A Scheme for Supporting Optimal Path in 6LoWPAN Based MANEMO Networks*

Jin Ho Kim and Choong Seon Hong**

Department of Computer Engineering, Kyung Hee University, Korea
{jinhowin,cshong}@khu.ac.kr

Abstract. In this paper, we focus on the scheme for the route optimization in 6LoWPAN based MANEMO environments. If 6LoWPAN mobile routers for supporting NEMO protocol are organized by nested NEMO, this nesting of 6LoWPAN mobile router makes the extremely un-optimal route between 6LoWPAN nodes and its correspondent node. This is so, because all of the packets should be forwarded through the bi-directional tunnel which is established between 6LoWPAN mobile router and its home agent. Therefore, the more the number of nested levels, the packet route will become increasingly complex and it causes more end-to-end packet delay. This problem can be handled efficiently by applying MANEMO, which provides integration of MANET and NEMO protocols. With the application of MANEMO in 6LoWPAN, we can avoid the nested NEMO since MANET consisting of 6LoWPAN mobile routers can directly communicate with each other. In this paper, we propose an interoperable architecture between MANEMO and 6LoWPAN to solve the un-optimal route problem of the nested NEMO. With proposed scheme, we can provide the route optimization to communicate between 6LoWPAN node and correspondent node. Furthermore, we can also reduce the tunneling overhead and the end-to-end packet delay.

Keywords: 6LoWPAN, NEMO, MANEMO.

1 Introduction

6LoWPAN (IPv6 over Low power WPAN) [1][2] is a simple low-cost communication protocol that allows wireless connectivity in applications with limited power. The 6LoWPAN protocol adopts the IPv6 protocol stack for seamless connectivity between IEEE 802.15.4 [3] based networks and the IPv6 based infrastructure. The 6LoWPAN protocol could be more suitable for smaller devices with lower energy consumption. Also, it enhances the scalability and mobility of sensor networks. The network mobility (NEMO) [4] protocol maintains the session continuity of moving networks, which are group of nodes that constitute a subnet of a mobile router (MR), even when the MR dynamically changes its point of attachment to the Internet. So, if NEMO is applied in

* This work was supported by the IT R&D program of MKE/IITA. [2008-F-016-02, CASFI]
** Corresponding author.

C.S. Hong et al. (Eds.): APNOMS 2009, LNCS 5787, pp. 161–170, 2009.

the 6LoWPAN network to provide mobility for 6LoWPAN nodes that constitute within a subnet of the 6LoWPAN MR, even though each 6LoWPAN node does not equipped with the mobility function, it can maintain connectivity with the Internet through the 6LoWPAN MR as a network unit.

However, if the 6LoWPAN MRs for supporting NEMO protocol are organized by nested NEMO as shown in Fig. 1, this nesting of 6LoWPAN MR makes the extremely un-optimal route between 6LoWPAN nodes and its correspondent node (CN). This is so, because all of the packets should be forwarded through the bi-directional tunnel which is established between 6LoWPAN MR and its home agent (HA). Therefore, the more the number of nested levels, the packet route will become increasingly complex and it causes more end-to-end packet delay. This problem can be handled efficiently by applying MANEMO (MANET for NEMO) [5], which provides integration of MANET and NEMO protocols. With the application of MANEMO in 6LoWPAN, we can avoid the nested NEMO since MANET consisting of 6LoWPAN MRs can directly communicate with each other. However, there is no scheme for the route optimization in 6LoWPAN based MANEMO environments. Therefore, in this paper, we propose an interoperable architecture between MANEMO and 6LoWPAN to solve the un-optimal path problem of the nested NEMO. With proposed scheme, we can provide the optimal path to communicate between 6LoWPAN node and CN. Furthermore, we can also reduce the tunneling overhead and end-to-end packet delay.

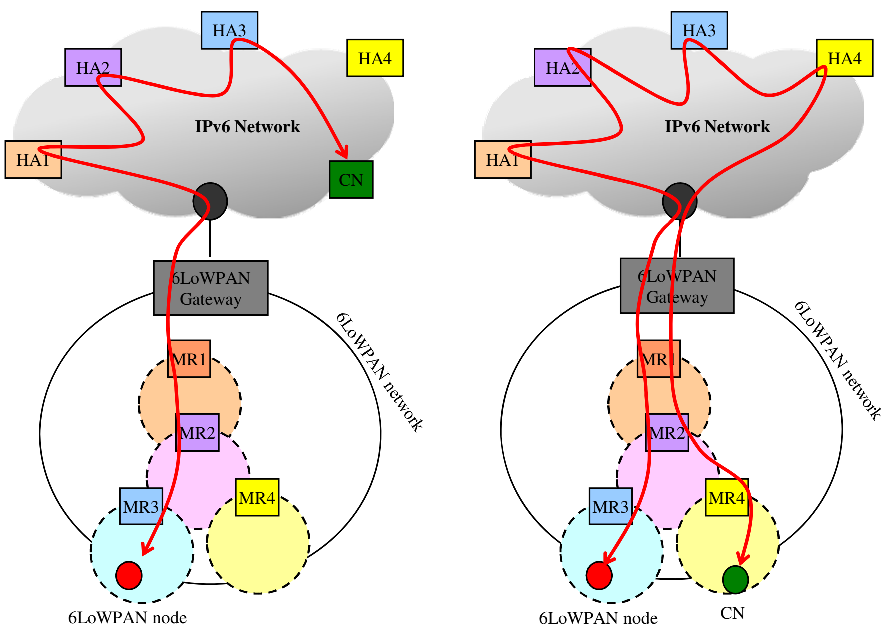

Fig. 1. Pinball routing problem in the nested NEMO

Our paper is organized as follows. In section 2, we briefly introduce the concept of 6LoWPAN and its packet format. In section 3, we describe a detailed scheme for supporting the optimal path in 6LoWPAN based MANEMO networks. Then we show performance analysis in section 4. Finally, we conclude in section 5.

2 Background

The challenge of 6LoWPAN is that IPv6 network and IEEE 802.15.4 network are totally different. The IPv6 network defines the maximum transmission unit (MTU) as 1,280 bytes, whereas the IEEE 802.15.4 packet size is 127 octets. Therefore, the adaptation layer is defined between the IP layer and the MAC layer to transport IPv6 packets over IEEE 802.15.4 links. The adaptation layer is responsible for fragmentation, reassembly, header compression, decompression, mesh routing, and addressing for packet delivery under mesh topology. The 6LoWPAN protocol supports the scheme to compress the IPv6 header from 40 bytes to 2 bytes. There are three types of 6LoWPAN dispatch header (1 byte) formats: addressing, mesh, and fragmentation [2]. All types of 6LoWPAN dispatch headers are orthogonal. The dispatch header indicates the information of the next header. For example, addressing dispatch indicates information of the IP or UDP header, and a mesh dispatch is used in mesh routing. A fragmentation dispatch indicates the information for fragmentation and reassembly of the packet. Actual headers are followed by its dispatch header. The header for a new function can be included by defining a new dispatch. A dispatch header has the following structure. If the 0 and 1 bits (the first 2 bits of the dispatch header) are 00, the next header is not a LoWPAN header. If they are 01, the next header is compressed or uncompressed IPv6, while 10 indicates a header for mesh routing and 11 indicates a header for fragmentation. If the dispatch pattern is 01000001, the following header is an uncompressed IPv6 header (40 bytes). If the pattern is 01000010, the following IPv6 header is fully compressed from 40 bytes to 2 bytes. When more than one LoWPAN header is used in the same packet, they should appear in the following order: mesh, fragmentation, and addressing header.

3 Proposed Mechanism

In this section, we explain detailed operation of a scheme for supporting the optimal path in 6LoWPAN based MANEMO networks. We define the 6LoWPAN packet format of router solicitation (RS) and router advertisement (RA) messages to discover a 6LoWPAN-MANEMO Gateway. Also, we define the 6LoWPAN format of 6LoWPAN prefix request (6LoPREQ) and 6LoWPAN prefix reply (6LoPREP) messages to discover the CN's prefix.

3.1 6LoWPAN-MANEMO Gateway Discovery

6LoWPAN networks are consisted of one 6LoWPAN-MANEMO Gateway and several 6LoWPAN based MANEMOs which support network mobility to 6LoWPAN nodes. Each 6LoWPAN based MANEMO has one 6LoWPAN MR and some 6LoWPAN nodes. The 6LoWPAN-MANEMO Gateway acts as a default gateway in the 6LoWPAN network.

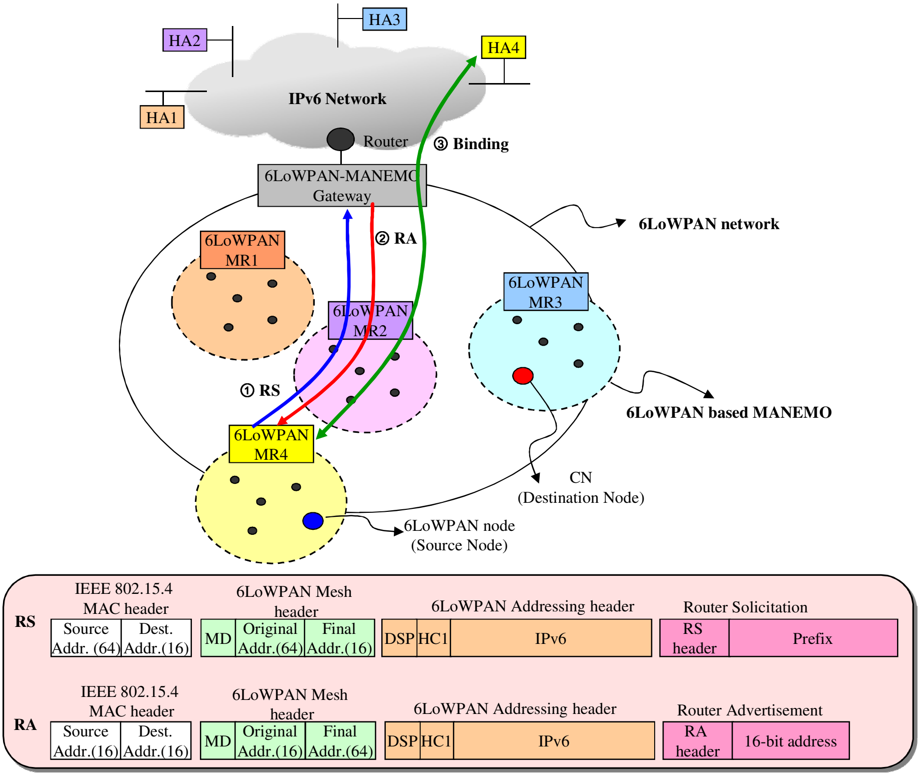

Fig. 2. 6LoWPAN-MANEMO Gateway discovery scenario and proposed RS/RA messages format

Fig. 2 shows the scenario when the 6LoWPAN MR joins a 6LoWPAN network using proposed RS and RA messages. When a 6LoWPAN MR4 moves to the new 6LoWPAN network area, it can detect its movement since the current PAN ID is different from the previous PAN ID by receiving the beacon message. If the 6LoWPAN MR4 is aware of the new 6LoWPAN network attachment, it sends a proposed unicast RS message as a 6LoWPAN packet format to the 6LoWPAN-MANEMO Gateway in order to join and notify attachment of the current 6LoWPAN network. The RS message should contain 6LoWPAN mesh header for the multi-hop routing. The original and final addresses in the mesh header of the 6LoWPAN RS message are set to the 6LoWPAN MR4's 64-bit MAC address and the 6LoWPAN-MANEMO Gateway's 16-bit address, respectively. We assume that all of 6LoWPAN-MANEMO Gateway's 16-bit address is 0x0001. So, the final address field of the 6LoWPAN mesh header can be set to 0x0001, which is fixed 16-bit address of the 6LoWPAN-MANEMO Gateway. The proposed RS message includes the 6LoWPAN MR4's prefix option, which is assigned to the ingress interface of the 6LoWPAN MR4. If the intermediate 6LoWPAN MR2 receives the RS message, then it just relays the RS message to the 6LoWPAN-MANEMO Gateway. The RS message is forwarded to the 6LoWPAN-MANEMO Gateway according to the final address of the mesh header. The 6LoWPAN-MANEMO Gateway obtains the 6LoWPAN MR4's information such as 64-bit MAC address, link-local address and 6LoWPAN prefix from the mesh header, the IP header and the RS option, respectively. The 6LoWPAN-MANEMO Gateway assigns a 16-bit address to the 6LoWPAN MR4 and it manages a list of all the 6LoWPAN MRs with 16-bit addresses which can be used for inside the 6LoWPAN network. Therefore, 6LoWPAN MRs do not require the 16-bit address collision avoidance mechanism. Upon receipt of the RS message, the 6LoWPAN-MANEMO Gateway sends a unicast proposed RA message to the 6LoWPAN MR4 to assign a 16-bit address which is only available within the 6LoWPAN network. The RA message contains the 6LoWPAN MR4's 16-bit address option which is assigned by the 6LoWPAN-MANEMO Gateway. The RA message should also contain 6LoWPAN mesh header for the multi-hop routing. The RA message will be delivered directly to the 6LoWPAN MR4 since both the source and destination of the RA message are unicast link-local addresses. The original and final addresses in the mesh header of the 6LoWPAN RA message are set to the 6LoWPAN-MANEMO Gateway's 16-bit address (0x0001) and the 6LoWPAN MR4's 64-bit MAC address, respectively. When the 6LoWPAN MR4 receives the RA message, its care-of address (CoA), which is the temporary IPv6 address at its current 6LoWPAN network attachment point, can be obtained by concatenating the prefix in the RA message, PAN ID in the beacon message and the assigned 16-bit address. The PAN ID and the 16-bit address are used as part of the IPv6 address. Finally, the 6LoWPAN MR4 registers binding between its home address and CoA with the HA.

3.2 6LoWPAN Mobile Network Prefix Discovery

Fig. 3 shows the scenario of 6LoWPAN prefix discovery of the Correspondent 6LoWPAN MR (CMR) using proposed 6LoPREQ and 6LoPREP messages. If the 6LoWPAN node in the 6LoWPAN MR4 wants to communicate with CN after the 6LoWPAN-MANEMO Gateway discovery has successfully finished, the 6LoWPAN MR4 should decide whether the CN is located in the current 6LoWPAN network or not. To accomplish this, the 6LoWPAN MR4 should perform mobile network prefix (MNP) discovery to find the location of the CN.

When the 6LoWPAN node sends the packet to the CN, the 6LoWPAN MR4 may receive this packet through its ingress interface. The 6LoWPAN MR4 discovers the destination prefix entry in the routing table to decide if the path to the CN is stored or not. If the route to the CN is not stored in the routing table, the 6LoWPAN MR4 sends the 6LoPREQ message to the 6LoWPAN-MANEMO Gateway including CN's prefix option to aware of where the CN is located. The 6LoWPAN-MANEMO Gateway can make a decision whether the CN's prefix is within the current 6LoWPAN network or external since it manages all of 6LoWPAN MRs and its MNP information by exchanging RS and RA messages. If the destination's prefix matches the CN's prefix in the mapping table, the 6LoWPAN-MANEMO Gateway replies 6LoPREP messages to the 6LoWPAN MR4. The 6LoPREP message includes a 16-bit address of CMR to which the CN belongs. On the other hand, there is no 6LoPREP header in the 6LoPREP message if the destination's prefix does not match. With MNP discovery, 6LoWPAN MR4 is able to get CMR's 16-bit address.

Upon receipt of the 6LoPREP message, the 6LoWPAN MR4 performs MANET routing protocol such as exchange RREQ and RREP messages to establish the optimal path between CMR and 6LoWPAN MR4 using the CMR's 16-bit address. With exchange 6LoPREQ and 6LoPREP messages, the optimal path is established between 6LoWPAN node and CN.

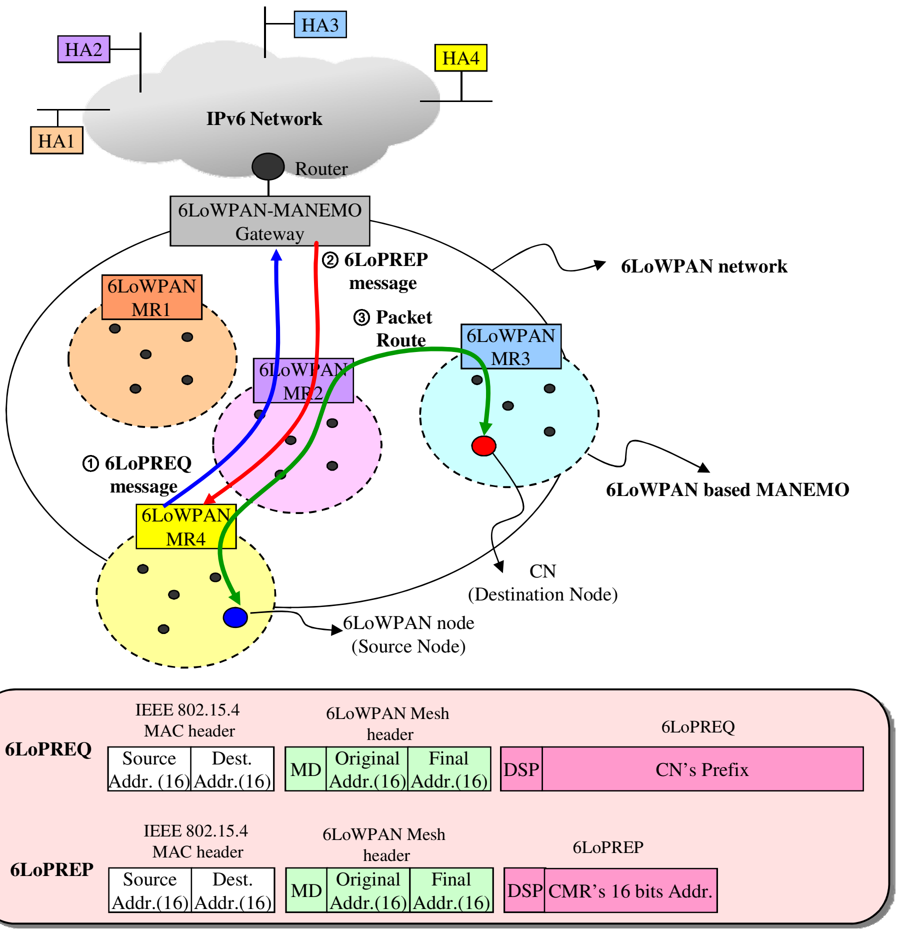

Fig. 3. 6LoWPAN prefix discovery scenario and proposed 6LoPREQ/6LoPREP messages format

Table 1 shows the all the necessary headers to send the 6LoPREQ message in detail. A mesh header is needed for the multi-hop routing between the 6LoWPAN MR and the 6LoWPAN-MANEMO Gateway. We define an another new dispatch header pattern, which is set to '00000001', for the 6LoPREQ message. The CN's prefix is included in the 6LoPREQ header to request matching the CMR’s 16-bit address. Table 2 shows the all the necessary headers to reply the 6LoPREP message in detail. Also, we define a new dispatch header pattern, which is set to ‘00000010’, for the 6LoPREP message. If the CN’s prefix is within the current 6LoWPAN network, the CMR’s 16-bit address is contained in the 6LoPREP header.

Table 1. 6LoPREQ message format and data

Header	Field	Data	Size
IEEE 802.15.4 MAC header	Source Address	6LoWPAN MR's 16-bit MAC address	2 bytes
	Destination Address	6LoWPAN Intermediate MR's 16-bit MAC address	2 bytes
6LoWPAN Mesh header	MD (Mesh Dispatch)	Original address flag=16-bit Final address flag=16-bit	1 byte
	Original Address	6LoWPAN MR's 16-bit address	2 bytes
	Final Address	6LoWPAN-MANEMO Gateway's 16-bit address	2 bytes
6LoPREQ header	DSP (Dispatch)	6LoWPAN Prefix Request (00000001)	1 byte
	6LoPREQ	CN's Prefix	8 bytes

Table 2. 6LoPREP message format and data

Header	Field	Data	Size
IEEE 802.15.4 MAC header	Source Address	6LoWPAN-MANEMO Gateway's 16-bit MAC address	2 bytes
	Destination Address	6LoWPAN Intermediate MR's 16-bit MAC address	2 bytes
6LoWPAN Mesh header	MD (Mesh Dispatch)	Original address flag=16-bit Final address flag=16-bit	1 byte
	Original Address	6LoWPAN-MANEMO Gateway's 16-bit address	2 bytes
	Final Address	6LoWPAN MR's 16-bit address	2 bytes
6LoPREP header	DSP (Dispatch)	6LoWPAN Prefix Reply (00000010)	1 byte
	6LoPREP	CMR's 16-bit address	2 bytes

Fig. 4 shows the proposed signaling flow for supporting the optimal path in 6LoWPAN based MANEMO networks. As mentioned above, the packet routing is optimized by MNP discovery and MANET routing protocol between 6LoWPAN MRs without bi-directional tunnel between 6LoWPAN MR and its HA.

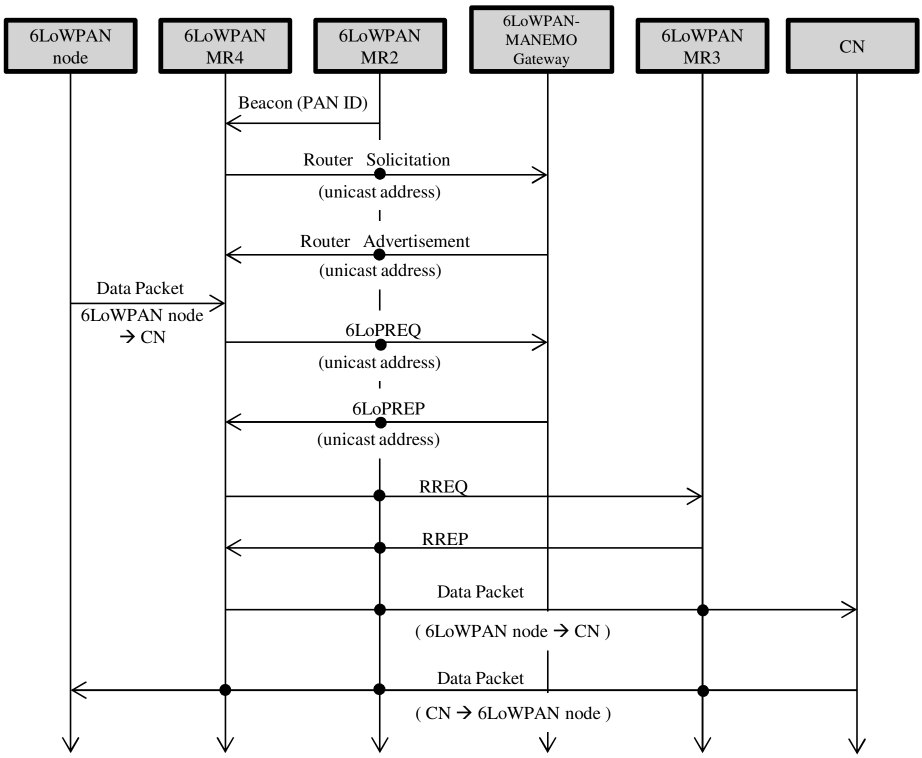

Fig. 4. Proposed signaling flow for supporting the optimal path in 6LoWPAN based MANEMO networks

4 Performance Analysis

To evaluate the performance of our proposed scheme, we perform simulation using NS-2 [6]. The IEEE 802.15.4 MAC protocol is employed as the Data Link layer. Table 3 shows the parameters for the simulation. We compare proposed 6LoWPAN based MANEMO and 6LoWPAN based NEMO schemes in terms of the tunnel overhead and end-to-end packet delay by increasing the number of 6LoWPAN MR in the 6LoWPAN network. The tunnel overhead and end-to-end packet delay are experienced by constant bit rate (CBR) traffic rate 10 packets per second, where each packet size is 50 bytes. In the simulation, we configure 6LoWPAN network with ten 6LoWPAN NEMOs deployed over an area of 100x100 square meters.

Table 3. Parameter for simulation

Parameter	Values
Area size	100m * 100m
Number of 6LoWPAN NEMO	10
Send packets	10 packets/sec
Data size	50 bytes
Transmission range	5m
Traffic type	CBR

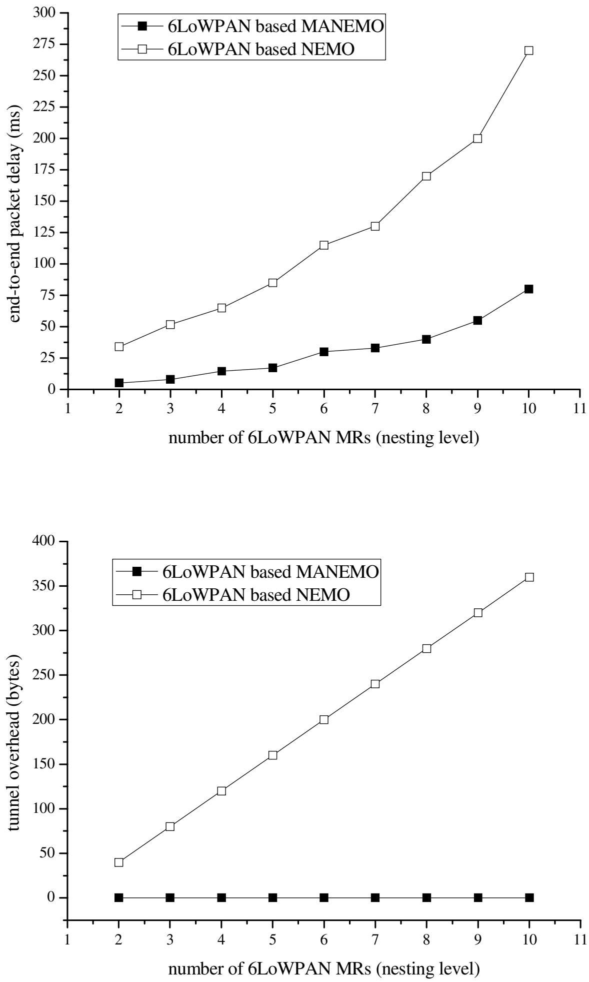

Fig. 5. End-to-end packet delay and tunnel overhead

Fig. 5 shows the result of the end-to-end packet delay between 6LoWPAN node and CN. In case of 6LoWPAN based NEMO scheme, if 6LoWPAN MRs are organized in nested NEMO, the path can become extremely un-optimal to communicate between 6LoWPAN node and its CN. Packets would travel through all HAs since all of packets should be forwarded through the bi-directional tunnel which is established between 6LoWPAN MR and its HA. The more the number of nested levels, the packet route will become increasingly complex and it causes more packets overhead such as pinball routing problem. However, in case of proposed 6LoWPAN based MANEMO scheme, which provides integration of MANET and NEMO protocol, 6LoWPAN MRs constitute ad-hoc network and they can directly connect to each other. Therefore, proposed 6LoWPAN based MANEMO can reduce the tunnel overhead and provide the optimized path to communicate between 6LoWPAN MR and CN. Also, it can minimize the end-to-end packet delay as shown in Fig. 5.

5 Conclusion

In this paper, we focus on the scheme for the route optimization in 6LoWPAN based MANEMO environments. With the application of MANEMO in 6LoWPAN, we can avoid the nested NEMO since MANET consisting of 6LoWPAN MRs can directly communicate with each other. Therefore, an interoperable architecture between MANEMO and 6LoWPAN can solve the un-optimal route problem of the nested NEMO. We define the 6LoWPAN packet format of RS and RA messages to discover a 6LoWPAN-MANEMO Gateway. Also, we define the 6LoWPAN format of 6LoPREQ and 6LoPREP messages to discover the CN's prefix. With proposed scheme, we can provide the optimal path to communicate between 6LoWPAN node and CN. Furthermore, we can also reduce the tunneling overhead and the end-to-end packet delay.

References

1. Kushalnagar, N., Montenegro, G., Schumacher, C.: IPv6 over Low-Power Wireless Personal Area Networks (6LoWPANs): Overview, Assumptions, Problem Statement, and Goals, IETF RFC 4919 (August 2007)
2. Montenegro, G., Kushalnagar, N., Hui, J., Culler, D.: Transmission of IPv6 Packets over IEEE 802.15.4 Networks, IETF RFC 4944 (September 2007)
3. IEEE Computer Society, IEEE Std. 802.15.4-2003 (October 2003)
4. Devarapalli, V., Wakikawa, R., Petrescu, A., Thubert, P.: Network Mobility (NEMO) Basic Support Protocol, IETF RFC 3963 (January 2005)
5. Wakikawa, R., Clausen, T., McCarthy, B., Petrescu, A.: MANEMO Topology and Addressing Architecture, IETF (January 2008) draft-wakikawa-manemoarch-01.txt
6. Network Simulator (ns) version 2, `http://www.isi.edu/nsmam/ns`