currently supported and provided by Qualnet libraries, an emulated IPv6 packet with a minimum 1280 bytes MTU has been successfully implemented and validated by enlarging the 576 bytes of IPv4 MTU in the Qualnet simulator. The performance of 6LoWPAN with this developed adaptation layer is evaluated and compared to WSN in terms of packet delivery ratio, throughput, average end-to-end delay and total average energy consumption. The obtained results show that 6LoWPAN has higher packet delivery ratio and throughput by 14% and 201.34% respectively compared to WSN. However, as a tradeoff, 6LoWPAN experiences an extra 33.66% average end-to-end delay and 274.4% higher total average energy consumption than WSN. These are the drawbacks of the introduction of fragmentation and reassembly mechanisms into 6LoWPAN adaptation layer.

References

1. Damaso, A.V.L., Domingues, J.P.O., Rosa, N.S.: SAGe: Sensor Advanced Gateway for Integrating Wireless Sensor Networks and Internet. In: IEEE 24th International Conference on Advanced Information Networking and Applications Workshops (WAINA), pp. 698–703 (2010)
2. Zimmermann, A., Silva, J.S., Sobral, J.B.M., Boavida, F.: 6GLAD: IPv6 Global to Link Layer Address Translation for 6lowpan Overhead Reducing. Next Generation Internet Networks, 209–214 (2008)
3. Zeeb, E., Behnke, R., Hess, C., Timmermann, D., Golatowski, F., Thurow, K.: Generic Sensor Network Gateway Architecture for Plug And Play Data Management in Smart Laboratory Environments. In: IEEE Conference on Emerging Technologies & Factory Automation (ETFA), pp. 1–8 (2009)
4. IEEE Standard 802.15.4-2003: Wireless Medium Access Control and Physical Layer Specifications for Low-Rate Wireless Personal Area Networks (2003)
5. Ma, X., Luo, W.: The Analysis of 6LoWPAN Technology. In: IEEE Pacific-Asia Workshop on Computational Intelligence and Industrial Application (2008)
6. Shin, M.K., Kim, H.J.: L3 Mobility Support in Large-Scale IP-Based Sensor Networks (6LoWPAN). In: 11th International Conference on Advanced Communication Technology, pp. 941–945 (2009)
7. Kushalnagar, N., Montenegro, G., Schumacher, C.: IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals. RFC4919 (2007)
8. Ee, G.K., Ng, C.K., Noordin, N.K., Ali, B.M.: A Review of 6LoWPAN Routing Protocols. In: Proceedings of the Asia Pacific Advanced Network, APAN (2010)
9. Montenegro, G., Kushalnagar, N., Hui, J., Culler, D.: Transmission of IPv6 Packets over IEEE 802.15.4 Networks. RFC4944 (2007)
10. Ee, G.K., Ng, C.K., Noordin, N.K., Ali, B.M.: Path Recovery Mechanism in 6LoWPAN Routing. In: International Conference on Computer and Communication Engineering, ICCCE (2010)